Calculation of GHG Emissions in

Waste and Waste-to-Energy Projects

November 2013 (revised version)

JASPERS Knowledge Economy and Energy Division

Staff Working Papers

Calculation of GHG Emissions in Waste and Waste-to-Energy Projects

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JASPERS Staff Working Papers are prepared by JASPERS experts with the aim of facilitating the discussions with counterparts in the context of their different assignments, mostly in terms of project scoping and applicable criteria and methodology. These papers normally originate as part of the assessment of a specific project, in which case the version published here is edited to be made non-project and non-country specific and therefore easily applicable to other projects in the sector. This particular paper: (i) describes a methodology for the quantification of GHG emissions in projects developing individual facilities or groups of facilities for municipal waste management; (ii) was developed with a view to produce the data basis for the quantification of economic costs and benefits from GHG emissions in waste projects as required for the CBA; and (iii) comes along with a companion spreadsheet for the calculations.

Contents

1 Introduction

In the current EU financing perspective 2007-2013, JASPERS has provided advice on the Cost-Benefit Analysis of Waste and Waste-to-Energy Projects (hereafter referred to as Waste Management Projects) in the context of the preparation of Cohesion Fund and ERDF applications.

In the economic analysis, JASPERS advised project developers and their consultants to include the quantification of incremental GHG emissions caused by new waste management facilities built by projects, which served as a basis for the subsequent monetization of the related environmental externalities. The methodology for the quantification of GHG emissions was generally based on standard emission factors for different waste management facilities which were estimated in a study by AEA Technology on "Waste Management Options and Climate Change", financed by DG Environment and published in 2001[1] (hereafter referred to as the "AEA study").

This paper further develops the methodology described in the AEA study and presents a detailed GHG calculation methodology which is accompanied by a sample calculation model in Excel format that can be used by project developers or their consultants to calculate the GHG emissions of waste management projects[2].

The methodology described in this paper is somewhat more complex than the one proposed in AEA study, but allows more flexibility with regards to input waste composition and its changes over time as well as the technological configurations of facilities included in projects[3]. For comparison, the standard emission factors used in a number of projects already approved by the European Commission in the sector is presented in annex 2.

The first part of the paper (section 2) is dedicated to explain the scope of emissions as well as the general methodology and assumptions suggested by JASPERS.

The second part of the paper (section 3) provides users of the sample calculation model a more detailed explanation of the inputs required to run the model.

Where additional information is required to complement or elucidate on specific issues addressed in this paper, this is included in the Annexes.

It should be finally noted that the methodology described in this paper is largely compatible with the EIB's Carbon Footprint methodology (EIB, 2012)[4], as both are ultimately based on the 2006 IPCC Guidelines for National GHG Inventories[5]. It has to be noted, however, that the objective of the EIB's carbon footprint calculation is to report its project induced GHG emissions within the common framework developed with other international financial institutions (ADB et. al., 2013)[6] and not to quantify the economic costs and benefits due to the projects' incremental GHG emissions. Because of these different objectives the EIB approach and the methodology developed in this paper are in some aspects different, in particular as regards the definition of the baseline, the scope of the emissions considered and the definition of project boundaries. Also the EIB reports average emissions, while for the purpose of the cost-benefit analysis emissions are estimated on an annual basis in the present paper.

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[1] Link: http://ec.europa.eu/environment/waste/studies/pdf/climate_change.pdf

[2] It should be noted that the revision of the methodology concerns only the quantification of the net GHG emissions and not their economic valuation

[3] This method was based on standard emission factors for standard waste treatment methods which were calculated based on a standard input waste composition

[4] Link: http://www.eib.org/attachments/strategies/eib_project_carbon_footprint_methodologies_en.pdf

[5] Link: http://www.ipcc-nggip.iges.or.jp/public/2006gl/vol5.html

[6] Link: https://www.nib.int/filebank/a/1358516702/86247517d51b1706d7963cecbe5421ea/2792-IFI_CO2_framework.pdf

2 General Methodological Approach

In a nutshell the methodology behind the GHG calculation model is the following. GHG emissions released (directly or indirectly) or avoided by waste management projects are calculated applying the incremental approach, i.e. the project GHG emissions are compared to the GHG emissions of a hypothetical baseline scenario without the project. Incremental GHG emissions are quantified separately for different components of waste management systems such as facilities for mechanical sorting and separation, facilities for biological and thermal treatment of wastes and landfills.

Total net GHG emissions from these facilities are then aggregated in five different sub-categories:

- GHG emissions from waste transport
- GHG emissions from waste treatment
- GHG emissions from waste landfilling
- GHG emissions avoided through material recovery from waste
- GHG emissions avoided through energy recovery from waste

and then to a grand total for the project which can be positive (for net GHG contributors) or negative (for net GHG avoiders).

In the following this approach is explained in more detail.

2.1 Incremental approach

In the CBA of waste management projects, JASPERS recommends the application of the incremental method as defined in the CBA Guide of the European Commission[7] (hereafter referred to as the EC CBA Guide). This requires the comparison of the scenario with the project, with a baseline or counterfactual scenario without the project. As the estimation of the GHG emissions is part of the CBA, the incremental method applies also to the quantification of GHG emissions of the project.

In general, the JASPERS approach defines the business-as-usual scenario (BAU) as the baseline or counterfactual scenario for the quantification of the project's GHG emissions, which is in line with the EC CBA Guide. The EC CBA Guide defines the BAU scenario as the one which is most likely to occur if the project is not implemented. By definition, the BAU scenario is a hypothetical future scenario with no investments for additional infrastructure. This scenario is not necessarily non-costly, in particular in the case of existing infrastructures. It comprises incurring operational, maintenance and repair costs (as well as cashing the revenues generated, if any). In the case of the new EU member states that are currently developing their waste management infrastructure to comply with EU Directives, the baseline scenario is therefore in many cases one in which waste separation and recycling is insufficiently developed and most municipal waste is deposited in landfills, and hence is not compliant with the requirements of the relevant EU Directives in the waste sector (Waste Framework Directive - 2008/98/EC, Landfill Directive - 1999/31/EC and Packaging Waste Directive - 94/62/EC).

2.2 Scope of GHG emissions

The quantification of GHG emissions typically includes the following Kyoto gases that are considered most relevant for the waste management sector (the other Kyoto gases are considered negligible in this context):

- Carbon dioxide (CO_2)
- Methane (CH_4)
- Nitrogen dioxide (N_2O)

Total emissions of these gases are counted in units of CO_2 equivalents (CO_2 eq), which are calculated based on their different global warming (GHG) potential:

[7] European Commission (2008), Guide to Cost-Benefit Analysis of Investment Projects, July 2008, http://ec.europa.eu/regional_policy/sources/docgener/guides/cost/guide2008_en.pdf.

- GHG factor applied for CO_2 emissions: 1
- GHG factor applied for CH_4 emissions: 21
- GHG factor applied for N_2O emissions: 310

For the definition of the scope of GHG emissions to be taken into account in a carbon footprint calculation, the literature has generally accepted the approach developed by the WRI/WBCSD GHG Protocol[8], which differentiates between the following types of emissions:

- scope 1: direct emissions, i.e. from within the project boundaries,
- scope 2 indirect emissions, i.e. those that do not occur within the project boundaries but that can be controlled by the project operator's action, typically electricity consumption.
- scope 3: indirect emissions outside the control of the operator, such as emissions by suppliers.

JASPERS suggests considering scope 1 and 2 emissions as well as avoided emissions as a consequence of material or energy recovery by the project. Avoided emissions outside of the project limits are considered in the calculation as the economic CBA is carried out from the point of view of society and not from the point of view of the project operator. Avoided emissions create a net benefit to society that clearly has to be included as an economic benefit of the project.

The following table provides an overview of the scope of GHG emissions produced by different waste management activities.

