Protocol for the quantification of greenhouse gases emissions from waste management activities

Entreprises pour l'Environnement

Version 4.0 - April 2010

Table of contents

Table of contents

Acknowledgements and Contact

This protocol was developed by the Entreprises pour l'Environnement working group composed of the following companies:

- SECHE ENVIRONNEMENT
- SUEZ ENVIRONNEMENT
- VEOLIA ENVIRONNEMENTAL SERVICES

The initial redaction of the protocol was done by Ernst & Young on the basis of the REGES Draft Guidance second version published by Entreprises pour l'Environnement.
EpE gives very special thanks to Alexandra LALET (Suez Environnement SITA), Pauline MAGNIEN (Veolia Propreté) and Olivier PENAUD (Suez Environnement) for their intensive work on updating this tool.

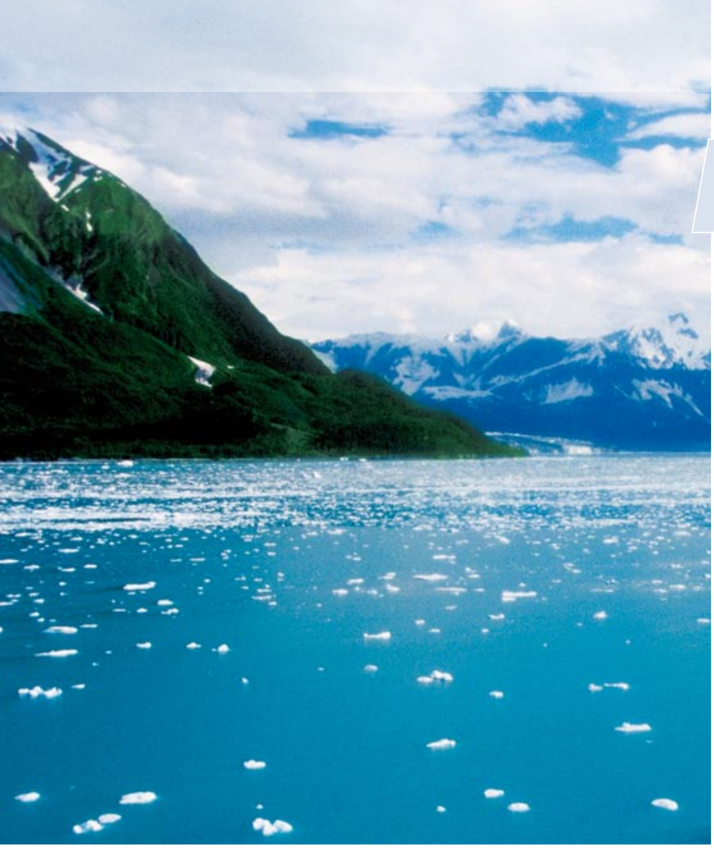
Entreprises pour l'Environnement

50 rue de la Chaussée d'Antin
Paris 75009

Tel : +(33) 1 49 70 98 50
Fax : +(33) 1 49 70 02 50
E-mail : contact@epe-asso.org

http://www.epe-asso.org

EpE is a partner of the WBCSD (World Business Council for Sustainable Development) which unites round 200 international companies to promote the role of companies in sustainable development.
EpE relays in France the WBCSD's main publications, and both players have frequent exchanges on their current works.



Foreword

Foreword

Greenhouse gases (GHG) emissions are of major environmental concern. New policies have been implemented by authorities and companies to reduce emissions from the main emission sources since United Nations Framework Convention on Climate Change (UNFCCC) and the 1997 Kyoto Protocol.

Therefore, under the initiative of the World Business Council for Sustainable Development (WBCSD) and the World Resources Institute (WRI), the GHG Protocol[1] was published enabling guidance to companies for GHG emissions accounting. In North America, a GHG emission trading system, the Chicago Climate Exchange was created.

In Europe, the IPPC[2] Directive led to the creation of the E-PRTR[3] register and to the annual declaration for European sites of their emissions to the authorities. In parallel, a GHG emissions trading market for some industrial sectors was implemented on January 1st 2005.

The Entreprises pour l'Environnement (EpE) Association drew up a GHG emissions quantification, reporting and verification protocol for industries, with 14 sector specific protocols annexed to it. The 32 AERES[4] companies committed to reducing or controlling their GHG emissions over the 2003-2004 and 2005-2007 periods; they used the protocol established by EpE.

The global direct GHG emissions resulting from waste management activities were around 1.3Gt CO_2 eq. or approximately 3 – 5% of total anthropogenic emissions in 2005 (IPCC 2007).

For several years, most companies in the waste sector have implemented emission reporting systems, notably for GHG emissions. Several calculation tools were published for specific emissions from various waste treatment methods. The aim of this protocol is to homogenize calculation methods and to have a GHG global reporting protocol that can be applied to all of the waste management activities. The EpE protocol tool is exclusively dedicated to annual GHG reporting. It is not intended to be used to compare scenarios.

An emissions QUANTIFICATION, REPORTING and VERIFICATION system is an essential core tool for any action or commitment on GHG emissions. Such a tool is also an essential basis to allow comparisons between the waste sector and other industrial sectors on the basis of comparable reporting principles. It aims at giving support to waste management plant managers for preparing their GHG emissions inventory.

Three companies, Veolia Environmental Services, Séché Environnement and Suez Environnement, members of the association Entreprises pour l'Environnement, established a Working Group led by EpE and contributed their competence and expertise.

The present document along with the Excel emissions calculation worksheet, constitutes the waste management sector specific protocol of the general EpE protocol.

1. http://www.GHGprotocol.org
2. Integrated Pollution Prevention and Control
3. European Pollutant Release & Transfer Register
4. Association des Entreprises pour la Réduction de l'Effet de Serre – French association of companies for the reduction of greenhouse effect.

Waste Management Sector Presentation

Sector Specificities

The primary objective of the waste sector is to treat – or recover – as efficiently as possible undesirable residues from anthropic activities to limit their impacts on the environment. The main specificity of companies in this sector lies in their paradoxical position: as actors of the products' « end of life », they generate environmental impacts that **they are not the cause of**, since they are not responsible for the very creation of these wastes.

In this context, one of the main issues is the determination of the scope of responsibility for the impacts caused. Whether it be during the transportation phase (collection, transport) or waste treatment, waste management activities generate atmospheric emissions. The waste sector companies must act with waste producers to have an influence on the quantity and quality of the waste they receive. The implementation of pre-treatment methods already allows the reduction of atmospheric emissions from treatment activities or downstream recovery.

In general, the waste sector is under strict monitoring regulations in terms of environmental impacts. This is why treatment facility emissions and discharges are reported as accurately as possible by the operators.

However, GHG emissions monitoring presents an important uncertainty today, because of several factors:

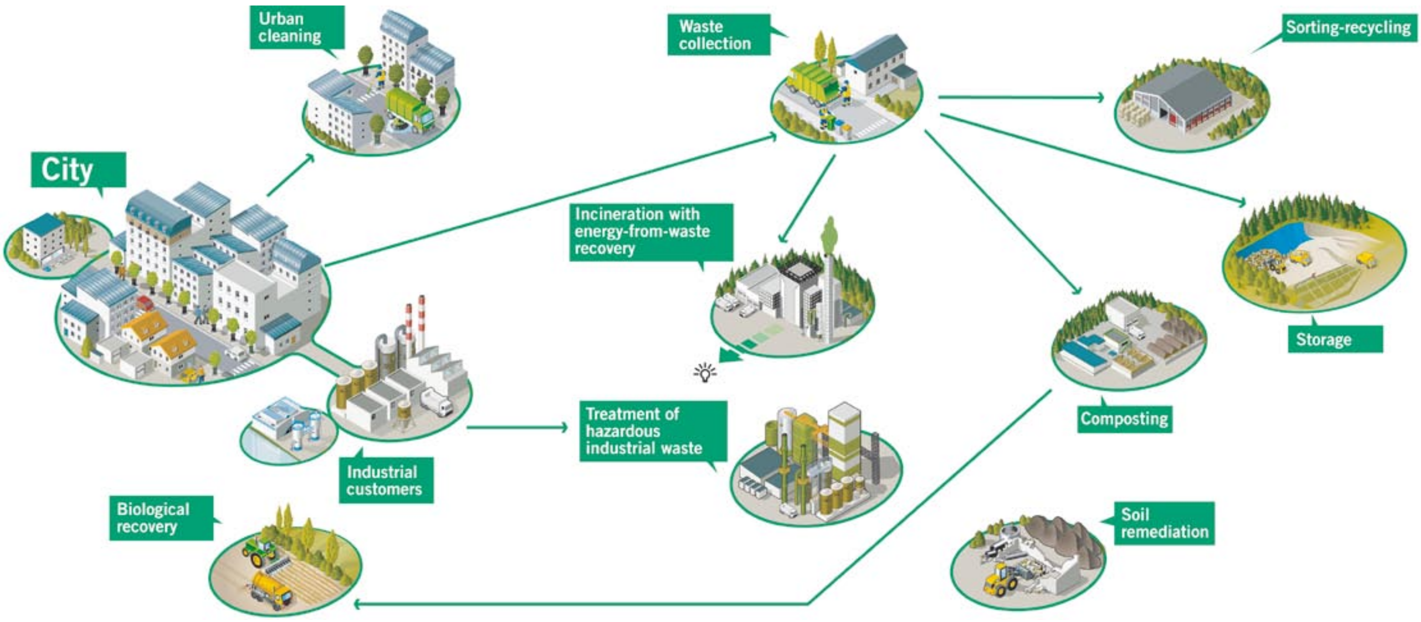
- Firstly, an important number of waste treatment activities incorporate complex processes (notably biological) for which it is difficult to reach the same accuracy as in the other industrial activities' emissions to quantify GHG emissions,
- Secondly, waste management activities are interdependent,
- Finally, the composition of treated wastes is often very heterogeneous, for which a statistical approach is recommanded and most practicable, introducing important but unavoidable bias.

Finally, the waste sector supports the definition of specific atmospheric emissions:

- **Emissions from biomass**: products containing vegetal or animal matter (biodegradable wastes, wood, green waste , wastes from agriculture and food industry…) emit greenhouse gases – when decaying or burning. International conventions[1] agree that carbon dioxide from biomass should not be accounted for, since it comes from carbon captured by living organisms in the first place.
- **Avoided emissions**: one of the goals of the waste management sector is to recover as much as possible the treated products, either as material (reuse, recycling, composting…), or as energy (landfill gas recovery, incineration with energy recovery…). The materials and energy recovered subsitute for the materials/energy whose production would have emitted GHG. For example, one tonne of steel from selective recycling can be re-used, therefore avoiding the manufacturing of one tonne of steel in a steelworks plant and the associated atmospheric emissions. A definition of avoided emissions is given in paragraph 1.15.