Table 1: Scope of GHG emissions produced by different waste management activities

Activity	Net direct GHG emissions (scope 1)	Indirect GHG emissions (scope 2)	Avoided GHG emissions
Material recovery facility (MRF)	CO_2 released from fuels consumed in waste collection and transportation to and from the facility	CO_2 from grid electricity consumption	CO_2 avoided through material recovery from waste and recycling
	CO_2 released from fuels consumed in waste treatment facility (i.e. by vehicles)		
Biological treatment (composting-anaerobic digestion)	CO_2 released from fuels consumed in waste collection and transportation to and from the facility	CO_2 from grid electricity consumption	CO_2 avoided through energy recovery from combustion of biogas produced in anaerobic digestion
	CH_4 and N_2O released in anaerobic processes during waste treatment		
	CO_2 released from fuels consumed in waste treatment facility (i.e. by vehicles)		
MBT	CO_2 released from fuels consumed in waste collection and transportation to and from the facility	CO_2 from grid electricity consumption	CO_2 avoided through material recovery from waste and recycling

[8] http://www.ghgprotocol.org/files/ghgp/public/ghg-protocol-revised.pdf

	CH_4 and N_2O released in anaerobic processes during biological treatment		CO_2 avoided through energy recovery from incineration of RDF/SRF produced from mixed waste
	CO_2 released from fuels consumed in waste treatment facility (i.e. by vehicles)		CO_2 avoided through energy recovery from combustion of biogas produced in anaerobic digestion
Incineration	CO_2 released from fuels consumed in waste collection and transportation to and from the facility	CO_2 from grid electricity consumption	CO_2 avoided through energy recovery from incineration of waste
	CO_2 released in waste incineration (fossil carbon only, biogenic carbon not included)		
	N_2O released in waste incineration		
	CO_2 released from fossil fuels added in waste incineration		
	CO_2 released from other fuels consumed in waste treatment facility (i.e. by vehicles)		
Landfill	CO_2 released from fuels consumption in waste collection and transportation to and from the facility	CO_2 from grid electricity consumption	CO_2 avoided through energy recovery from landfill gas
	CH_4 released from landfill		
	CO_2 released from fuels consumed on the landfill site (i.e. by vehicles)		

Source: based on EpE (2010)

Other GHG emissions (highlighted in grey in the table above) may be added if reliable project-specific data is available but have not been considered in the sample model presented in the attached Excel spreadsheet. These are in particular:

- CO_2 emissions produced from fuels consumed inside the waste treatment facilities (i.e. by vehicles). An exception are CO_2 emissions from fuel consumption on landfills, which were integrated in the attached sample model because an average figure on fuel consumption was available from the AEA study.
- CO_2 emissions released from fossil fuels added to support combustion in waste incineration facilities.

Carbon sequestration in landfills or composted material, which is referred to and estimated in the AEA study (2001) can also be included. It is *not* considered in the attached sample calculation[9]. For a further description and an illustration of the carbon sequestration process, see Annex 1.

2.3 General methodology applied for the calculation of GHG emissions

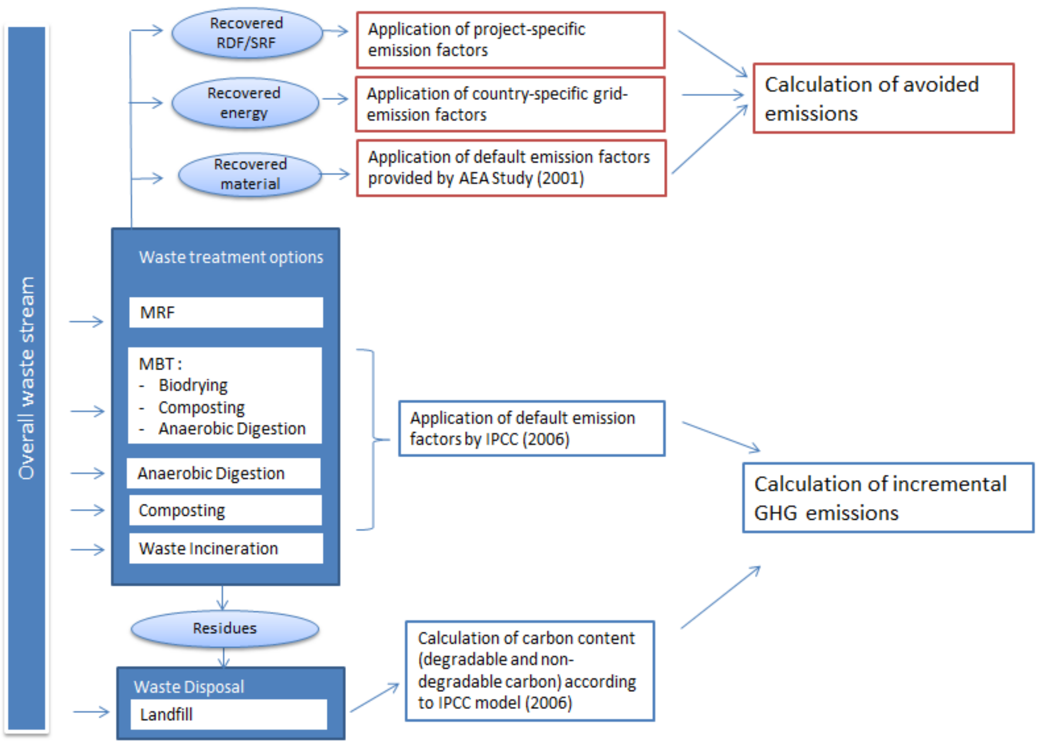
The following figure illustrates the individual waste management practices included in the sample GHG calculation model and the general methodology applied to quantify GHG emissions.

In order to quantify GHG emissions released and avoided in the waste management system, the system is separated into its individual components, that is facilities for:

- Material Recovery Facility (MRF)
- Anaerobic digestion
- Composting
- Mechanical-biological treatment (MBT)
- Waste incineration and
- Landfilling.

Specific emission factors taken from the literature are applied to calculate the GHG emissions that are characteristic for the individual processes that take place in these facilities. The assumptions and exact emission factors are presented further below.

Figure 1: JASPERS approach to GHG emission calculation



Note: MRF = Material Recovery Facility, MBT=Mechanical Biological Treatment Plant, SRF=solid recovered fuel, RDF=refuse derived fuel.

[9] This is because the methodology focusses only on climate relevant carbon emissions, which do not include carbon of biogenic origin. In addition, in the CBA of waste projects, usually only project costs and benefits are considered that are certifiable within the reference period of the project, which usually extends over 30 years. By convention, only biogenic carbon that is stored for longer than 100 years can be considered as sequestered (EpE, 2010).

2.4 Specific assumptions used for the calculation of GHG emissions

2.4.1 Assumptions as regards fractional composition and carbon contents of municipal solid waste

In order to estimate the GHG emissions released from different waste management practices, assumptions are necessary as regards the carbon contents of the different waste fractions treated in the different projects.

The following table shows the different waste fractions considered in the sample models as well as their carbon contents (for total, degradable/dissimilable organic carbon and fossil carbon). In the attached sample model, the values shown in the table below are disclosed in the basic assumption sheet of the Excel spreadsheet (Rows 1-36).

Organic carbon is carbon bound in organic compounds derived from plants and animals ("biomass"). Degradable organic carbon (DOC) is the portion of organic carbon that is susceptible to biochemical decomposition. The term "dissimilable" DOC refers to the easily degradable organic carbon released through biochemical decomposition under anaerobic conditions (in form of CH_4 and CO_2). Fossil carbon is carbon bound in inorganic (fossil) compounds such as petroleum, natural gas and coal ("fossil fuels").

Table 2: Carbon content of distinct mixed waste components

	Total Carbon (TC) in distinct MSW components (% of wet mass)	Degradable Organic Carbon (DOC) in distinct MSW components (% of wet mass)	Dissimilable Organic Carbon (DOCf) in distinct MSW components (% of DOC)	Fossil Carbon (FC) in distinct MSW components (% of wet mass)
Putrescibles (average for food+garden waste)	19%	19%	64%	0%
Food waste	15%	15%	75%	0%
Garden waste	24%	24%	50%	0%
Wood[10]	45%	30%	50%	0%
Textiles	39%	20%	30%	19%
Paper + cardboard	33%	33%	35%	0%
Plastics	61%	0%	0%	61%
Metal	0%	0%	0%	0%
Glass	0%	0%	0%	0%
Other[11]	24%	16%	39%	8%

Data source: AEA (2001), p. 97, 141, with the exception of the categories "wood" (estimate based on data from different sources examined by JASPERS) and "other" (calculated by JASPERS based on disaggregated data presented in the AEA study)

The largest part of DOC in MSW is contained in kitchen, food and garden wastes as well as paper and cardboard, but also in some types of textiles. Fossil carbon (FC) is mainly contained in plastics and other smaller MSW fractions such as rubber and textiles.

The absolute contents of DOC, DOCf and FC for the different MSW flows included in the project are calculated in the "waste forecast" sheet.

[10] The difference between TC and DOC of wood are mainly attributable to lignins, complex organic substances which are hardly biodegradable even under aerobic conditions (complete mineralization in nature takes very long periods of time, up to several years and even decades, and involves a limited group of specialized microorganisms).
[11] Including the fine fraction and miscellaneous combustible and non-combustible fractions.

2.4.2 Assumptions as regards GHG emissions from waste collection and transportation

The GHG emissions due to waste collection and transportation depend on the distance travelled by waste collection and transport vehicles, the vehicle type and size of payload[12] (AEA, 2001).