1. See for example : 2006 IPCC Guidelines for National Greenhouse Gas Inventories
   Volume 1 – "Introduction" : «Carbon dioxide from the combustion or decay of short-lived biogenic material removed from where it was grown is reported as zero in the Energy, IPPU and Waste Sectors (for example CO_2 emissions from biofuels, and CO_2 emissions from biogenic material in Solid Waste Disposal Sites."
   Volume 5 - " Waste " : "CO_2 is also produced in SWDS, wastewater treatment and burning of non-fossil waste, but this CO_2 is of biogenic origin and is therefore not included as a reporting item in this sector»

Treatment Activities



The waste cycle is presented above, with the different existing waste management routes.

The various steps of the waste cycle are briefly presented below.
To be noted is that only emissions related to waste management activities are considered here. For the calculation of other types of emissions, other tools should be used (for example emissions related to transporting of persons : refer to the EpE Transport Protocol).

Collection and transportation

Principle
Collection is the first step of the waste cycle. It aims at gathering waste before treatment and recovery. Collection can be done door-to-door, using dedicated vehicles, or after preliminary voluntary drop-off in specific containers (packaging, paper, and glass). Waste that is collected this way from communities, individuals or companies are consolidated and then transported to a transfer center or directly to a treatment or material recovery facility.

GHG emission source
No source is attributed to the waste itself. Emitted GHG comes from fuel used for transport. Fuel change can result in GHG emissions reduction.

Transfer

Principle
Waste that is collected from communities, individuals or companies can be consolidated in a transfer center and then transported to a treatment or material recovery facility.

GHG emission source
No source is attributed to the waste itself. Emitted GHG are associated with on –site fuel and electricity consumptions.

Mechanical pre-treatment

Principle
Waste can undergo several methods of pre-treatment to facilitate their recovery or recycling. For example, electric and electronic equipment waste can be dismantled.

GHG emission source
This step does not generate direct emissions, apart from potential fuel consumption for equipment. However, this step allows optimization of downstream treatment activities and thereby reduces their environmental impact.

Sorting, recycling and material recovery

Principle
Waste is sorted to separate the diverse materials. Recyclable materials are then recycled by introducing them in the production cycle as a partial or total substitution (paper, glass, steel, etc.).Solid Recovered Fuels (SRF) can be produced and then used in substitution of conventional fossil fuels.

GHG emission source
No source is attributed to the waste itself. Emitted GHG come from energy consumption associated

with the sorting operation of the recycling center. Recycling results in avoided GHG emissions since the recycled products/fuels are used to replace materials/ fuels whose production would have generated GHG emissions.

Physico-chemical treatment

Principle
Mechanical, physical or chemical treatment of hazardous waste in dedicated installations. Alternative fuels can be produced.

GHG emissions source
No source is attributed to the waste itself. The emitted GHG come from consumed electricity or on-site fuel consumption.
Use of hazardous waste as alternative fuels results in avoided GHG emissions since they replace conventional fossil fuels whose production would have generated GHG emissions.

Biological treatment (composting, anaerobic digestion)

Principle
This treatment type allows the recovery of organic waste through aerobic/anaerobic fermentation to get an organic amendment that can be used in agriculture. This process can be applied to agro-food industry waste, biowaste as well as sewage sludge.

GHG emission source
Composting allows waste stabilization through aerobic fermentation. In facilities using proper operating practices, waste is regularly aerated and its degradation should only generate carbon dioxide (not taken into account in the final balance since it comes from biomass). Actually, research programs show that methane (CH_4) and nitrous oxide (N_2O) emissions can occur and should be accounted. The produced compost is a soil improver. It can be used in agricultural recovery and come in substitution to chemical fertilizers and peat. Compost also helps to bind carbon in soils.

In the case of **anaerobic digestion**, controlled anaerobic fermentation of waste in a digester results in the production of biogas which is mainly composed of methane. Produced biogas is captured and combusted in flares or recovered to produce thermal or electric energy. Again, carbon dioxide from combustion is not taken into account in the final balance since it comes from biomass. Here as well, methane (CH_4) and nitrous oxide (N_2O) emissions might occur (leakage at digester).

Research programs are underway to evaluate these emissions. Available data (European BREF on waste management[1]) seem to show that these emissions would be negligible.

See Annex 4 for a synthesis of values encountered in the literature for N_2O and CH_4 emissions factors from composting activities.

Landfilling

Principle
Landfilling, refers to the more modern sites where waste is placed in lined disposal areas which are environmentally isolated, and where waste is naturally degraded. Within best practices, emissions produced by decaying waste (gas and leachate) may be recovered through drainage systems and treated. The amount and quality of these emissions are variable in time and depend on the composition of the stored wastes.

GHG emission source
Organic waste decomposition produces landfill gas (comprised of methane and carbon dioxide in nearly the same amounts). Part of this landfill gas can be captured and destroyed through flares or recovered to produce energy. Combustion converts the captured methane into carbon dioxide, which has an impact on the greenhouse effect that is 21 times less. Moreover, this carbon dioxide comes from biomass and is therefore not taken into account in the final balance. However, all of the produced landfill gas cannot be captured and part of it is emitted to the atmosphere (diffuse emissions). These are difficult to measure and are therefore estimated using modeling methods mentioned in this protocol.

Carbon sequestration in landfills
In parallel to the common approach which consists in taking into account the methanogenic potentials of the waste fractions disposed in landfills, it is possible to consider, in an opposite logic, the carbon storage factors of the different waste fractions.
See Annex 3 for a compiling of existing studies on the subject.

1. Reference document on best available techniques for the waste treatments industry (BREF), 08/2005

Incineration

Principle

Waste is degraded through thermal treatment in incinerators. Incineration can concern municipal solid waste, industrial waste and sometimes sewage sludge. Recovering the energy produced can feed heating networks and/or electric turbines. Furthermore, solid residue from combustion (bottom ash) are recovered and scrap metal can be recycled.

GHG emission source

As in any burning process, carbon dioxide and nitrous oxide are produced. Part of these emissions comes from the biomass waste, the waste itself having various compositions and depending on local population habits.

For municipal solid waste incineration, an emission factor is used to estimate the GHG emissions. For hazardous waste incineration, waste composition varies significantly, making it necessary to measure the emissions by mean of continuous measurement methods at the stack.

Energy production linked to waste incineration results in avoiding emissions from the production of an equivalent quantity of energy from a power plant using fossil fuels.

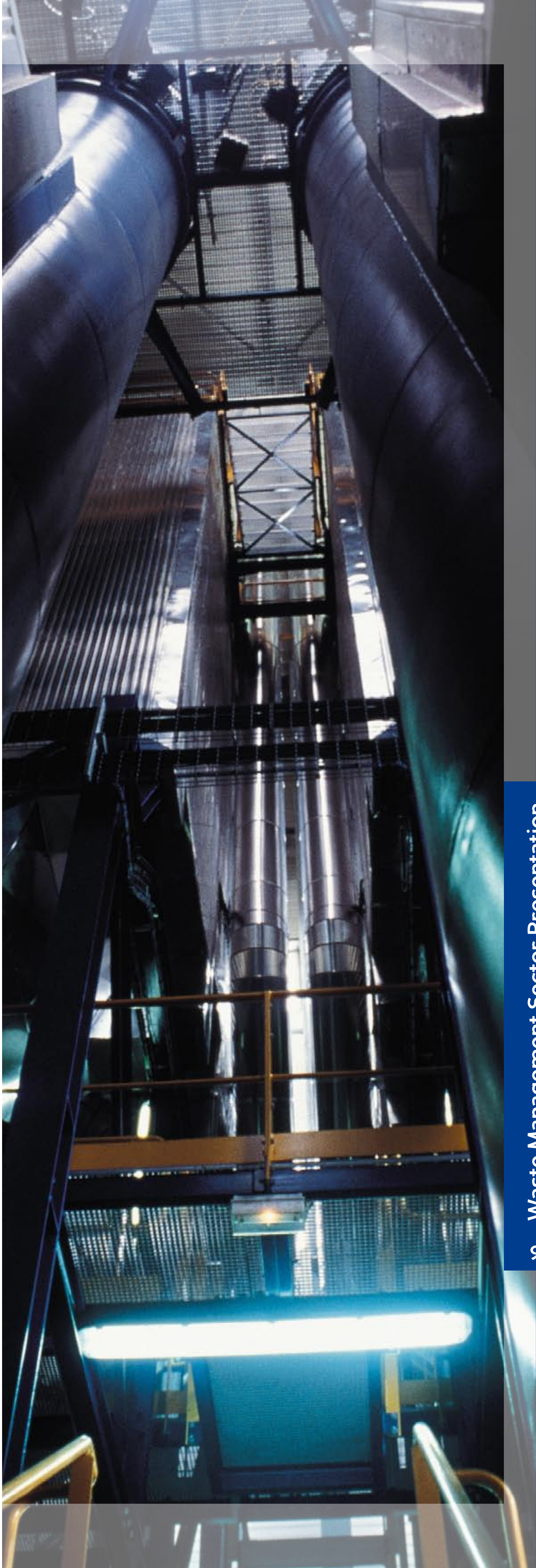
Mechanical biological treatment (MBT)

Principle

MBT is a intermediate treatment step between waste collection and the subsequent treatment steps (landfill, thermal treatment, agronomic reuse, recycling or any other existing form of treatment). It is mainly used to treat municipal solid waste with an adequate biodegradable content to feed the biological step. In some cases, commercial and industrial waste or biowaste can also feed the plant. The configuration of the MBT process can vary. The process can start with the mechanical step and then a biological step or the other way round, depending on the target of the plant : compost production, SRF production, energy production from biogas and/or stabilat production.

GHG emission source

Mechanical and biological pre-treatment steps generate direct and indirect emissions due to their own consumption of fossil fuels and electricity. During the biological step, CH_4 and N_2O emissions might occur. It also must be kept in mind that it will be necessary to take into account the final treatment of the residues of the MBT processing (landfills,...) as long as it is under operation control.



Objectives and principles

Protocol's objectives

This document is intended to guide local authorities and companies whose activity is waste management, as well as companies managing their own wastes, to quantify, report and verify greenhouse gases (GHG) emissions, in order to obtain a GHG emissions inventory. The purpose of this protocol is to establish best practice for the implementation of an annual inventory of GHG emissions.

The reported data should be consistent with the guidance outlined in this document. Any deviation from these guidelines should be described fully in the report supporting the GHG emissions inventory.

This protocol is compatible with the Greenhouse Gas Protocol – A Corporate Accounting and Reporting Standard – Revised edition, elaborated by the WBCSD[1] and the WRI[2]. It is also compatible with the ISO standards related to GHG emissions inventory.

This protocol is a dynamic document: it may be modified according to new knowledge and/or improved calculation and measurement techniques.

GHG Emissions Accounting Principles

It is essential that the data submitted be as complete and as accurate as possible. The following recommended principles for developing and reporting a corporate GHG emission inventory are based on "International Financial Reporting Standards" (IFRS), established for financial accounting and reporting.

Consistency:

Inventory and reported data must be prepared in such a way that valid year to year comparisons can be made. Any changes in the basis of reporting should derive from continuous improvement of inventory quality. Changes must be clearly stated and documented to allow year to year comparison.

Completeness:

The choice of the boundaries and scope of the inventory must be representative of the entity's activities. All material source types within the chosen boundary must be included in the inventory.
However, in some cases, the entity may define a minimum threshold below which emissions are excluded from the inventory, or choose to exclude some source types.
This will be possible only if the entity documents and justifies its choices in a transparent manner (see Section 2).

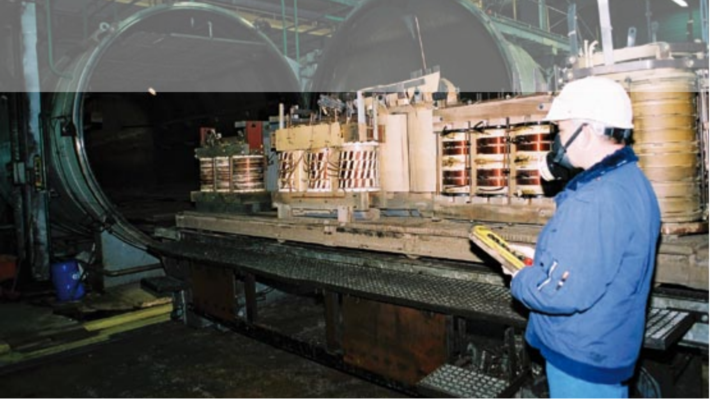
Accuracy:

Care must be taken to ensure that systematic errors are avoided, that random errors are minimized through effective controls and that uncertainties are quantified as far as practicable (see Section 5). It is highly recommended to use specific emission factors reflecting the entity situation. As a default, national or international factors can be used.

Transparency / Verifiability:

The basis of the reported data must be clear and state any assumptions made and the methodologies used. Records should be kept to provide a clear audit trail.
To be noted is that the realization of an annual inventory consists in the evaluation of emissions from waste management activities for a given year, but that, because of the deferred emissions from certain devices, these emissions are not only related to the waste amounts generated during this precise year.

1. World Business Council for Sustainable Development
2. World Resources Institute



Section 1: Scope

Data Characteristics

1.1 The protocol applies to the following greenhouse gases :

- Carbon dioxide (CO_2)
- Methane (CH_4)
- Nitrous oxide (N_2O) :

Emission factors are available for N_2O emissions from municipal solid waste incineration; they are included in the present protocol.
For the waste sector's other activities, research is on-going. For example, today, there is still limited knowledge about N_2O emissions from biological treatments. Some examples are provided in the excel tool. A larger bibliographical synthesis of values encountered in the literature is presented in annex 4.
It is considered that waste management does not generate sulfur hexafluoride (SF_6), and does not generate HFC (Hydrofluorocarbons) or PFC (Perfluorocarbons) in normal operating conditions.

1.2 Reporting unit : metric tons equivalent CO_2 (t CO_2 eq)

1.3 Period: GHG emissions are reported on the basis of activity data cumulated over one year exercise.

1.4 An entity is a group, a company, a subsidiary, a local authority or a site performing a GHG emissions annual inventory.

1.5 The entity reporting boundary takes into account all of its operations that collect, receive or treat wastes or have a commercial activity.

Direct / Indirect / Avoided emissions

1.6 A definition of direct and indirect GHG emissions is given below. It must be underlined that the term "direct GHG emissions" applies to the source type of emissions. In the same way the term "indirect GHG emissions" does not mean emissions of indirect greenhouse gases but emissions from indirect source types.

1.7 **Direct GHG emissions (scope 1):** emissions from process or equipment owned or controlled by the entity.
Example : emissions from combustion installations (CO_2, N_2O), landfills (CO_2, CH_4), company-owned vehicles (CO_2, N_2O[1]).

This protocol differentiates between **gross direct emissions and net direct emissions.**
Gross direct emissions are total direct emissions generated by waste management activities; they take into account GHG emissions from biomass, such as CO_2 emissions from landfill gas flaring.
Net direct emissions are those ultimately taken into account in the inventory and reporting of emissions, after applying conventions concerning biomass[2], whereby the GHG emissions originating from biomass combustion are accounted for zero.
Biomass is defined[3] as non-fossil and biodegradable organic material from plants, animals and micro-organisms. Biomass also takes into account products, by-products, residues and waste from agriculture, forestry and associated industries, as well as the biodegradable and non-fossil organic fractions from industrial and municipal waste. It takes into account gases and fluids recovered from the decomposition of non-fossil biodegradable organic material.

1. It has been decided, as it is the case in EPE's Transport Protocol and in the WBCSD's sectoral protocols, to mention the existence of N2O emissions related to transport (fuel combustion). Likewise, N2O emissions from landfill gas combustion in engines can be mentioned. These emissions are currently not quantified and therefore do not appear in the recap table presented in Section 2, Annual Inventory.
2. See for instance Annex IV of Directive 2003/87/CE of the European Parliament and of the council of 13 October 2003 establishing a scheme for greenhouse gas emission allowance trading within the Community
3. Commission decision of 29 January 2004 establishing guidelines for the monitoring and reporting of greenhouse gas emissions pursuant to Directive 2003/87/EC of the European Parliament and of the Council.

1.8 Indirect GHG emissions : emissions linked to the activity of the entity, but physically occurring at sites or operations owned or controlled by an organization other than the reporting entity.
Direct emissions from the waste management activities therefore correspond to part of the indirect emissions from waste producers.
Examples : emissions from the following activities:

- Production of the electricity (CO_2 and N_2O[1] emissions) used by the entity but produced by a third party,
- waste transport in vehicles not owned (or not controlled) by the entity (CO_2 and N_2O[1] emissions).

1.9 Indirect emissions are separated in two parts:

- emissions from imports of electricity, heat or steam that are not self-produced (scope 2);
- other indirect emissions, for instance construction equipment and reagent consumption (scope 3).

1.10 The inventory must include the net direct GHG emissions.
Direct gross emissions may also be calculated and the calculation will be kept.

1.11

- The reporting of indirect emissions arising from electricity or other imported energy (Scope 2) is required. In order to obtain a GHG emissions inventory as complete as possible, entities may also wish to report other indirect GHG emissions (Scope 3).
- **The reporting of direct and indirect emissions must be clearly differentiated.**

1. It has been decided, as it is the case in EPE's Transport Protocol and in the WBCSD's sectoral protocols, to mention the existence of N2O emissions related to transport (fuel combustion) and to the production of purchased electricity. These emissions are currently not quantified and therefore do not appear in the recap table presented in Section 2, Annual Inventory.

1.12 Indirect emissions linked to import and/or export of electricity, heat and steam :
To be consistent with the WBCSD/WRI Greenhouse Gas Protocol, it is recommended to indicate the quantities of electricity and thermal energy purchased and consumed.
The corresponding GHG emissions must therefore be completed with the applied emission factor descriptions and their source.
It is recommended to use the average national electricity emission factors listed in the "Factors" sheet of the Excel tool, provided by the International However, if the user has official documentation (emanating for example from a national energy or environmental agency) explaining that electricity from waste origin actually replaces the marginal electricity production source instead of the average electricity mix, this specific emission factor can be used. Clear references should be provided.

1.13 Electricity transport and distribution: related GHG emissions are reported by the electricity producer. The electricity consumer reports GHG emissions corresponding to the electricity quantity displayed on the electricity meter.

1.14 Concern is often expressed that accounting for indirect emissions will lead to double counting when two different reporting entities include the same emissions in their respective inventories. **Double counting should be avoided**. Entities must therefore clearly identify direct and indirect emissions in their reporting.

1.15 Avoided emissions :
Certain waste management activities contribute to energy generation or the re-use of materials or fuels. This is why greenhouse gases emissions linked to the production of an equivalent quantity of energy or material from raw materials or fossil fuels are avoided. Avoided emissions occur in the following situations:

- Electric and thermal energy production from landfill gas and biogas from anaerobic digestion: avoided emissions correspond to CO_2 emissions that would have occurred to produce an equivalent quantity of energy.
- Electric and thermal energy production from waste incineration: avoided emissions correspond to CO_2 emissions that would have occurred to produce an equivalent quantity of energy.
- Recycling of the following materials:
  - Paper/Cardboard
  - Glass
  - Steel
  - Aluminum
  - Plastics
  - Incineration residues
  - Bottom ashes
  - Scrap metal (slag)
  - Substitute fuels (either Solid Recovered Fuels from non-hazardous waste or alternative fuels from hazardous waste): avoided emissions correspond to the difference between CO_2 emissions associated with the combustion of the waste-origin alternative fuel and CO_2 emissions that would have occurred during the combustion of the substituted conventional fossil combustible (taking into account the same energy content).
  - Others
- Avoided emissions correspond to emissions that would have occurred to produce an equivalent quantity of materials.

Avoided emissions cannot be deduced from direct or indirect emissions calculated by the entity, and have to be reported separately.

Avoided emissions associated with material recovery are calculated using a Life Cycle Analysis (LCA) approach.
Several studies exist and provide factors for the avoided emissions related to the recovery of different fractions (plastics, paper, metal...). In the excel tool associated with this protocol, we decided to provide emission factors resulting from seven major studies:

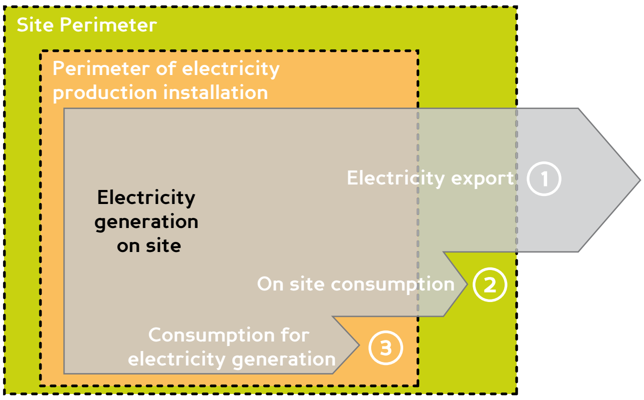
- Waste management options and climate change, AEA Technology, study for the DG Environnement, 2001
- Solid Waste Management and Greenhouse Gases: A Life-Cycle Assessment of Emissions and Sinks, 3rd edition, US EPA, 2006
- Etude technico-économique sur le bilan des filières de recyclage, ADEME/Ecobilan, 2007
- Resource savings and CO_2 reduction potential in waste management in Europe and the possible contribution to the CO_2 reduction target in 2020. Prognos. October 2008
- SenterNovem website: Kentallen CO_2 besparing 2008
- CO_2 kentallen afvalscheiding. JHB Benner et al. CE Delft, September 2007
- Report on the Environmental Benefits of Recycling - Bureau of International Recycling (BIR), October 2008.