In order to precisely estimate CO_2 emissions from collection and transport of waste in any given project, the calculation would require data on average distances between households and disposal/treatment facilities and/or waste transfer stations as well as between transfer stations and disposal/treatment facilities. It is to be noted that multiple ways can be taken for different separated and mixed residual wastes transported to treatment and also for treatment outputs transported to reprocessors or to landfills.

The AEA study (2001) provides a simplified method to quantify GHG emissions from collection and transportation of waste, which uses general fixed assumptions on vehicle types used, payloads and km travelled. The average emission factors used in the attached sample model are summarised in Table 3 below.

Table 3: Assumptions as regards GHG emission factors for collection and transport of waste for different treatment options

GHG emission factors for waste collection and transport			
Separately collected metal to sorting and recycling	0.010	t CO_2 (eq)/t recycled material	AEA (2001), p. 88
Separately collected plastic to sorting and recycling	0.015	t CO_2 (eq)/t recycled material	AEA (2001), p. 88
Separately collected paper/cardboard to sorting and recycling	0.010	t CO_2 (eq)/t recycled material	AEA (2001), p. 88
Separately collected glass to sorting and recycling	0.010	t CO_2 (eq)/t recycled material	AEA (2001), p. 88
Separately collected biowaste to composting	0.008	t CO_2 (eq)/t recycled material	AEA (2001), p. 87, modified by JASPERS
Separately collected biowaste to AD	0.008	t CO_2 (eq)/t recycled material	AEA (2001), p. 87, modified by JASPERS
Mixed waste to MBT	0.009	t CO_2 (eq)/t recycled material	AEA (2001), p. 87, modified by JASPERS
Mixed waste to incineration	0.008	t CO_2 (eq)/t recycled material	AEA (2001), p. 87, modified by JASPERS
Mixed waste to landfill	0.007	t CO_2 (eq)/t recycled material	AEA (2001), p. 87, modified by JASPERS

It can be decided to consider GHG emissions from waste collection and transport in a more project specific approach if the necessary data (waste collection and transport is commonly not an integral part of waste projects appraised by JASPERS) is available.

2.4.3 Assumptions as regards GHG emissions from waste treatment

In the following tables the emission factors and assumptions for the calculation of the GHG emissions released from different waste treatment processes are presented.

[12] Collection frequency can be assumed to have no impact if there is no change in total weight of waste collected and if collection vehicles are always filled. Similarly, separate collection of waste should not give rise to greater emissions from vehicles, if the waste collection system is optimised so that all refuse collection vehicles operate at full loads.

Table 4: Assumptions as regards GHG emission factors for different treatment options

GHG emission factors for composting			
CH_4 emissions from composting	0.004	kg CH_4/t BDW (wet mass)	IPCC (2006)
N_2O emissions from composting	0.0003	kg N_2O/t BDW (wet mass)	IPCC (2006)
GHG emission factors for anaerobic digestion			
CH_4 emissions from anaerobic digestion	0.001	kg/t BDW (wet mass)	IPCC (2006)
CH_4 share in biogas	Between 40% and 60%	%	Use reported/predicted value or default value: 60%
CO_2 share in biogas	Between 30% and 40%	%	Use reported/predicted value or default value: 35%
GHG emission factors for incineration			
Lower calorific value MSW	Between 8.0 and 12.0	MJ/kg	Use reported/predicted value or estimate
MSW fossil (non-biomass) combustible share	40%	% of energy content	
Fossil CO_2 emissions from incineration of MSW	91.7	t CO_2/MJ	IPCC (2006), for mixed MSW from households and similar wastes only
CH_4 emissions from incineration of MSW	0.0000002	t CH_4/t of waste	IPCC (2006)
N_2O emissions from incineration of MSW	0.00005	t N_2O/t of waste	IPCC (2006)
GHG emission factors for landfilling			
Methane correction factor (MCF)	Between 0.4 and 1		Use reported/predicted value or estimate
Volumetric CH_4 fraction in landfill gas (F)	Between 40% and 60%	%	Use reported/predicted value or default value: 50%
Volume of CH_4 recovered per year for energy use or flaring (RG) (with project)	75%	%	Use reported/predicted value or estimate
Volume of CH_4 recovered per year for energy use or flaring (RG) (without project)	Between 0% and 75%	%	Use reported/predicted value or estimate
Fraction of CH_4 released that is oxidised below surface within the site (OX)	Between 0% and 10%	%	Use reported/predicted value or default value: 10%
Share of collected methane flared	Between 0% and 100%	%	Use reported/predicted value
Flare efficiency	Between 0% and 90%	%	Use reported/predicted value or default value: 90%
Share of collected methane transformed in electricity	Between 0% and 100%	%	Use reported/predicted value
Methane LCV (Lower calorific value)	48	MJ/kg	
Energy efficiency of gas engine	Between 30% and 80%	%	Use reported/predicted value
CO_2 emissions from operations at the landfill	1.2	CO_2/t of waste	AEA (2001), p. 94

For more details on the calculation of GHG emissions of different waste treatment options refer to section 3.2.

2.4.4 Assumptions as regards avoided GHG emissions through recycling of recovered materials

Table 5 shows the specific emission factors applied to calculate avoided GHG emissions through recycling of materials recovered from waste. These correspond to GHG emissions avoided in raw material extraction and processing. Although the recycling process is not part of municipal waste management operations, the GHG emissions avoided are still assigned to the project, as the project is the pre-condition for their materialization.

Table 5: Assumptions as regards avoided GHG emissions through recycling of materials recovered from waste

GHG emission factors for material recycling	Value	Unit
Ferrous metal	-1.521	t CO_2 (eq)/t recycled material
Non-ferrous metal	-9.108	t CO_2 (eq)/t recycled material
PET	-0.530	t CO_2 (eq)/t recycled material
HDPE	-1.800	t CO_2 (eq)/t recycled material
Glass	-0.287	t CO_2 (eq)/t recycled material
Paper/cardboard	-0.634	t CO_2 (eq)/t recycled material

Source: AEA study (2001)

2.4.5 Assumptions as regards avoided GHG emissions through recovery of energy from waste

In order to calculate avoided GHG emissions from energy recovered from waste, the specific GHG emission factors of the heat and electricity sources in the baseline scenario are necessary (expressed in t CO_2/MWh).

Table 6: Assumptions as regards GHG emissions avoided through recovery of energy from waste

	Value	Unit	Comments
Electricity - country grid emission factor incl. grid losses (for electricity imported from grid)	Country-specific values	t CO_2(eq)/ MWh	Based on country specific electricity generation mix
Electricity - country grid emission factor excl. grid losses (for electricity exported to grid)	Country specific values	t CO_2(eq)/ MWh	
Heat - specific emission factor	Project-specific values	t CO_2(eq)/ MWh	Based on the specific facility and fuel displaced by the project.

In the case of heat produced by the project, the emission factor used to calculate the GHG emissions avoided is project-specific, i.e. it depends on a specific heat source and the fuel displaced by the project. The calculation of the GHG emission factor uses the specific GHG emissions of the fuel displaced (in t CO_2(eq) per tonne or per GJ) and the specific energy efficiency of the plant (in % of energy input).

In the case of electricity produced by the project, the emission factor used to calculate GHG emissions avoided are country-specific, i.e. they are calculated for the countries' specific electricity generation mix (mix of many sources and fuels used in domestic electricity generation).

Note that GHG emissions avoided through the project's own electricity production should not be netted with the project's indirect GHG emissions from electricity consumption. Therefore, the model provides for a separate calculation of avoided and induced indirect GHG emissions, which are based on two different emission factors:

1) **EF (Emission Factor) for electricity consumption imported from the grid**: this EF includes grid losses for transmission and distribution of electricity.

2) **EF (Emission Factor) for electricity produced by the project and electricity consumption from own production:** this EF does not include grid losses for transmission and distribution of electricity

Grid losses depend on the type and quality of the grid, which can vary from country to country. In well managed electrical grids in the EU, losses in the transmission and distribution grids are usually around 7%. This value can be used as a default value to calculate the EF when no country specific values are available.

The following table shows the EF including and excluding grid losses. The EF excluding grid losses are country specific data provided by the EIB (2012). The EF for grid losses are calculated by applying the standard 7% losses in well managed electrical grids in the EU.

$EF_{(grid\ losses)} = EF_{(generation)} * L$

Where

- EF (grid losses) = EF from grid losses
- EF (generation) = EF from electricity generation
- L = grid losses

JASPERS recommends a more simplistic approach in the sense that it considers only the existing power plants whose current electricity generation would be affected by the waste project. Future power plants are not considered. One approach proposed in the literature is to calculate a weighted average between the so-called *"operating margin"* (refers to the current existing power plants affected by the proposed project) and *"built margin"* (refers to the future power plants whose construction and future operation would be affected by the proposed project).