The users will have to choose between these seven databases according to their geographical context. If the users want to use values other than those cited in the "Recycling factors" sheet, they should document them and give the references of the LCA study at the origin of his figures.

Avoided emissions by energy production from landfill gas or incineration can be calculated in the same way as indirect emissions linked to energy.

Avoided emissions linked to electricity generation will be taken into account as described in the diagram below:
①and②: The electricity generated on site is taken into account as an avoided emission, whether it is supplied to the grid or intended for on - site uses other than auto-consumption (uses that would have required electricity purchase from the grid if there was no on-site generation);
③ : Electricity auto-consumption linked to electricity production is not taken into account for avoided emissions.

If there are no accurate onsite measurements for ②and③, only the emissions associated with① will be taken into account as avoided emissions.



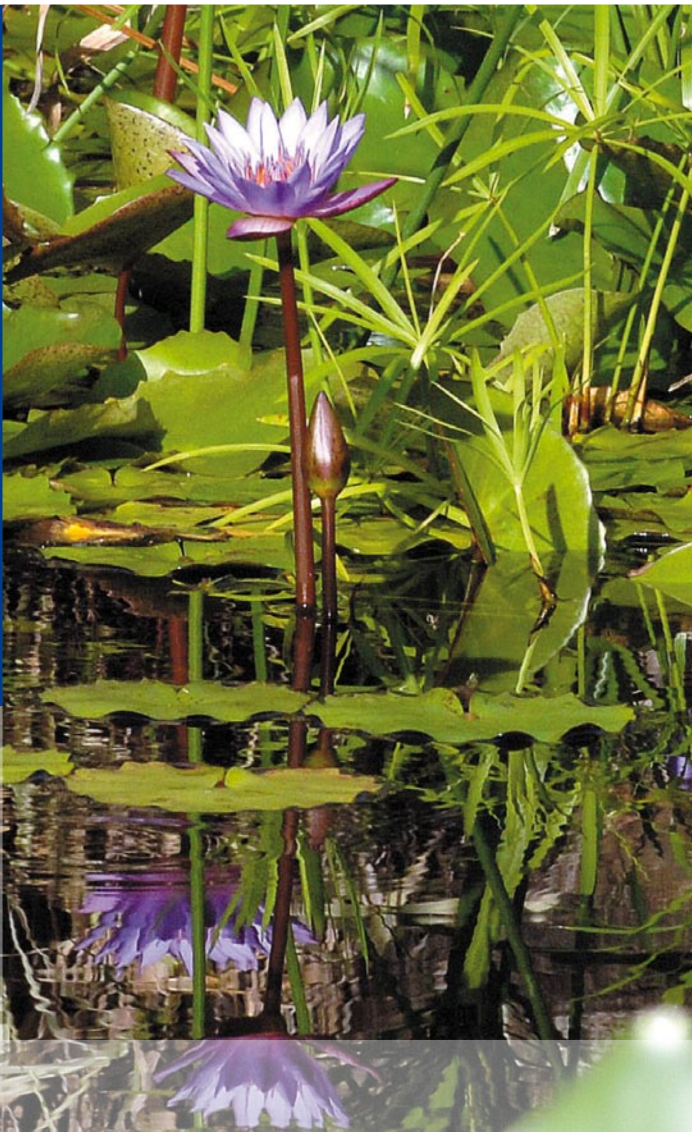
GHG Accounting when there is a shared ownership

Because of the waste management activities' specificities, which often enter in the framework of the delegation of services, it seems necessary to enlarge the control perimeter taken into account in the GHG Protocol.

1.16 Operational control: Boundary approach that takes into account GHG emissions from source types under operational control.
An entity has operational control over a source type when it exercises **dominant influence** over the emissions from a source type, by having the ability to direct the operating policies governing the emissions from a source type.
In the operational control approach, the entity includes 100% of the GHG emissions from a source type in its inventory.

1.17 Examples :
An entity could exercise dominant influence over one source type if one of the following conditions is fulfilled:

- It holds a majority of the voting rights in the reporting entity,
- It holds the operating permit delivered by the administration,
- It has the power to impose its Health, Safety and Environmental (HSE) procedures at the considered site(s),
- It has been delegated the authority to make economic decisions concerning the technical operation of the considered installation. [1],
- by virtue of the terms and conditions contained in the contract governing the operation of the source type.



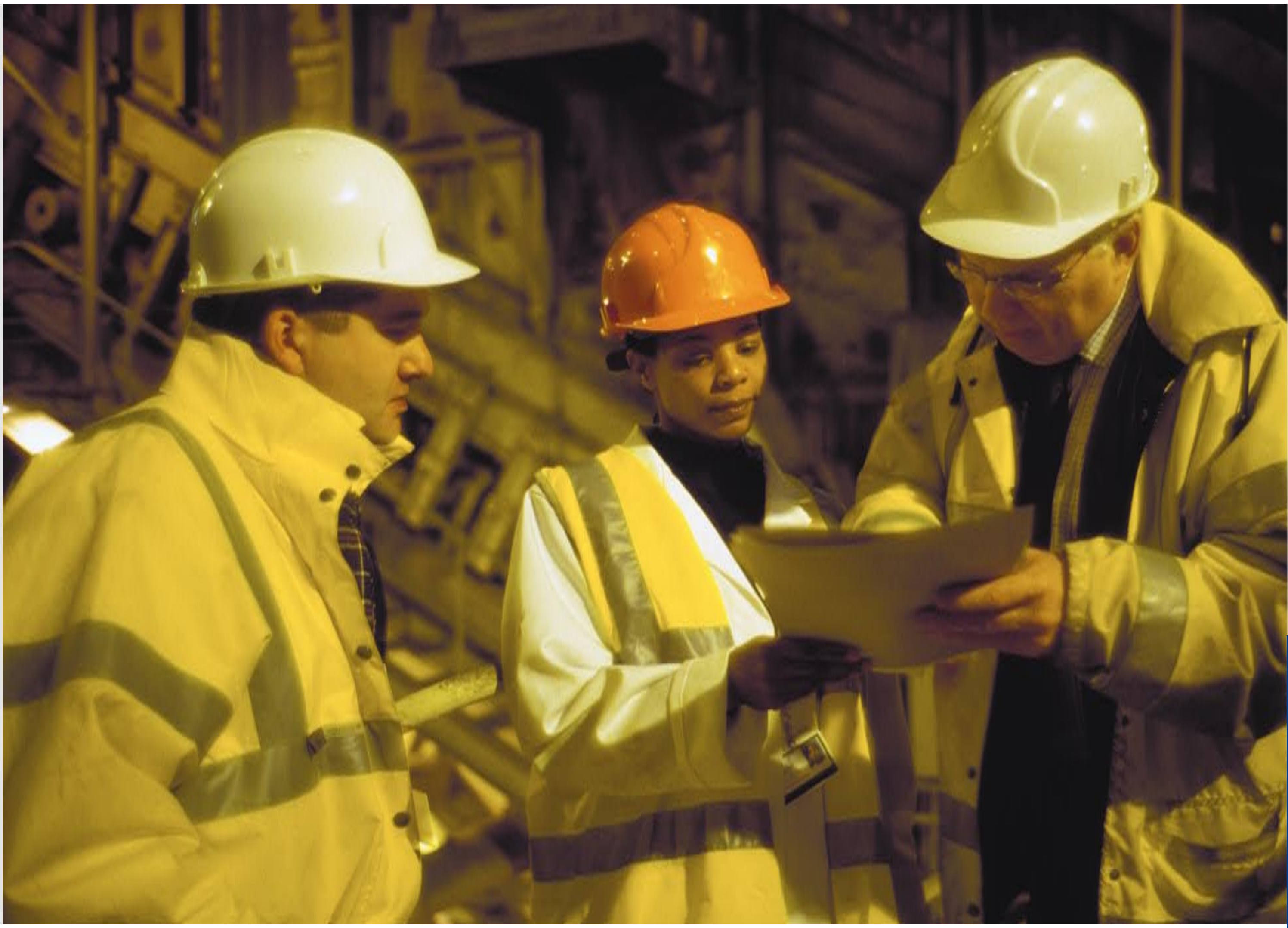
1.18 The « operational control » approach has been adopted in this protocol.
It has to be highlighted that an entity that has operational control does not necessarily have the power to take all decisions concerning source types. In case of significant investments for example, approval from all of the partners that have a financial share will be required.
For some source types, an entity could have financial control shared with other entities, but not have operational control. In this case, the entity will have to refer to contractual agreements to establish which partner has the authority to introduce and implement operational procedures and therefore has the responsibility to report GHG emissions according to the operational control approach.

1.19 The operational control approach also applies in the case of sub-contractors of the entity. Therefore, GHG emissions from the sub-contractors will be included in the entity's direct emissions reporting if it maintains operational control over the activities it has assigned them, i.e. if it has the authority to make decisions over operational procedures generating these emissions. If the entity does not keep operational control over the delegated activities, corresponding GHG emissions will be integrated into the indirect emissions. In all cases, the entity will have to coordinate with its sub-contractor to make sure that the data reported as direct emissions for one and as indirect emissions for the other in their respective inventories are consistent.

1.20 Consolidation at multiple levels: Consistency of GHG emissions consolidation will be reached only if all organizational levels follow the same approach. The « operational control » approach must therefore be implemented at all organizational levels.

1. European Directive 2003/87/CE

Section 2: Annual Inventory



Definitions

2.1 **Source type**: Process or equipment which releases direct and indirect GHG emissions into the atmosphere. Source types are characterized by an identical calculation methodology. Homogeneous source types must be added and considered as a single source type, within the previously defined scope.

2.2 The following table summarizes the source types linked to the waste management activities. Among the direct emissions, it distinguishes direct gross emissions, i.e. the total amount of direct GHG emissions, from direct net emissions, corresponding to direct emissions actually taken into account in the inventory as a result of the conventions applicable to CO_2 emissions from biomass. For biomass combustion, the emission factor is taken at zero[1].

In these different source types, point source emissions (stacks, flares, etc.) as well as diffuse emissions (landfills) are taken into account.

1. According to the Annex IV of the Directive 2003/87/CE from European Parliament and of the October 13 Council establishing a greenhouse gases emission quotas trading scheme in the Community and modifying the 96/61/CE directive from the Council.

Activity	Direct Emissions		Indirect Emissions	Avoided Emissions	Emission Reducing Actions
	Gross Emissions	Net Emissions			
Collection and Transportation	• CO_2 from fuels consumption	• CO_2 from fuels consumption	• CO_2 from electric vehicles • CO_2 from outsourced transport		• Use of electric vehicles • Uses of alternatives fuels (diester, biofuels, etc.) • Development of alternative means of transportation (rail and waterway transport)
Transfer	• CO_2 from on-site fuel consumption	• CO_2 from on-site fuel consumption	• CO_2 from electricity consumption		• Actions done to improve energy efficiency of equipments and facilities
Mechanical pre-treatment (dismantling)	• CO_2 from on-site fuel consumption	• CO_2 from on-site fuel consumption	• CO_2 from electricity consumption		• Actions done to improve energy efficiency of equipments and facilities
Sorting, Recycling and Recovering	• CO_2 from on-site fuel consumption	• CO_2 from on-site fuel consumption	• CO_2 from purchased electricity consumption	• Avoided GHG corresponding to the emissions resulting from the production of an equivalent quantity of materials • CO_2 avoided through potential production of solid recovered fuels (SRF)	• Actions done to improve sorting rate before selective sorting • Recovery of sorting rejects
Physico-chemical waste treatment	• CO_2 from on-site fuel consumption	• CO_2 from on-site fuel consumption	• CO_2 from purchased electricity consumption	• CO_2 avoided through potential production of alternative fuels	• Action done to optimize alternative fuel production

Activity	Direct Emissions		Indirect Emissions	Avoided Emissions	Emission Reducing Actions
	Gross Emissions	Net Emissions			
Biological Treatment (composting-anaerobic digestion)	• CO_2 from biomass • CO_2 from on-site fuel consumption • CH_4 and N_2O	• CO_2 from on-site fuel consumption • CH_4 and N_2O	• CO_2 from purchased electricity consumption	• CO_2 avoided through energy production • CO_2 avoided through compost use in agricultural recovery • CO_2 avoided through recovery of the heat produced by the composting process.	• Optimization of aerobic conditions for composting processes • Optimization of energy and/or material recovery
Landfill	• CH_4 from landfill gas • CO_2 from landfill gas • CO_2 from on-site fuel consumption	• CH_4 not captured • CO_2 from on-site fuel consumption	• CO_2 from purchased electricity consumption	• CO_2 avoided through energy production	• Optimization of CH_4 capture and combustion • Optimization of energy recovery
Incineration	• CO_2 from waste • CO_2 from additional fossil fuels • N_2O	• CO_2 from waste (except fraction from biomass) • CO_2 from additional fossil fuels) • N_2O	• CO_2 from purchased electricity consumption	• CO_2 avoided through energy production • CO_2 avoided through slag and ash recycling	• Optimization of energy recovery
Mechanical Biological Treatment (MBT)	• CO_2 from on-site fuel consumption • CO_2 from biomass • CH_4 and N_2O	• CO_2 from on-site fuel consumption • CH_4 and N_2O	• CO_2 from purchased electricity consumption	• CO_2 avoided through energy production • CO_2 avoided through compost reuse • CO_2 avoided through material recovery • CO_2 avoided through potential production of alternative fuels	• Actions done to improve sorting and compost quality • Optimisation of energy and material recovery

Exclusions

2.3 Under the definition of the completeness principle given in the introduction, every source type that is in the chosen perimeter must be included in the inventory.
However, in practice, the entity can encounter obstacles in the quantification of some sources types:

- Missing data,
- Negligible emissions,
- Disproportionate cost associated with data collection,
- High level of uncertainty of data, etc.

The entity may then choose to remove its inventory some source types' emissions, as long as it is documented and clearly justified.
A third party verifier could evaluate the potential impact and the relevance of the exclusion.
If the need arises (when reporting for several sites), the entity will indicate its data coverage rate in its reporting. The data coverage rate refers to the proportion of the activity or the turnover covered by the sites that reported data, over the total reporting perimeter, expressed through a relevant indicator (activity data, turnover, etc.).

Identifying the Source type List

2.4 **Source type list**: List describing the source types included by the entity in the inventory, according to the repartition presented in the table on pages 16 to 17.
In the Excel tool, a dedicated sheet entitled "Source Type List" helps the user to identify the emission sources that should be included in his reporting perimeter.

2.5 An annual inventory is made up of consolidated annual emissions from all source types. Therefore, an entity must identify, every year, the Source types, it is taking into account to calculate the annual inventory emissions. The entity should keep a written record of the decisions taken during the identification of the Source Type List.

2.6 To determine its Source List, **the entity must identify all sources over which it has operational control**. This list must be as exhaustive, complete and accurate as possible.

Calculating the annual emissions

2.7 The entity should follow the following steps:

1. Quantify annual GHG emissions over year N for all source types in the Source type list.
2. If any source included in the annual inventory is not covered by the calculation tool annexed to this protocol, the entity should indicate and document the specific calculation protocol it uses. This additional protocol should present an estimate of the uncertainty in emission calculation inherent in its use.

2.8 After completing these two steps, the entity will have completed its annual inventory.

Adjustments to the source type list and reported annual emissions

2.9 Changes may relate to the entity's group structure or to their operations e.g. through the acquisition or divestiture of subsidiaries or assets. It follows that the source types in the Source type list may not be fixed over time.

2.10 Each time an entity changes its structure or operations, adjustments must be made to the source list and corresponding annual emissions calculations.

2.11 Any adjustment to the source list must be completed by the end of the same year in which the structural or operational change occurred.

Adjustments for loss of operational control

2.12 An entity can divest operational control over source types within its Source type list through:

- A de-merger or divestiture,
- Outsourcing one or several activities,
- A re-organization of operational control (change of contractor, ...),
- Termination of an activity (source type).

2.13 Should an entity divest operational control over source types within its Source type list, that entity will be required to adjust its Source type list and annual GHG emissions.

2.14 In case of closure of a source type, GHG annual emissions will be taken into account until the final closing.

2.15 The method to take into account structural changes must be explained.

Adjustments for taking operational control

2.16 An entity can acquire operational control over source types outside of its Source list through:

- A merger,
- An acquisition,
- Internalization of an activity,
- A re-organization of operational control (contractor's change, ...),
- Opening a new source type.

2.17 Should an entity acquires operational control over source types outside of its source list, that entity will be required to make an adjustment to its source type list and to its annual GHG emissions.

2.18 In the case the start up of a new activity, GHG emissions will be taken into account from the start date.

2.19 The method to take structural changes into account must be explained.

Historic Emission Adjustments

2.20 Historic emissions are modified in the following cases:

- Change in the sources types list (mergers, acquisitions, transfers, outsourcing or insourcing of sources types),
- Emissions quantification method change,
- Error detection in emissions quantification.

2.21 If the entity considers that it has a significant impact on the inventory, historic emissions have to be recalculated.
The process must be clearly documented and justified.

2.22 Historic emissions are not adjusted in case of an activity stopping or starting.

2.23 The entity must indicate if the necessary historic data are not available. It can then choose not to adjust the concerned historic data.

Section 3: Emissions Calculation

Approach/Hierarchy

3.1 The purpose of this section is to outline a common approach and methodology for quantifying GHG emissions, using the Excel calculation tool associated to this protocol.

3.2 Different levels of accuracy can be achieved depending on the type of methodology used (use of standard emission factors, periodic measurement, continuous measurement, etc).

3.3 In order to ensure continuous improvement, it would be recommended that participants move to more accurate methods wherever practical. However, it is recognized that the chosen method will depend on the significance of the source type and the uncertainties associated with the available methods of assessment. The level of uncertainty remaining for certain methods continues to act as a barrier to the establishment of universally accepted methods. Moreover, even when measurements are involved, there can be accuracy differences between alternative measurement techniques.

3.4 Regulatory measurements of CO_2 emissions of stacks can be used by the site manager in case of GHG emissions due to hazardous waste incineration, as long as it can be justified that this method is more accurate than a calculation method using activity data (for example fuel consumption) and an emission factor.
In this case, the proper functioning of the emissions analyser should be verified, and a preventive maintenance program should be implemented to avoid any deviation in the operation of the measuring device. Maintenance records should be archived.

Methodology

3.5 In some cases, several methods can be used.

In case of continuous measurement, there might be several sampling protocols applicable to perform a representative sampling for analysis.
Likewise, for the same calculation, several emission factors from different bibliographic sources can be used.

The entity needs to clearly document the methodology used and the reasons for its choice.

3.6 The present document does not make any recommendation concerning specific techniques of sampling, measurement or analysis. All sampling, measurement and testing methods employed shall be performed in compliance with appropriate national or international standards. If such standards do not exist, a complete documentation concerning applied methods shall be archived.

Global Warming Potentials

3.7 Global warming potentials are given in Annex 1 for CO_2, CH_4 and N_2O (Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories – Reference Manual - Volume 3).
The considered GWP values come from the second IPCC[1] assessment report and are used within the context of the Kyoto Protocol for the first commitment period (2008-2012).

Global warming potentials have been successively revised and updated in IPCC third and fourth reports.

Calculation Tool

3.8 An Excel calculation tool has been developed as an annex of this protocol. It is an integral part of the present protocol.

1. Intergovernemental Panel on Climate Change

3.9 This tool is made of several spreadsheets:

- Source Type List: Establishment of list of the source types included in the reporting perimeter
- Transport: calculation of emissions due to waste collection and transport. This table is based on the emissions calculation sheet for GHG emissions from transport published by EpE and focuses on relevant transport activities in waste management.
- Sorting - Transfer: calculation of emissions due to transfer and sorting facilities
- Anaerobic digestion: calculation of emissions du to anaerobic digestion of waste
- Composting: calculation of emissions du to composting process
- SRF: calculation of emissions due to Solid Recovered Fuels preparation
- MBT: calculation of emissions due to Mechanical-Biological treatments
- Landfills: sheet presenting the recommendations and requirements concerning emissions calculation from landfills. Four theoretical methane production and emission models are presented (methane production calculation equation, major parameters…)
- Incineration: calculation of emissions due to waste incineration (all types)
- Avoided: calculation of avoided emissions through waste recovery following the principles presented in the present protocol
- Source Type List with Results: sheet detailing the direct/indirect and avoided emissions results associated with the activities covered by the inventory
- Synthesis: sheet summarizing the results of the inventory
- Factors: sheet summarising the recommended emission factors to be used for the reporting
- Recycling Factors: Recommended factors for avoided emissions associated with material recovery

3.10 The user has different types of data entry fields:

- Fields where the user has to enter the site's specific values (such as activity data, such as incinerated waste tonnage)
- Fields where default values are presented (emission factors). Default values refer to nationally or internationally accepted values, when they are available. Sources are presented within the table. The user can adapt these default values to give the most accurate vision of his site situation. However, in this case, selected values will have to be documented and justified.

3.11 By filling in the calculation table, the user will see notes that indicate how to fill in the tool, precautions to take and some recommendations mentioned in this protocol.

3.12 **Specific case of hazardous waste incineration**: emissions due to hazardous waste incineration using a calculation associating the tonnage of the different categories of incinerated wastes and corresponding emission factors, or, preferably, using measurements done at the stack, as long as a greater accuracy of this method can be proven.

In this second case, the user must avoid a double count:

- The implementation of a calculation based on the waste tonnage incinerated requires filling in the section in the calculation tool concerning incineration as well as the section 1 concerning fossil fuels used as an extra fuel.
- Stack measurements apply to all of the incinerated carbon containing products. It is therefore not necessary to do a second calculation for the emissions due to additional fuels.