Table 7 provides data for country-specific electricity emission factors with and without grid losses that can be used in the carbon footprint calculation.

Table 7: Electricity grid emission factors: Data for countries in which JASPERS is active

Country	**EF excl. grid losses (g CO_2(eq)/kWh)**	**EF incl. grid losses (g CO_2(eq)/kWh) (default T&D loss of 7%)**
Bulgaria	593	638
Croatia	384	412
Cyprus	811	872
Czech Republic	654	703
Estonia	1134	1219
Hungary	380	409

Latvia	144	155
Lithuania	93	100
Malta	973	1047
Poland	875	941
Romania	534	575
Slovak Republic	230	248
Slovenia	361	388

Source: EIB (2012), p. 39-42

3 Instructions for the use of the sample model

This section provides detailed instructions for the use of the accompanying Excel Sheet.

3.1 The structure of the model

The Excel workbook has a very simple structure and is composed of three spreadsheets for data input and calculation and a summary table showing the results of the calculations:

The **"Basic assumptions"** sheet is where the main variables used in the model are inputted, including:

- degradable/dissimilable and fossil carbon contents for individual waste fractions
- specific emission factors applied to calculate GHG emissions released/avoided through individual waste management processes
- variables to determine the methane emissions from landfills (different assumptions possible for the "with-project" scenario and the baseline scenario)

In the basic assumption sheet, the red coloured cells need to be filled in with project specific data, while the green cells contain default values to be used for all projects. If the user of the model wishes to change the assumptions represented in the green cell this is possible but this has to be explicitly indicated and justified.

The **"Waste forecasts"** sheet contains the projections of quantities and fractional composition of waste flows considered and requires data inputs over the entire reference period. Most important of all, data must be entered separately for the "with-project" scenario and for the baseline (BAU or "without-project") scenario, reflecting the way waste is managed (i.e. separated, treated and disposed of) in each scenario.

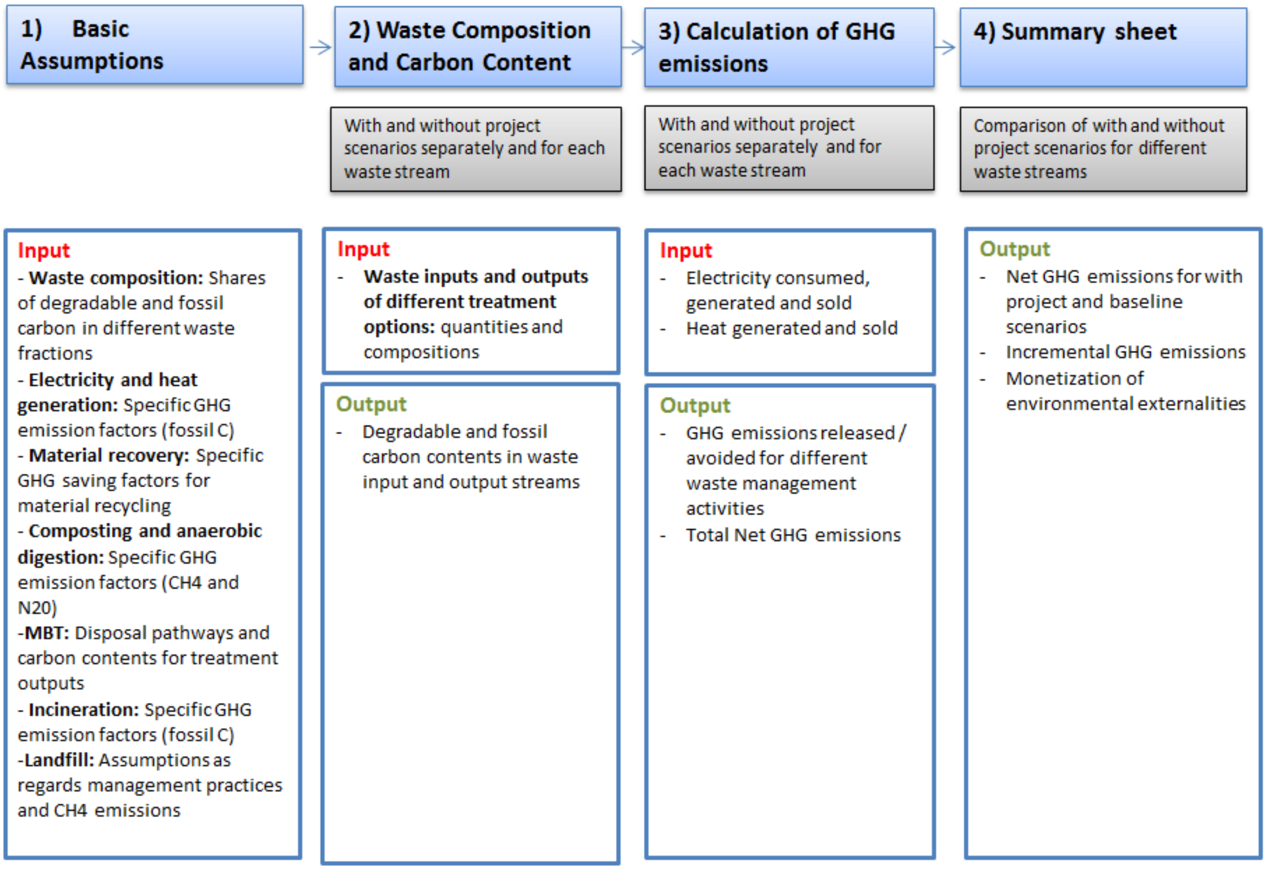
The "Waste forecasts" sheet allows data input for waste flows from up to four different sources (i.e. mixed waste from households & commerce, bulky waste from households, green waste from parks and garden, street cleaning waste etc.), but may be expanded to include more.

The **"GHG emissions"** sheet calculates for each individual waste flow, the GHG emissions released/avoided in the "with-project scenario" and the baseline scenario, in accordance with the waste management system foreseen.

Manual data input in this sheet is needed for electricity and heat consumption and generation in each component of waste management system included in the with-project scenario and the baseline scenario, as well as for calorific values and carbon contents of RDF/SRFs.

The following figure provides a general overview of the inputs to be provided in the different sheets and the outputs produced by the model.

Figure 2: Structure of model



3.2 Calculations of GHG emissions for different components of the Waste Management System

In this section it will be explained in detail how the attached sample model estimates GHG emissions released by different components of the waste management system. It is also explained what assumptions are used and what kind of input data is needed in each case.

3.2.1 Material Recovery

Material recovery is either done in so-called Material Recovery Facilities (MRFs) where paper, plastics (HDPE, PET), glass, metals (ferrous and non-ferrous) and other materials are separated at source, collected and subsequently sorted, baled and bulked and transferred to re-processors that produce marketable materials and products[13] (EC, 2001). Alternatively, some of these materials may also be recovered from mixed waste streams during or after waste treatment (i.e. metal separation in MBT and incinerators).

In both cases, material recovery from waste and subsequent recycling leads to avoided GHG emissions compared to a situation where raw materials are used.

[13] In general, the economic benefits related to material and energy recovery from waste are quantified as the avoided cost for conventional production. In the case of recyclable materials (plastics, metals, glass and paper) and compost, the market value/price is usually used as a proxy. The proxy applied in the case of heat from waste is the market price as well, while in the case of electricity it is the feed-in tariff into the public grid, without green certificates or other applicable bonuses.

In MRFs, GHG emissions are indirectly released through the electricity consumed in the waste sorting process. Also the transportation of the materials leads to GHG emissions.

Inputs into the model

The following table shows the model inputs required to calculate direct and indirect GHG emissions as well as avoided GHG emissions of MRFs.

Table 8: Inputs needed for the calculation of incremental GHG emissions from MRFs

	Input	Sheet	Row number in Model	Unit
1	Total waste flow (from given waste source)	Waste Forecasts	Row 1	t/year
2	Quantities of recyclable materials separated *at source* sent to MRF (plastics, glass, paper, metal)	Waste Forecasts	Rows 2-5	t/year
3	Quantities of rejects from MRF (=impurities contained in MRF inputs)	Waste Forecasts	Rows 15, 20, 23, 26, column E (averages for reference period)	% rejects that are discarded
4	Quantities of special plastic (PET, HDPE) and metal (Fe/ non-Fe) fractions separated and sent to recycling	Waste Forecasts	Rows 16-17 (plastics), 27-28 (metals), column E (averages for reference period)	% of (clean) material sorted and sent to recycling
5	Specific GHG emissions avoided due to material recycling	Basic assumptions	Rows 42-47 (averages for reference period)	kg CO_2(eq)/t recycled material
6	Electricity consumption from grid	GHG Emissions	Row 21	MWh/year
7	Country grid emission factor including grid losses (for imported electricity)	Basic assumptions	Row 37 (average for reference period)	t CO_2(eq)/MWh
8	Specific GHG emission factors for waste collection and transport	Basic Assumptions	Rows 48-51	t CO2(eq)/t recycled material

With regards to GHG emissions arising from the final disposal of MRF rejects, the following inputs are required in the model.