Specific case of landfill emission modelling

3.13 Accounting for methane captured in landfills can be easily done using flowmeters placed on the landfill gas collection system and composition analysis. However, field conditions make diffuse emissions accounting difficult. To date, the most common approach has been to use landfill gas production models to estimate the diffuse emission.

Annex 2 presents a comparative study of the existing models. Conclusions and recommendations that we can obtain from it that are useful to make a GHG emissions inventory are listed below:

- The use of models is required to estimate diffuse emissions. Among the diversity of existing models, only the models using first order equations can take into account the various factors affecting landfill gas production today. The entity should therefore use these models, and ban the use of models using "0" order equations (or using standard emission factors).
- The various existing models were created to describe certain conditions and provide standard factors for waste that can be adapted. They each have their pros and cons and the corresponding numerical results can vary widely. Each model requires time to understand its specificity and functionality.
- Today, because of the very nature of the modeling exercise, no model is recommended over another. It is advised to resort to the model accepted by local authorities for regulatory declarations. If there is no locally accepted model, the entity should use a model that is published, accepted and available in scientific and technical literature (the calculation tool associated with this protocol lists the preferred models), and the parameters of the model should be adapted to reflect site specific conditions. The choice of the model as well as the parameter adaptation should be documented and justified.
- The chosen model will have to consider the waste composition.
- Because of the necessary adaptation of the model's parameters, the reporting entity should make sure that the same model is used every year, except if it justifies the use of another model that allows better representation of the landfill conditions.
- Good use of a landfill's emissions estimation model requires a real competence (essentially because of the great sensitivity to the input data). The accuracy of the results also highly depends on the knowledge of the landfill to be modelled (biogenic carbon content, waste age, landfill gas capture rate), as much as on cultural criteria (food, waste sorting practices). It is important that the site operational staff work in close collaboration with the Modellor. There are a number of on-going research studies assessing field monitoring approaches for diffuse landfill methane emission. The entity should provide pertinent data for input parameters and perform a consistency check on the calculated data, even by conducting a calculation using data provided by the Operation Managers.
- The use of these models implies a high level of uncertainty that is difficult to assess.

Section 4: Reporting requirements

4.1 The reporting process must be detailed in order to ensure the data transparency and verifiability, for efficient internal control and external verification.

Data to be reported

4.2 The following minimum information shall be reported in the **management GHG emissions inventory report**:

- Management letter, signed by management or a designated representative, attesting that the data reported is a faithful representation of the entity's emissions, and complies with the protocol's requirements,
- Source type list defined for year N, and changes made to the source type list during year N (example: structural changes),
- Annual direct GHG emissions, with their respective level of uncertainty and methodologies used,
- Corresponding activity data.

4.3 At a minimum, the **documentation**, necessary for internal control and external verification, should consist of the following elements:

- Internal protocol developed by the entity, including calculation and computation methods and evidence of the sources of emission factors used. When an entity uses a calculation method different from the protocol, it must describe its methodology precisely and explain its choice,
- Explanation of the inclusions and exclusions which have been decided regarding the definition of the source type list,
- Any changes in the methodology that may influence the comparability of data reported to historic data,
- Description of any events that may have impacted the reported data,
- Any background data needed to assess data quality.

4.4 The provided information shall be clear and concise.

4.5 The entity is required to record in a systematic manner (such as using an electronic database) both the data and the methods that underpin the data collection and consolidation. Recording should concern all annual emissions and baseline year emissions.

Activity Data Reporting

4.6 **Activity data**: Representative data of an activity taking place during a given period of time. The entity is free to select activity data as long as its choice is justified.

4.7 Data might be directly linked to the activity, such as collected, treated, sorted or recycled waste tonnage. However, activity data might differ from waste annual tonnage. Examples : unit of GDP, turnover.

4.8 Ratio indicators may generally provide information on the efficiency of an activity, on the intensity of an impact or on the progress on a specified objective.

Intensity ratios may be established and provided. They are presented as relative or specific emissions and express GHG impact per unit of activity or unit of value. Example: tonnes CO_2 equivalent per tonne of waste treated.

Section 5: Managing Uncertainty

5.1 A simplified calculation method for global uncertainty is given in the EpE protocol on GHG emissions quantification, reporting and verification (section 5 of the « REGES » Protocol). The entity could refer to it to make a calculation.

5.2 However, at this stage, it is difficult to perform a calculation whose result will be relevant in the specific case of waste management. In this industry, GHG emissions monitoring shows a significant uncertainty, due to several factors:

- An important number of waste treatment methods rely on complex processes (notably biological) for which it is difficult to reach the same level of accuracy as in other industrial sectors,
- Waste treatment methods are interdependent,
- Some emissions are diffuse and, therefore, are estimated by theoretical models,
- Treated waste shows very heterogeneous compositions, for which a statistical approach is compulsory, introducing important but unavoidable biases. Standard factors, which precision is unknown, can be used.

Uncertainty in GHG emissions inventories

5.3 By their nature, data inventory, evaluation and collection lead to uncertainties. Assessing this uncertainty is essential in GHG emissions reporting. It does not aim at questioning the validity of inventory data but to determine the level of reliability. It also helps identifying possible areas of improvement in reporting accuracy, and to direct methodological choices.

5.4 Emissions totals reported by entities are usually provided as a unique figure with implicit or explicit confidence intervals. For example, reported total emissions of 125,000 tons of CO_2 equivalent could be more accurately phrased as "total emissions likely to be between 115,000 and 135,000 tons" or "total emissions are 125,000 tons plus or minus 10%". The degree of uncertainty will vary widely for different emissions estimates, depending upon the emissions source type, the calculation method used and the level of effort expended to gather and validate data.

Sources of uncertainty

5.5 Even when the best available calculation methodologies are used, there are many sources of uncertainty for GHG emissions totals:

- Estimation to compensate for missing data (e.g. non-reporting facilities, or missing fuel bills),
- Imprecise measurement of emissions-producing activity,
- Calculation errors and omissions,
- Use of "average case" emission factors not perfectly matched to certain circumstances,
- Assumptions that simplify the estimation of emissions from highly complex processes,
- Use of approximative emission factors.

Recommendations to reduce residual uncertainty

5.6 Uncertainty is inherent to the establishment of a GHG emissions inventory. However, the entity should aim at reducing this uncertainty and to keep residual uncertainty as low as possible.

5.7 To do so, the following principles should be implemented by the entity. This entity will have to:

- Make sure it uses measurement and analysis instrumentation, as well as all means necessary for preparing an inventory that are adapted and commonly used within the sector
- Implement a preventive maintenance on measurement and analysis instrumentation, supported by procedures and records to avoid potential deviation of the instrumentation. These documents should be kept and presented to the verifier, if necessary,
- Implement internal controls that will be formalized and archived (see below) as well as a management validation process for the reporting entity,
- Make sure GHG emissions quantification process and used methods are constant, and that the reporting is consistent over the years.

Internal Controls

5.8 The entity will have to implement the necessary internal controls to reduce significant error risks to an acceptable level. These controls will have to be documented and formalized. It could be for example:

- Consistency check on year to year reported data,
- Order of magnitude check on reported data,
- Consistency check of calculated data to activity data,
- Validation of the calculation by a third party within the entity.

Uncertainty standard-values

5.9 A table presenting uncertainties associated with instrumentation commonly used on waste management sites and the data entered in GHG emissions calculation is presented below. This table is indicative, and has been made through data given by experts from Veolia Environmental Services, Séché Environnement and Suez Environment.

Type of device/ measure	Examples of use	Uncertainty-type	Observations
Flow meter	Flow measurement for used natural gas for incinerators	2%	Commercial measurement or integrated in a preventive maintenance approach. Constructor's value cannot be used, it is necessary to take into account real use and maintenance conditions. It is recommended to archive calibration certificates and monitoring and maintenance documents.
	Captured landfill gas measurement	5 – 10%	Non-commercial measurement and instrumentation used for daily operational monitoring. Corrective maintenance only.
	Incinerators flue gas flow measurements	5 – 10%	Difficult operating conditions (location of meter, variability of measured flow); risks of equipment failure.
Weighbridge	Determination of tonnage of waste collected, treated or recycled	2%	Commercial or integrated in a preventive maintenance programme. It is recommended to archive calibration certificates and maintenance monitoring documents.
Tank levels	Visual plotting of tank levels of additional liquid fuels	10%	Uncertainty due to the imprecise methods to determine the fuel oil or domestic oil tank levels.
Analyzers	CO_2 content determination of flue gas using on site devices	5 - 10%	Difficult operating conditions (localization); frequent failure risks. However, analyzers undergo strict regulatory monitoring.
	Determination of the carbon content of fuel using laboratory analyzers (gas chromatography)	5%	Devices that require preventive maintenance and periodical calibration. It is recommended to archive maintenance monitoring documents. It is necessary to have a sampling frequency that guarantees the representativeness of the measured values and to document the choice of the frequency.

5.10 Furthermore, it is noted that uncertainty principles apply to data from measures or analysis. This is the reason why these principles cannot be applied to the modelling that is performed to estimate methane emissions from landfills.

Section 6: Verification

6.1 It is highly recommended that GHG annual emissions inventory from the entities are verified by a third party.

Scope of the Verification

6.2 The purpose of the verification is to assess that:

- An internal protocol has been developed and complies with this guidance (including the verification of the completeness of source types within the source type list),
- Reported data are free from material discrepancies (validation of GHG emissions and associated uncertainty for each source type).

Material discrepancy within annual emissions

6.3 A verifier's assessment of materiality will include consideration of both the amount and nature of the errors. For example, a relatively small omission or error repeated frequently could, once accumulated, have a material impact on the total emissions figure. A verifier will assess the materiality of any individual misstatement as well as the aggregate of uncorrected discrepancies.
Therefore, verifiers will take into account any omission or error that could lead to material discrepancies on annual figures.

Annex 1: Global Warming Potentials

Gas	Global Warming Potential[1]
CO_2	1
CH_4	21
N_2O	310

The Global Warming Potentials (GWP) used in the Excel calculation tool are those proposed in the 2nd IPCC report (Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories – Reference Manual - Volume 3). These GWPs are those which have been integrated in the Kyoto Protocol framework and its associated project mechanisms.

They are consequently imposed until 2012 (the end of the protocol's application period) in spite of regular reviews by the IPCC. It was decided to use these GWP values to be coherent with the Kyoto Protocol values.

1. Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories – Reference Manual (Volume 3) - http://www.ipcc-nggip.iges.or.jp/public/gl/invs1.htm

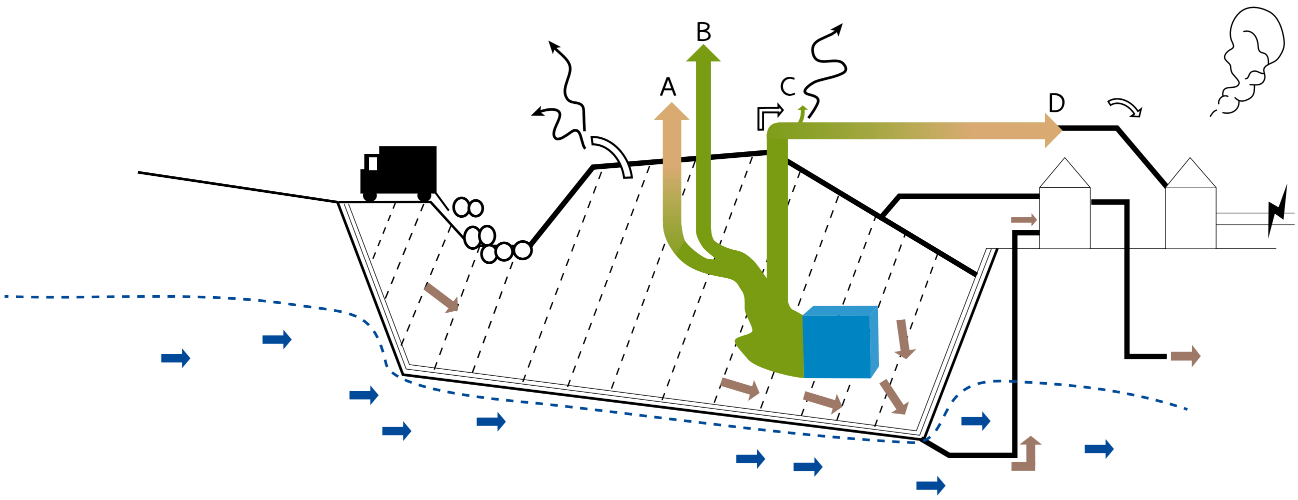
Annex 2: Comparative analysis of the greenhouse gases models for landfills

Context – overview of emission sources

Landfills are one of the main greenhouse gases emissions sources in the waste management sector. Disposal of waste in landfills generates landfill gas, due to waste decay. This landfill gas is mainly composed of CO_2 and CH_4, as well as trace elements such as N_2, O_2, H_2S, CO, NH_3, H_2, VOC. Carbon dioxide comes from waste's organic components aerobic decomposition, methane coming from anaerobic decomposition.

Most controlled landfills are now equipped with recovery equipment for landfill gas produced in cells. Their efficiency may vary, from 10% to more than 90% of recovered gas. These gases are then flared or used to produce electricity and/or heat. However, a part of the gases produced cannot be recovered. They may become fugitive emissions, going into the atmosphere after passing through the cells cover, undergoing partial oxidation.

The following scheme shows the different emissions sources (source: EAA 2005):



A : landfill gas oxidized within the cover layer and diffused in the atmosphere – CO_2 only
B : landfill gas diffusion in the atmosphere – CO_2 and CH_4
C : leak in the landfill gas collection system – CO_2 and CH_4
D : landfill gas flared or combusted in a turbine or a boiler – CO_2 only

It is also necessary to keep in mind that the lifetime of a landfill is made of several phases, during which landfill gas formation conditions are different:

1. **Operating cell**: aerobic conditions, no landfill gas recovering,
2. **"Completely filled" cell, not yet covered**: aerobic and anaerobic conditions, important atmospheric diffusion, not optimum landfill gas recovery,
3. **Covered cell**: aerobic and anaerobic conditions, optimum landfill gas recovery, reduced diffusion.

The landfill gas quantity produced by a landfill and its composition (and therefore the quantity of greenhouse gases) depend on several criteria. The main criteria are:

- Landfilled waste quantity,
- Age of landfilled waste,
- Composition of landfilled waste[1],
- Environmental physico-chemical conditions (humidity, temperature, pH, etc),
- Efficiency of the landfill gas collecting system,
- Cover type.

1. This factor is highly variable from one region to another (food habits, waste sorting efficiency etc.). It explains the significant discrepancies that one might observe between the models of the different countries.

Accounting for captured greenhouse gases can easily be done using flowmeters installed in the landfill gas collection system (presenting a high level of certainty) and analysis of the gas composition. However, diffused emissions accounting shows a limit due to the difficulty, because of field conditions, to assess the quantities of landfill gas emitted to the atmosphere. Diffuse emissions measurements can indeed be done, but they are complex and expensive to implement and are of limited accuracy.

To solve this difficulty, research has been done to model landfills atmospheric emissions. An inventory of these models and a comparative analysis of the main models are presented below. It appears that landfill generated emissions modeling is a complex exercise that requires taking into account numerous factors.

Existing models

Model diversity

Numerous models exist to assess pollutants emissions from landfills, whose goals and complexity vary significantly. In this analysis, we are interested in the models that allow an estimation of landfill gas production, so that we can assess greenhouse gas emissions.

Models based on a theoretical production calculation require knowledge of landfilled tonnage. According to their accuracy, we distinguish:

- **«0» order** models (IPCC Tier I type): the methods used require emission factors and take into account the tonnages landfilled on the year of the calculation. Resorting to standard values, they do not take into account the complexity of the landfill specific conditions and rather aim at making estimated calculations, typically at a regional or national level. They do not allow reaching the accuracy that is necessary for the emissions calculation that has to be performed in the present protocol.
- **1st order** model (IPCC Tier II type): These models take into account a landfill's waste filling history or yearly average inputs and the site operating life (years). They are based on first order kinetic equation, and are more or less complex, depending on whether they take into account recovered landfill gas, methane oxidation through the cover, or other types of parameters. The most sophisticated models (known as multi-phase) distinguish several waste types according to the speed at which they degrade.

The most frequently used models (older or more accomplished) in the literature are the IPCC Tier II model, Landgem (developed by the US EPA), GasSim (developed by the British Administration) and the ADEME model in France.

E-PRTR Specific Context

The implementation of the European Pollutant Release and Transfer Register (E-PRTR), replacing the European Polluant Emission Register (EPER) since 2006, accelerated the development of national GHG emissions estimation models for landfills.

According to the regulation 166/2006 of the European Parliament and of the Council (also known as E-PRTR), the activities registered in the Annex I of the IPPC (Integrated Pollution Prevention and Control) Directive and exceeding the thresholds set in the Annex I of the E-PRTR regulation must declare their polluting emissions to competent authorities. Landfills may fall under the 5.c category «Installation for the disposal of non hazardous waste (>50t/day)» or the 5.d category «landfills (>10t/day)

As part of the E-PRTR reporting, Member States have to collect data from sites that are subject to declaration and transmit them to the European Commission. Member States are free to choose the model they use to assess emissions. It should be noted that, according to the E-PRTR, uncertainties remain in assessing diffuse atmospheric emissions from landfills in some countries.

National models used for E-PRTR

Within the European Union, the models used by the member states are listed below (source: E-PRTR 2004):

Country	Model used	Short description
Germany	National model	Order 0 – adaptation of the tier I model from IPCC + some elements from tier II for CH_4 emissions
Austria	2 (national) models depending if waste is residual (Tabasaran and Rettenberger metho-dology) or not (Martico-rena methodology)	Order 1 – takes into account historical emissions Deduces captured landfill gas, cover oxidation – 2 waste types (1-20 and 20-100 years half-life)
Belgium	National model	Order 1, based on IPCC tier 2 – Deduces captured landfill gas, cover oxidation – only 1 waste type
Denmark	*No data available*	
Spain	*No data available*	
Finland	Adapted tier 2 IPCC model	IPCC model: Order 1 with a change on methane corrective factor
France	National models (ADE-ME) – one tier 2 type model and another one based on captured lan-dfill gas	1st model: order 1 – captured landfill gas, cover oxidation – 3 categories of waste and 4 categories of waste age 2nd model: order 0 – uses the collecting device effi-ciency and the quantity of captured landfill gas
Greece	*Tier 1 IPCC model*	Order 0
Ireland	LandGem (USEPA)	Order 1 – only 1 waste category, takes into account cover oxidation and captured landfill gas – For-merly created to model landfill gas production and not diffuse emissions
Italy	*Taken from IPCC tier 2Model*	Order 1
Luxembourg	*No data available*	
Netherlands	2 national models (TNO)	The 2 models are order 1 models – Takes into account captured landfill gas, cover oxidation. The difference between the 2 models is made on the number of waste category 1 or 3. These TNO models are used by government to provide NOR reporting, but landfill operators are using a variety of models, developed by various consultants
Portugal	LandGem (USEPA)	*See Ireland*
United Kingdom	National model (GasSim)	Order 1 – takes into account cover oxidation and deduces recovering from cover characteristics – 3 waste categories
Sweden	*No data available*	

Outside the E-PRTR scope and outside the model developed by US EPA (see below), Norway also developed a national First Order Decay model, that takes into account the various types of stored wastes.

Comparison of main models

The comparison presented below concerns models that are the most usually referred to, and that are sometimes used outside their source country:

- ADEME model (France, national E-PRTR model),
- GasSim (UK, national E-PRTR model),
- LandGem (USA, EPA model),
- IPCC Tier II model (international reference).

Modeling methodology

All the studied models are based on a first-order kinetic equation of the following type:

$$Q_{CH4} = L_o . M . k. e^{-k(t-x)}$$

Where :
Q_{CH4} : Quantity of methane produced per year (Nm^3/year)
L_o : methane generation potential (Nm^3 CH_4 / t of waste)
M : tonnes of landfilled waste (t)
k : kinetic constant ($year^{-1}$)
x : year when waste has been landfilled
t : year of emissions inventory ($t \geq x$)

This formula is the models' core equation. The number of years "x" when waste was landfilled is summed. L_o and M depend on "x". The result is sometimes detailed by waste categories, the L_o, M and k values depend on the waste categories. Depending on the models, other parameters can also be taken into account, such as landfill gas capture, oxidation through the cover, physico-chemical factors, etc.

The following table summarizes the main technical characteristics (default data (*)) of the various models (source: Ogor and Guerbois 2005).

	Tier II	LandGem (EPA) (8)	GasSim	ADEME
Model type	Monophase (1)		Multiphase (6)	
Input data	Historic of landfilled waste tonnages + % of inert waste		Historic of landfilled waste tonnages + waste composition	
Methane generation potential L_o	110 (does not take into account inert waste) (5)	170 (does not take into account inert waste)	Automatically calculated	(2) Fast: 88 Medium: 44 Slow: 0
Kinetic constant k	Determined by the user	0,05	Fast: 0.016 Medium: 0.076 Slow: 0.046	Fast: 0.50 Medium: 0.10 Slow: 0.04
Biogas capture efficiency	Calculated (ratio capture / theoretical production)	Calculated (ratio capture / theoretical production)– maximum at 85%	Calculated (ratio capture / theoretical production)	(3) Capture efficiency average based on cover type in proportion to the surface areas
Inputs due to capture	Average flow of methane captured during the year			(4) surface area every cover type
Oxidation (7)	10%	10%	Automatically calculated	10%

(*) In most models, the factors mentioned here (L_o, k, etc.) can be modified by the user to be more representative of the modeled landfills' actual conditions.