Table 9: Inputs needed for the calculation of incremental GHG emissions from the final disposal of MRF rejects

	Input	Sheet	Rows/Cells	Unit
1	Quantities of rejects sent to landfill/incineration	Waste Forecasts	Rows 18, 19, 21, 22, 24, 25, 29, 30, column E (averages for reference period)	% of total rejects going to landfill % of total rejects going to incineration
2	Fossil carbon content in SRF/RDF (for GHG emissions from incineration)	GHG Emissions	Rows 82-83 (averages for reference period)	%, on wet mass basis
3	DOCf content in SRF/RDF (for GHG emissions from landfill)	GHG Emissions	Rows 128-129 (averages for reference period)	%, on wet mass basis

For simplicity purposes, it is assumed that the rejects from MRFs have a similar composition as RDF produced in MBTs (see section 3.2.5).

It is to be noted that in the model, GHG emissions from incineration and landfilling of MRF rejects and RDF are included under the emission source categories “SRF/RDF incineration” and “Landfill” and not under the category “Material recovery” (see sections 3.3.6 and 3.3.7 below).

Indirect GHG emissions from electricity consumption are calculated based on country specific grid emission factors (see section 2.4.4).

Based on the respective inputted emission factors and the waste streams the model calculates automatically the net GHG emissions from material recovery and presents the results in row 24 of the “GHG emissions” sheet.

3.2.2 Composting

Composting is the aerobic degradation of organic waste, whose product (compost) can be used to improve the quality of the soil. Good quality compost is generally produced only when organic material is separated at source. Most composting schemes use mainly garden waste, although some schemes also use separately collected food and kitchen wastes. Some types of paper may also be composted (in small quantities).

Under aerobic conditions, organic carbon bound in the biomass is oxidized and released as CO_2. According to the usually applied convention, this “biogenic” CO_2 is neutral in terms of global warming (assuming biomass is renewed at the same rate as before) and is therefore not counted as a GHG. In addition trace amounts of CH_4 and N_2O are released as well, where anaerobic conditions temporarily occur in the composited mass. Under well controlled process conditions, these emissions are usually not very important.

Other direct GHG emissions occur as a consequence of fuel consumption by vehicles operated in the composting plant (i.e. front end loaders and other machinery).

Indirect GHG emissions from composting originate from the use of electricity at the plant (i.e. for turning and processing the compost).

Inputs into the model

The following table shows the model inputs required to calculate direct and indirect GHG emissions as well as avoided GHG emissions of composting plants:

Table 10: Inputs needed for the calculation of incremental GHG emissions from composting plants

	Input	Sheet	Rows/Cells	Unit
1	Total waste flow (from given waste source)	Waste Forecasts	Row 1	t/year
2	Quantities of biowaste separated at source and processed in composting plant	Waste Forecasts	Rows 6 (in t/y) and 7 (in %, average for reference period)	t/year of separately collected biowaste and % sent to composting plant
3	Specific GHG emission factors for composting	Basic assumptions	Rows 57-58 (averages for reference period)	kg CH_4 and kg N_2O/t of waste composted
4	Electricity consumption from grid	GHG Emissions	Row 29	MWh/year
5	Country grid emission factor including grid losses (for imported electricity)	Basic assumptions	Row 37 (average for reference period)	t CO_2(eq)/MWh
6	Specific GHG emission factor for waste collection and transport	Basic assumptions	Row 52	t CO_2(eq)/t of waste composted

With regards to point 3 above, the following default emission factors provided by IPCC (2006) are used in the calculations:

- 4 kg CH_4 per ton of waste composted
- 0.3 kg N_2O per ton waste composted

CH_4 and N_2O have a much higher global warming potential than CO_2 (21 higher for CH_4 and 310 times higher for N_2O). Hence, CH_4 and N_2O are converted into CO_2 equivalents by applying a factor of 21 and 310 respectively.

Indirect GHG emissions from electricity consumption are calculated based on country specific grid emission factors (see section 2.4.4).

Based on the respective inputted emission factors and the waste streams the model calculates automatically the net GHG emissions from composting and presents the results in line 32 of the "GHG emissions" sheet.

3.2.3 Anaerobic digestion

Anaerobic digestion (AD) involves the biological decomposition of waste in air-tight vessels in absence of oxygen. A mix of CH_4 and CO_2 is produced in the process, which is collected and may be further processed to be used as a fuel or combusted under controlled conditions for electricity production. CH_4 is oxidized to CO_2 during the combustion process, although trace amounts of CH_4 can still escape from the system.

Electricity produced from biogas is usually used on-site in the plant operation. Surplus electricity is exported to the grid and replaces electricity produced from conventional sources. In some cases, heat from the gas combustion process can also be recovered and sold and thus lead to avoided GHG emissions by displacing other sources of heat generation.

Inputs into the model

The following table shows the model inputs required to calculate direct and indirect GHG emissions as well as avoided GHG emissions of AD plants

Table 11: Inputs needed for the calculation of incremental GHG emissions from anaerobic digestion

	Input	Sheet	Rows/Cells	Unit
1	Total waste flow (from given waste source)	Waste Forecast	Row 1	t/year
2	Quantities of biowaste separated at source and treated in AD plant	Waste Forecast	Rows 6 (in t/y) and 8 (in %, average for reference period)	t/year of separately collected biowaste and % sent to AD plant
3	Specific CH_4 emission factor for AD	Basic assumptions	Row 59	kg CH_4/t of waste digested
4	Electricity generated / Electricity consumed (from own generation, from grid)	GHG Emissions	Rows 36-38	MWh/year
5	Country grid emission factors including/excluding grid losses (for imported/exported electricity)	Basic assumptions	Row 37-38 (averages for reference period)	t CO_2(eq)/MWh
6	Heat generation exported	GHG Emissions	Row 43	MWh/year
7	Specific GHG emission factor for heat source displaced by project	Basic assumptions	Row 39 (average for reference period)	t CO_2(eq)/MWh
8	Specific GHG emission factor for waste collection and transport	Basic assumptions	Row 51	t CO2(eq)/t of waste digested

With regards to point 3 above, the following default emission factor provided by IPCC (2006) is used in the calculations:

- 1 kg CH_4 per ton of waste composted

CH_4 has a much higher global warming potential than CO_2 (21 higher). Hence, CH_4 is converted into CO_2 equivalents by applying a factor of 21.

The model differentiates electricity consumption from grid and from own generation. Electricity that is not used for own consumption is assumed to be exported. For electricity consumed from the grid, indirect GHG emissions are calculated applying the country grid emission factor for electricity consumption (incl. grid losses). For electricity exported to the grid a reduced country grid emission factor for electricity export is applied (excl. grid losses) to calculate the GHG emissions avoided. The country grid factors as well as a discussion on the assumptions behind the data are reproduced in section 2.4.4.

Based on the respective inputted emission factors and the waste streams the model calculates automatically the net GHG emissions from anaerobic digestion and presents the results in row 46 of the "GHG emissions" sheet.

3.2.4 Mechanical Biological Treatment (MBT)

Mechanical biological treatment (MBT) refers to a very wide range of different waste treatment methods but usually involves some sort of mechanical pre-treatment aimed at separating the biodegradable fraction of waste for subsequent biological treatment. Depending on the selected process technology, metals, paper and plastic can also be recovered in separate fractions during the mechanical pre-treatment process. Another common waste fraction selectively separated in the mechanical treatment stage is a light, high calorific fraction that can be transformed into residue-derived fuel (RDF), which has increasing demand as a replacement of conventional fuels in industrial and municipal heat and power plants. Where there is no demand for RDF, this waste fraction is usually landfilled without further treatment together with the other largely inert residues from the mechanical pre-treatment stage.

In the biological stage, the biodegradable waste fraction is usually treated either under aerobic (composting) or anaerobic conditions (anaerobic digestion). The ultimate aim of this treatment is to produce a volume-reduced, biologically stabilized waste that can be safely landfilled and is largely stripped of its methane emission and leachate producing capacity. Another alternative involves bio-drying which is aimed at preserving the energy contained in the waste and producing a high calorific solid recovered fuel (SRF) that can be incinerated to produce heat and electricity.

Relevant direct GHG Emissions from MBT treatment facilities arise from

- the biological treatment process (as in the composting and anaerobic digestion processes described above),
- the landfilling of the untreated biodegradable residues (residues from mechanical pre-treatment, in particular textiles, paper and cardboard),
- incineration of fossil carbon contained in the RDF fraction (mainly in plastics and rubber).

Indirect GHG emissions originate from

- Grid electricity consumed at the plant

GHG emission savings originate from:

- Materials recovered in mechanical pre-treatment and sent to recycling
- Energy recovered from waste in form of electricity and heat produced from biogas or RDF/SRF.
-

Inputs into the model

The following table shows the model inputs required to calculate GHG emissions from MBT

Table 12: Inputs needed for the calculation of incremental GHG emissions from MBT

	Input	Sheet	Rows/Cells	Unit
1	Total waste flow (from given waste source)	Waste Forecasts	Row 1	t/year
2	Quantity of waste sent to MBT	Waste Forecasts	Row 9	t/year
3	Type of biological treatment provided in MBT plant	Waste Forecasts	Rows 10-12 (averages for reference period)	% of total waste flow treated through bio-drying, composting, AD
4	Composition of waste treated in MBT (fractional composition)	Waste Forecasts	Rows 79-88	t/year and/or % of total waste flow
5	Specific GHG emission factors for composting / AD	Basic assumptions	Rows 57-59 (averages for reference period)	kg CH_4 and N_2O/t of waste composted
6	Outputs of the mechanical pre-treatment stage and the biological treatment stage	Waste Forecasts	Rows 112-122	t/year
6	Specific GHG emissions avoided due to material recycling	Basic assumptions	Rows 42-47 (averages for reference period)	kg CO_2 (eq)/t of recycled material
7	Electricity consumed in mechanical pre-treatment stage	GHG Emissions	Row 49	MWh/year
8	Electricity consumed/generated in biological treatment stage	GHG Emissions	Rows 65-67	MWh/year
9	Country grid emission factors including/excluding grid losses (for imported/exported electricity)	Basic assumptions	Rows 37-38 (averages for reference period)	t CO_2eq/MWh
10	Heat recovered and exported (AD only)	GHG Emissions	Row 72	MWh/year
11	Specific GHG emission factor for heat source displaced by project	Basic assumptions	Row 39 (average for reference period)	t CO_2eq/MWh
12	Specific GHG emission factor for waste collection and transport	Basic assumptions	Row 54 (mixed waste to MBT)	t CO2(eq)/t of waste treated in MBT

With regards to GHG emissions from the biological stage involving anaerobic digestion and/or composting (see point 5 in table above) the same emission factors apply as for the simple anaerobic digestion and composting that were dealt with earlier on (see sections 3.3.3 and 3.3.4 above).

Direct CH_4 and N_2O emissions are assumed negligible in MBTs involving biodrying as a final treatment stage, as in this case the biological degradation is interrupted at a relatively early stage to avoid loss of energy contained in organic material.

The GHG emission savings from recycling of metals, plastics and paper/cardboard recovered in the mechanical pre-treatment stage (see points 6 and 7 in the table above) are calculated based on the same emission factors presented in section 3.2.2 above.

In cases in which electricity is generated, electricity consumption may be from own generation or from the grid. Electricity that is not used for own consumption is assumed to be exported. For electricity consumed from the grid, indirect GHG emissions are calculated applying the country grid emission factor for electricity consumption (incl. grid losses). For electricity exported to the grid a reduced country grid emission factor for electricity export is applied (excl. grid losses) to calculate the GHG emissions avoided. The country grid factors as well as a discussion on the assumptions behind the data are reproduced in section 2.2.4.

With regards to GHG emissions arising from the final disposal of RDF/SRF produced in MBTs, the following inputs are required in the model.

Table 13: Inputs needed for the calculation of incremental GHG emissions from final disposal of RDF/SRF produced in MBTs

	Input	Sheet	Rows/Cells	Unit
1	Final disposal pathway for SRF/RDF	Waste Forecasts	Rows 123-126 (averages for reference period)	% of total RDF/SRF going to incineration % of total RDF/SRF going to landfill
2	Fossil carbon content in SRF/RDF (for emissions from incineration)	GHG Emissions	Rows 82-83 (averages for reference period)	%, on wet mass basis
3	DOCf content in SRF/RDF (for emissions from landfill)	GHG Emissions	Rows 128-129 (averages for reference period)	%, on wet mass basis

It is to be noted that in the model, GHG emissions from incineration and landfilling of SRF/RDF are included under the emission source categories “SRF/RDF incineration” and “Landfill” and not under the category “MBT” (see sections 3.2.6 and 3.2.7 below).

For the other outputs from the biological treatment stage (i.e. composts and CLO) it is assumed that all of the DOCf contained in the input waste is degraded during treatment, so no further GHG emissions have been considered after their final disposal (usually used as cover or backfilling material in landfills or landscaping).

Based on the respective inputted emission factors and the waste streams the model calculates automatically the net GHG emissions from MBT and presents the results in row 76 of the “GHG emissions” sheet.

3.2.5 Waste Incineration

Waste incineration implies the chemical oxidation of the elementary components of waste, including carbon compounds, through combustion. The residues of waste incineration are mainly inorganic ashes, which are biologically inert: they contain nearly no organic matter and therefore do not form organic leachate or methane after disposal in landfills.

Ferrous metals and sometimes also non-ferrous metals can be recovered from the incineration slag and bottom ash.

Energy, in form of heat, electricity or both can be recovered from the energy released during waste incineration, which may lead to avoided GHG emissions from conventional energy generation.

The GHG calculation model considers two types of waste incineration:

- ***Mass burn MSW incineration***: mass burn incineration of mixed wastes collected from households and commerce
- ***SRF/RDF incineration:*** incineration of solid recovered fuels (SRF) and refuse-derived fuels (RDF), which are mixed wastes with high calorific value produced in MBTs for incineration or co-incineration in combustion plants to generate heat and/or electricity.

Inputs into the model

The following table shows the model inputs required to calculate GHG emissions from mass burn incineration of MSW.

Table 14: Input needed for the calculation of incremental GHG emissions from mass burn incineration

	Input	Sheet	Rows/Cells	Unit
1	Total MSW flow (from given waste source)	Waste Forecasts	Row 1	t/year
2	Quantity of MSW sent to incineration	Waste Forecasts	Row 13	t/year
3	Composition of waste sent to incineration (fractional composition)	Waste Forecasts	Rows 128-146	t/year and/or % of total waste flow
4	Lower calorific value of MSW	Basic assumptions	Row 62 (average for reference period)	MJ/kg
5	MSW fossil (non-biomass) combustible share	Basic assumptions	Row 63 (average for reference period)	% of energy content
6	Fossil CO_2 emission factor for waste incineration	Basic assumptions	Row 64 (average for reference period)	t CO_2/TJ of waste incinerated
7	CH_4 and N_2O emission factors for waste incineration	Basic assumptions	Rows 65-66 (averages for reference period)	t CH_4/t of waste incinerated t N_2O /t of waste incinerated
8	Metals recovered from slag and bottom ash sent to recycling	Waste Forecasts	Rows 182-183	t/year
9	Specific GHG emissions avoided due to metal recycling	Basic assumptions	Rows 42-43 (averages for reference period)	kg CO_2 (eq)/t of recycled metals
10	Electricity generated and consumed in incineration plant (consumption from grid and from own generation)	GHG Emissions	Rows 107-109	MWh/year
11	Country grid emission factors for electricity including/excluding grid	Basic assumptions	Rows 37-38 (averages for reference period)	t CO_2 (eq)/MWh

	losses (for imported/exported electricity)			
12	Heat recovered and exported	GHG Emissions	Row 114	MWh/year
13	Specific GHG emission factor from heat source displaced by project	Basic assumptions	Rows 39 (average for reference period)	t CO_2eq/MWh
14	Specific GHG emission factor for waste collection and transport	Basic assumptions	Row 55	t CO2(eq)/t of incinerated waste

In the model, the method used for the calculation of the fossil CO_2 emissions from incineration is based on the fossil carbon content of the waste burned, which is assumed to be almost completely oxidized to CO_2 (98%). The fossil carbon content of a waste mix will depend on its fractional composition, in particular on its content of plastics and, to a lower extent, also of rubber and textiles. While the model automatically calculates the fossil carbon content of mixed MSW with known fractional composition (using the default fossil carbon contents of the main MSW fractions presented in section 3.3.1 above), fossil carbon contents of RDF and SRF must be inputted by hand. This is because the composition of RDFs and SRFs may vary significantly from one case to another as it depends to a great extent on the specific production processes applied.

For comparison, the model also calculates fossil CO_2 emissions from mass burn incineration of mixed MSW based on the following variables for which default values are included:

- Specific emission factor (MSW): 91.7 tCO_2(fossil)/TJ fossil energy input (IPCC, 2006)
- Lower calorific value for mixed MSW: 10.5 MJ/kg
- MSW fossil (non-biomass) combustible share: 40%

In addition to fossil CO_2 emissions, the model also calculates CH_4 and N_2O emissions from waste incineration. The standard emission factors used in the model are the following, which apply for both mixed MSW and RDF/SRF:

- 50 g N_2O / t of waste
- 0.2 g CH_4 / t of waste

CH_4 and N_2O emissions are converted into CO_2 equivalents by using a factor of 21 and 310, respectively

The GHG emission savings from recycling of metals recovered from the slag and bottom ash (ferrous and non-ferrous) are calculated based on the same emission factors presented in section 3.2.2 above.

In cases in which energy is recovered from the incineration process in form of electricity or heat, additional inputs are required for the plants electricity and heat generation and consumption. Electricity consumption may be from own generation or from the grid. Gross electricity generated that is not used for own consumption is assumed to be exported. For electricity consumed from the grid, GHG emissions are calculated applying the country grid emission factor for electricity consumption (incl. grid losses). For electricity exported to the grid a reduced country grid emission factor for electricity export is applied (excl. grid losses) to calculate the GHG emissions avoided. The country grid factors as well as a discussion on the assumptions behind the data are reproduced in section 2.4.4.

Based on the respective inputted emission factors and the waste streams the model calculates automatically the net GHG emissions from RDF/SRF and mass burn incineration and presents the results in rows 97 and 120 of the “GHG emissions” sheet.

3.2.6 Landfilling of waste

By far the largest direct GHG emission from landfill operations is methane, which is one of two main components of landfill gas. Methane constitutes around 50% (up to 60%) of total landfill gas volume and is produced during biological degradation of organic wastes under anaerobic conditions existing inside the landfill body. The other main component is CO_2, which is also a product of biological activity inside the landfill body, is assumed to be GHG neutral (short- cycle carbon).

The amount of methane emissions finally released from a landfill into the environment depends mainly on the type of waste deposited, in particular the amount of easily degradable ("dissimilable") carbon, but also on the structure of the landfill and the landfill management practices implemented:

- Whether the landfill is shallow or deep
- Whether the deposited waste is regularly compacted and covered with inert material
- The existence, extension and efficiency of landfill gas collection systems
- The implementation, operation regime and efficiency of gas flaring or gas combustion systems for electricity generation.

In state-of-the-art landfills, where waste is deposited in a controlled and systematic manner, methane emissions can be notably reduced by implementing efficient gas collection systems. On the other extreme (which is still the status quo in many countries in which JASPERS is active), where untreated wastes are deposited without control and landfills/dumpsites have no gas management systems, uncontrolled methane emissions can be significantly higher.

Other direct GHG emissions from landfills originate from fuel consumption by vehicles typically operated on the landfill (i.e. compactors, front end loaders, etc.). These are however quite small compared to the methane emission described above.

Where landfill gas is collected and electricity is produced from it, there is also a potential for GHG avoidance due to the replacement of electricity generation from conventional (fossil) fuels. In some cases, heat from the gas combustion process can also be recovered and exported and thus lead to avoided GHG emissions by displacing other sources of heat generation.

Input into the model

The following table shows the model inputs required to calculate other direct GHG emissions as well as avoided GHG emissions derived from landfill operations.

Table 15: Input needed for the calculation of incremental GHG emissions from landfills

	Input	Sheet	Rows/Cells	Unit
1	Total waste flow (from given waste source)	Waste Forecasts	Row 1	t/year
2	Quantity of (untreated) waste to landfill	Waste Forecast	Row 14	t/year
3	Composition of (untreated) waste landfilled (fractional composition)	Waste Forecasts	Rows 187-205	% of total waste incinerated and/or t/y
4	Quantity of rejects from MRF and MBT landfilled	Waste Forecast	Rows 18, 21, 24, 29 (rejects from MRF), Rows 123, 125 (RDF/SRF from MBT)	t/year and/or %

5	DOCf contents of rejects from MRF and MBT	GHG emissions	Rows 127-129 (averages for reference period)	% of total mass
6	Methane correction factor (MCF)	Basic assumptions	Rows 67-68 for with-project and baseline scenario (averages for reference period)	Value between 0 and 1
7	CH_4 fraction in landfill gas (F)	Basic assumptions	Row 69 (average for reference period)	%
8	Methane Recovery, i.e. mass of CH_4 recovered per year for energy use or flaring	Basic assumptions	Rows 70-71 for with-project and baseline scenario (averages for reference period)	%
	Oxidation factor, i.e. fraction of CH_4 released that is oxidised below surface within the site	Basic assumptions	Rows 72-73 for with-project and baseline scenario (averages for reference period)	%
10	Specific GHG emission factor from fuel consumption in landfill operations	Basic assumptions	Row 82 (average for reference period)	kg CO_2/t of landfilled waste
11	Electricity generated and consumed in landfill (consumption from grid and from own generation)	GHG Emission	Row 142-144	MWh/year
12	Country grid emission factors including/excluding grid losses (for imported/exported electricity)	Basic assumptions	Rows 37-38 (averages for reference period)	t CO_2eq/MWh
13	Heat recovered and exported	GHG Emission	Row 149	MWh/year
14	Specific GHG emission factor from heat source displaced by project	Basic assumptions	Rows 39 (average for reference period)	t CO_2eq/MWh
15	Specific GHG emission factor for waste collection and transport	Basic assumptions	Row 56 (mixed waste to landfill)	t CO2(eq)/t of landfilled waste

For the calculation of direct methane emissions from landfills, the sample model uses the IPCC Default Methodology Tier 1 (Rows 105 - 135 in the worksheet “GHG Emissions”). This evaluates the total potential yield of methane from the waste deposited, expressed as average annual emission.

$$CH_4 \text{ (t/y)} = [\text{ MSWT x L0 - R }] \text{ x } [\text{ 1 - OX }]$$

$$\text{L0 = MCF x DOC x DOCf x F x (16/12);}$$

Where

MSWT = *Annualised mass of MSW to be deposited,*

L0 = *Methane Generation Potential,*

R = *Methane Recovery, i.e. mass of* CH_4 *recovered per year for energy use or flaring,*

OX = *Oxidation Factor,*

MCF = *Methane Correction Factor,*

DOC = *Degradable Organic Carbon,*

DOCf = *fraction of DOC dissimilated,*

F = CH_4 *fraction in landfill gas.*

The methane correction factor (MCF) reflects the nature of the waste disposal practices and facility type. Recommended values by IPCC (2006) are:

- Managed (i.e. controlled waste placement, fire control, and including some of the following: cover material, mechanical compacting or levelling): MCF = 1

- Unmanaged- deep (> 5m waste): MCF = 0.8

- Unmanaged- shallow (< 5m waste): MCF = 0.4

- Uncategorised (default): MCF = 0.6.

The chosen values for CH_4 fraction in landfill gas (F) a default value 0.5 can be used but this choice should be explicitly justified. The recommended default value for the oxidation factor (OX) for well-managed sites is OX = 0.1, otherwise 0 (source: IPCC, 2006).

The standard emission factor from fuel consumption in landfill operations (point 9 in the table above) was assumed to be 1.2 kg CO_2/t landfilled waste and was taken from the AEA study (2001).

Based on the respective inputted emission factors and the waste streams the model calculates automatically the net GHG emissions from landfill and presents the results in row 153 of the “GHG emissions” sheet.

3.3 Summary of GHG emission calculations

As explained above, the model’s “GHG emissions” sheet presents the aggregated annual GHG emissions, in t CO_2 (eq), for the different components of the waste management system in the with-project scenario and the baseline (without-project) scenario, as follows:

- Material recovery in sorting plants (row 24)
- Composting (row 32)
- Anaerobic digestion (row 46)
- MBT (row 76)
- SRF/RDF incineration (row 97)
- Mass burn incineration, (row 120) and
- Landfill (row 153).

The total net GHG emissions for all system components are aggregated in row 159 of the model's "GHG emissions" sheet and broken down into:

- GHG emissions from waste collection and transport (row 154)
- GHG emissions from waste treatment (row 155)
- GHG emissions from landfilling of waste (row 156)
- GHG emissions avoided through recycling of materials recovered from waste (row 157)
- GHG emissions avoided through energy recovered from waste (row 158)

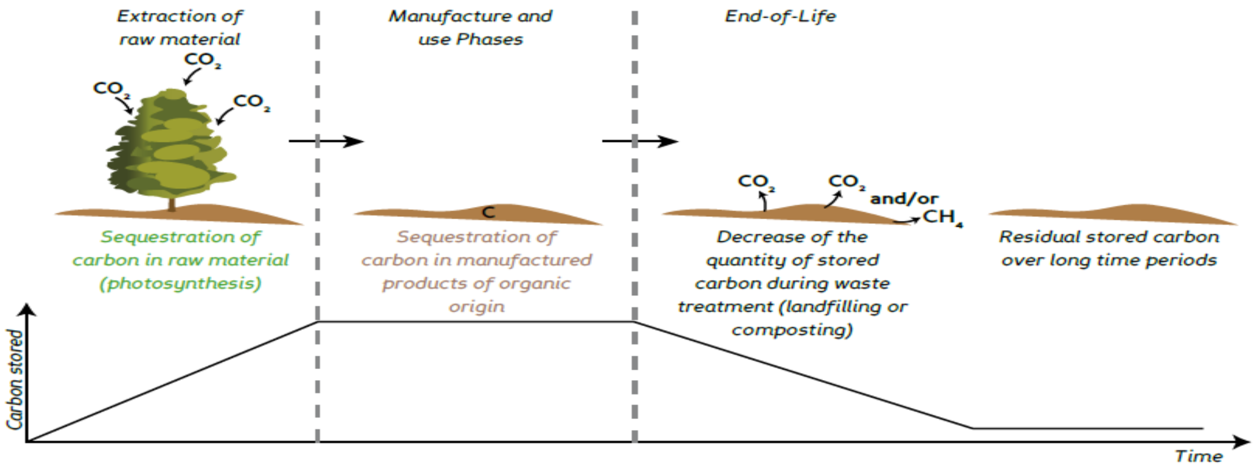
Note that the models allows the separation of the total municipal waste generated into separate waste sources (i.e. municipal waste produced by households, by commerce, etc.) to be able to show the contribution to total GHG emissions for each one of them.

Finally, summary tables present all this information in an easy-to-read manner in a separate sheet of the model, including the total incremental GHG emissions of the project ("Summary Project GHG Emissions").

Annex

Annex 1: The Principles of Carbon Capture Storage

Carbon sequestration refers to the storage of carbon, i.e. the removal of carbon from the global carbon cycle over long periods of time. By convention, only biogenic carbon that is stored for longer than 100 years can be regarded as sequestrated (EpE, 2010[14]). In the waste sector, carbon is mainly sequestrated when waste is composted or landfilled. While easily degradable organic carbon (referred to as "dissimilable" carbon) is rapidly decomposed under both aerobic and anaerobic conditions and emitted as CO_2 or CH_4 into the atmosphere, other less degradable carbon does not decompose completely or only very slowly. This is for instance the case of lignins contained in wood and some sorts of paper (newspaper). The amount of degradable carbon which is not decomposed and therefore remains sequestrated in landfills and soils depends on the type of waste.



Source: EPE (2010), p. 35

Annex 2: Current common practice for quantifying GHG emissions in projects appraised by JASPERS

In the financing perspective 2007-2013 common practice for quantifying GHG emissions used in a number of projects appraised by JASPERS and approved by the European Commission has been to calculate separately the following categories of GHG emissions:

a) GHG emissions directly or indirectly released through specific waste management/treatment processes
b) GHG emissions avoided through recycling of recovered waste materials
c) GHG emissions avoided through energy recovery from waste

a) GHG emissions released through specific waste management/treatment processes

. The calculation of GHG emissions released through the waste management/treatment processes presented in Table 16 below can be done by using standard emission factors taken from the AEA study (2001). The particular emission factors are also shown in the table below, broken down into different types of

[14] Entreprise pour l'Environnement (EpE) (2010), Protocol for the quantification of greenhouse gases emissions from waste management activities, Version 4.0 - June 2010, http://www.epe-asso.org/pdf_rapa/EpE_rapports_et_documents20.pdf

GHG (i.e. Fossil CO_2, CH_4, and N_2O) and sources of emissions inside each process (i.e. from (i) waste transport to/from the facility, (ii) energy use in treatment, and (iii) the treatment itself).

Table 16: Waste management/treatment processes and the standard emission factors presented in the AEA study, 2001

Waste management/treatment process	Standard emission factor (in kg CO_2 eq/tonne waste treated)	Reference (in AEA study)
Mixed waste not collected or disposed of in landfills with no or limited gas collection	833 kg CO_2 eq/t, of which - 7 Fossil CO_2 from transport - 1 Fossil CO_2 from energy use - 825 CH_4 from landfill	Fig 9, p. 28 Table A2.31, p. 104
Mixed waste going directly to compliant landfill	298, of which - 7 Fossil CO_2 from transport - 1 Fossil CO_2 from energy use - 290 CH_4 from landfill	Fig 9, p. 28 Table A2.31, p. 104
Mixed waste going directly to incineration	253, of which - 8 Fossil CO_2 from transport - 230 Fossil CO_2 from incineration - 15 N_2O from incineration	Table A3.39, p. 120
Mixed waste being transformed into RDF and going to incineration	236, of which - 3 Fossil CO_2 from transport - 29 Fossil CO_2 from energy use (RDF production) - 196 Fossil CO_2 from incineration - 8 N_2O from incineration	Fig. 13, page 33, average of fluidised bed combustors, power stations and cement kilns
Bio-waste collected separately and with aerobic composted	26, of which - 8 Fossil CO_2 from transport - 18 Fossil CO_2 from energy use	Table A5.52, page 159
Bio-waste collected separately and with anaerobic composting	8, of which - 8 Fossil CO_2 from transport	Table A6.55, page 165
Mixed waste to MBT for compost, with landfilling of rejects	161, of which - 5 Fossil CO_2 from transport - 22 Fossil CO_2 from energy use - 134 CH_4 from landfill	Table A4.44, p. 133 (Mean of cases 1&2)
Mixed waste to MBT for compost, with incineration of rejects	272, of which - 5 Fossil CO_2 from transport - 22 Fossil CO_2 from energy use - 37 CH_4 from landfill	Table A4.44, p. 133 (Mean of cases 1&2)

	- 205 Fossil CO_2 from incineration - 3 N_2O from incineration	

b) GHG emissions avoided through recycling of recovered waste materials

For separately collected and recycled materials (including paper and cardboard, plastics, glass and metals) an average emission factor of -1,037 kg CO_2eq/t of recycled material can be assumed. This value is estimated based on the following assumptions:

- Standard emission factor for material recycling: – 387 kg CO_2eq/t MSW (AEA study, Table 10, page 39, average for paper, plastic, glass and metal, including emissions from landfilling of residues which excluded carbon sequestration)
- Average share of recyclables in MSW of 53% (AEA study, Figure 1, p. 7)
- Separation efficiency for recyclable materials at source of 70% (own assumption)

c) GHG emissions avoided through energy recovery from waste

In waste management, energy can be recovered in form of electricity and/or heat through one or more of the following alternatives:

- collection and controlled combustion of landfill gas
- biogas produced in anaerobic digesters
- incineration of mixed residual wastes or SRF/RDF

For electricity and heat recovered from these processes the following default emission factors, which are taken from the AEA study, can be used:

- Electricity: -0.45 kg CO_2eq per kWh (average for electricity mix produced in EU 15)
- Heat: -0.28 kg CO_2eq per kWh (average for heat produced in EU 15)

These emission factors can be replaced with country- or project-specific emission factors, if such are available.

The main advantage of the above described method is its simplicity. The calculation only requires the knowledge of the total waste generated and the different waste fractions collected, the individual waste management systems implemented, as well as the amounts of material recycled and energy recovered in form of electricity and heat for both the with-project and the without-project scenario. The GHG emissions from each individual GHG source category are obtained by multiplying waste and energy amounts with the respective standard emission factors. The total project related (incremental) net GHG emissions results from the comparison of total net GHG emissions in the with-project and without-project scenario.

This method, however has important disadvantages. First of all, the standard emission factors applied in the calculations are based on assumptions on average waste composition and technological standards existing in the EU before 2001, year in which the AEA study was published. After ten years these assumptions are likely to be outdated. And importantly, the model does not allow for consideration of the specifics of individual waste projects, in particular:

- project specific waste composition and its projected change over time
- project specific waste collection systems, in particular for source separated recyclable materials, and projected efficiency improvements for different waste fractions over time
- project specific technologies for waste treatment and their performance

Depending on the characteristics of particular a project, all of this could lead to notable under-or overestimation of a project's GHG emissions over its assumed reference period.

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