(1) The terms multiphase or monophase refer to the fact that the model takes into account one or several types of waste. For LandGem, its use in multiphase has been mentioned during the interviews with the companies' experts.

(2) Takes into account the fact that the ADEME considers that during the first year, methane production is nil (aerobic conditions) – initial factors are respectively 100, 50 and 0.

(3) Used capture efficiencies are the followings: no capture (0%), operated area connected to a combustion unit (35%), semi-permeable cover (65%), natural impermeable cover (85%) and geomembrane (90%).

(4) A second approach has been developed by the ADEME. It uses the same capture rates as in the theoretical models, but is applied to the measured production.

(5) The Tier 2 methodology does not set any value for the methane generation potential but indicates a calculation method according to the quality of the landfilled waste. The value reported in the table above and used in the VEOLIA PROPRETÉ internal study was calculated under the hypothesis of a composition of 25% of putrescible waste and 30% of papers & textiles, but has to be adapted for every site.

(6) 3 waste categories: highly degradable, moderately degradable, and inert. For highly and moderately degradable waste, 3 kinetic constants are considered (fast, medium, slow), respectively associated to 15, 55 and 30% of waste.

(7) The oxidation rate applies only to the uncaptured methane.

(8) AP42 parameters. These are the parameters used for regulatory reporting in the USA, with CAA parameters.

Ease of use

All models show some complexity and require time to have a thorough knowledge so that they can be used in the best conditions, and to be an accurate image of a landfill characteristics. The ADEME and GasSim models are considered to be more complex than the others, since the EPA and Tier2 models only allow to consider one type of waste . The calculation codes underlying the models are not complex. It has to be noted that the equations used by GasSim are integrated in the calculation software and are therefore, unlike in the other tools, inacessible by the users.

In all cases, it came out of the discussions that the initial parameters of a model are not relevant to reflect the specific situation of each site. It is therefore essential to know how to modify the model's key factors (especially waste composition and kinetic constant) to adapt them to site specific conditions. This work has to be part of a long term approach, which makes constancy a primary target in the model choice.

Furthermore, it is sure that all available measured data (captured gas measurement that has to be completed by diffuse gas measures) constitutes a reliability and refinement source for the parameter setting of the used model.

Consistency of results

Studies were done to compare the different models, and also to compare them with typical landfills. The results of these studies vary significantly and show the extreme complexity of modelling (the results are very sensitive to factors' variation, notably k and Lo). The difficulty to measure diffuse methane should be pointed out; the different methods used in the comparative studies can show highly significant deviations.

To solve this methodological difficulty, the best way we can use to assess models' performances lies in the comparison of the estimations made for each model of the **total methane production** within the cells as compared to the **captured methane quantity**. This comparison inevitably induces a bias due to uncaptured landfill gas but, in the case of high capture output, it allows validation of the order of magnitude of the models' results.

Such a study shows that:

- When tests are done on several landfills, net tendencies appear: some models (EPA, Tier II) systematically predict higher productions than others (GasSim, Ademe). The estimations vary almost from **simple to double**, regardless of the landfill,
- However, the **total production estimations made by the models are sometimes below the captured gas quantity** (and therefore below the quantity of landfill gas actually produced).

The comparison between the estimated results of diffuse methane emissions and their in-situ measurements is much more random, and tendencies are not easily found.

- According to the type of measure done, the results on the quantity of methane diffused in the atmosphere range from 1 to 10 (even if it is possible to explain part of these gaps),

1. Remark: the term « complex » refers here to the model's conception and use (necessary input date, implemented calculation types, etc.). The complexity of model and of the implemented calculation methods is not necessarily linked to the final results accuracy.

- For the models that substract the measured quantity of captured methane from the estimated production, the result is sometimes negative, therefore inconsistent. The ADEME model eliminated this problem through its unique approach (capture rate estimation) and the EPA model defines a capture rate threshold at 85%.
- In cases where results are not negative, it is not possible to identify tendencies: the results of these models vary significantly, whether we compare the results of the different models or the models with field measurements.
- The uncertainty for measured emissions is much higher than for theoretical production.

Conclusions

General Conclusion

The outcome of this study is that, because of its very nature and unless costly emissions monitoring devices are set up, the best means for diffuse emissions estimates are the use of emission models.
Modelling is a difficult exercise, because of the diversity of physical, chemical and mainly biological factors that governs the waste degradation process. However, several models exist, that try to similate the actual landfill conditions.

As a consequence,

- The use of models is essential to assess diffuse emissions
- Among the diversity of existing models, only the order 1 models can today take into account the various factors that have an impact on landfill gas production. It is therefore advised to favor these models and to avoid using order 0 models (or models using standard emission factors).
- It is necessary to keep in mind that the use of these tools implies a very high level of uncertainty, a level difficult to asses. This level of uncertainty cannot be compared to the one that can be reached in GHG emissions calculation in other industrial facilities.
- The different existing models were created to reflect certain condition and include standard factors that can be adapted. They each have their pros and cons and can show wide variations in their numerical results. Today, because of the very nature of the modeling exercise, no model is recommended over another. Nonetheless, it is advised to resort to the model accepted by local authorities for regulatory declarations. If there is no locally accepted model, the entity should use a model that is published, accepted and available in scientific and technical literature, and the parameters of the model should be adapted to reflect the site's specific situation. The choice of the model as well as the parameter adaptation should be documented and justified.
- Because of the necessary adaptation of the model's parameters, the reporting entity will have to make sure the same model is used every year, unless another model can give a better representation of the landfills' situation.

Validity of the models

- In the present state of our knowledge, it is impossible to validate the models' results on the quantity of diffuse methane. It is also in vain to suggest an estimation of the uncertainty of these results,
- Total methane production assessments seem consistent, when we compare the different models and as compared to captured landfill gas measurements. An uncertainty of +/- 50% is conceivable on these results,
- The determination of a ranking based on model's performance seems unrealistic, for two main reasons:
  - The uncertainties due to the entire modelling exercise are too important,
  - There is a great sensitivity of the results to input factors (notably k and L_0), so that the results obtained for one single model can have a wide range of variations. Furthermore, a model that has used only default values does not seem pertinent; it has to be considered as a gross tool that needs to be refined to reflect the local situation,

- On the long term, methane production potential is a crucial parameter since it will influence directly the total cumulated methane production from a landfill. It is therefore important to make sure that these parameters' values are consistent from one model to another,
- Methane oxidation through the cover has been set at 10% in almost all models, according to the IPCC recommendations. However it is difficult to validate this hypothesis with precision.
- It is also recommended that the user converts the landfill gas production results in Nm^3 so that a consistent base of comparison with other sites is available.

Recommendations for use

- Multiphase models are more accurate in biochemical mechanisms' modelling and should allow sites to gain a more accurate image of their emissions,
- The ADEME model (in both versions) shows the non-negligible interest of suggesting an estimation of the diffuse landfill gas quantity in all cases, unlike the other models. This model was drawn up to show the 30-year evolution of a landfill.
- The measurement of the captured landfill gas remains by far the most accurate data. It can therefore be interesting to use it. However there is no method today to assess the efficiency of the collection system (or the cover efficiency),
- Good use of a landfill's emissions estimation model requires a real competence (essentially because of the great sensitivity of input data). The accuracy of the results also highly depends on the knowledge of the landfill to be modelled (biogenic carbon rate, waste age, collection system efficiency), as well as cultural criteria (food, habit of waste sorting). This is why it is recommended that the sites' operational staff work in close collaboration with the reporting entities' management. The entity should provide pertinent indicative elements on input parameters and perform a consistency check on the calculated data, even make the calculation using data given by the operators on site.
- The "management" of a model's constants according to the measured results (captured and diffuse landfill gas) appears to be an important source of progress in making the models more accurate. But this work needs to be done with extreme care:

  - So that the output of the capture system is not overestimated, inducing a reduction of the diffuse emissions (this would lead to bring the total methane production in line with the captured methane quantity),
  - Technically, diffuse methane measurements are uncertain and need to be done in good conditions to make sure the results are representative.
  - It is also recommended to update the parameters every year so that the waste characteristics' variations are considered.

References

- Interviews with experts of ADEME, CITEPA, European Topic Center for Resources and Waste Management, VEOLIA PROPRETÉ, SITA and SECHE ENVIRONNEMENT.
- ADEME : Calculation tool of emissions to air of CH_4, CO_2, SOx, NOx from waste storage sites and comparable – user manual (2003)
- COWI, 2000, A Study on the Economic Valuation of Environmental Externalities from Landfill Disposal and Incineration of Waste, Final Appendix Report for the European Commission
- E-PRTR : Supporting Document for the determination of diffuse methane emissions from landfill sites (2004)
- European Environment Agency : Waste Management in Europe and the Landfill Directive – Background paper from the ETC/RWM to the ETC/ACC workshop 'Inventories and Projections of Greenhouse Gas Emissions from Waste' (2005)
- GIEC : Tier 2 method, Revised 1996 IPCC Guidelines for National Emission Greenhouse Gas Inventories – Manuel de reference
- JACOBS J., SCHARFF H. : Comparison of methane emission models and methane emission measurements (2004)
- OGOR Y., GUERBOIS M., "Comparison of Landfill Methane Emission Models : a Case Study", Proceedings Sardinia 2005, Tenth International Waste Management and Landfill Symposium, S. Margherita di Pula, Cagliari, Italy, 3-7 October 2005
- UK Environment Agency : GasSIM – landfill gas risk assessment tool (2002)
- USEPA : LandGEM User's Manual Landfill Gas Emissions Model - Version 2.0 (1998)
- Workshop on Inventories and Projections of Greenhouse Gas Emissions from Waste – Organized by the European Environment Agency – Copenhagen (Denmark), 2 – 3 may 2005
- http://air-climate.eionet.eu.int/docs/meetings/050502_GHGEm_Waste_WS/meeting050502.html

Annex 3: Carbon Sequestration in Landfills And Soils After Compost Spreading

1. Background on carbon sequestration

1.1. Definitions

Carbon is considered as «stored» when it is removed from the global carbon cycle over long time periods.

Carbon is present under gaseous form in the atmosphere, especially in the form of greenhouse gases (mainly carbon dioxide). Carbon storage, whether natural (photosynthesis, ocean absorption) or artificial (manufactured products of biogenic origin), helps to reduce the amount of greenhouse gases in the atmosphere. Therefore, it participates positively in climate change mitigation.

1.2. Carbon sequestration in waste management

What exactly is the role of the waste sector in carbon sequestration? Two activities are concerned: landfilling and compost spreading. Both contribute to carbon sequestration: more precisely, they prolong the phenomena of sequestration over time (cf. Figure 1) and, in this sense, play the role of carbon sinks.

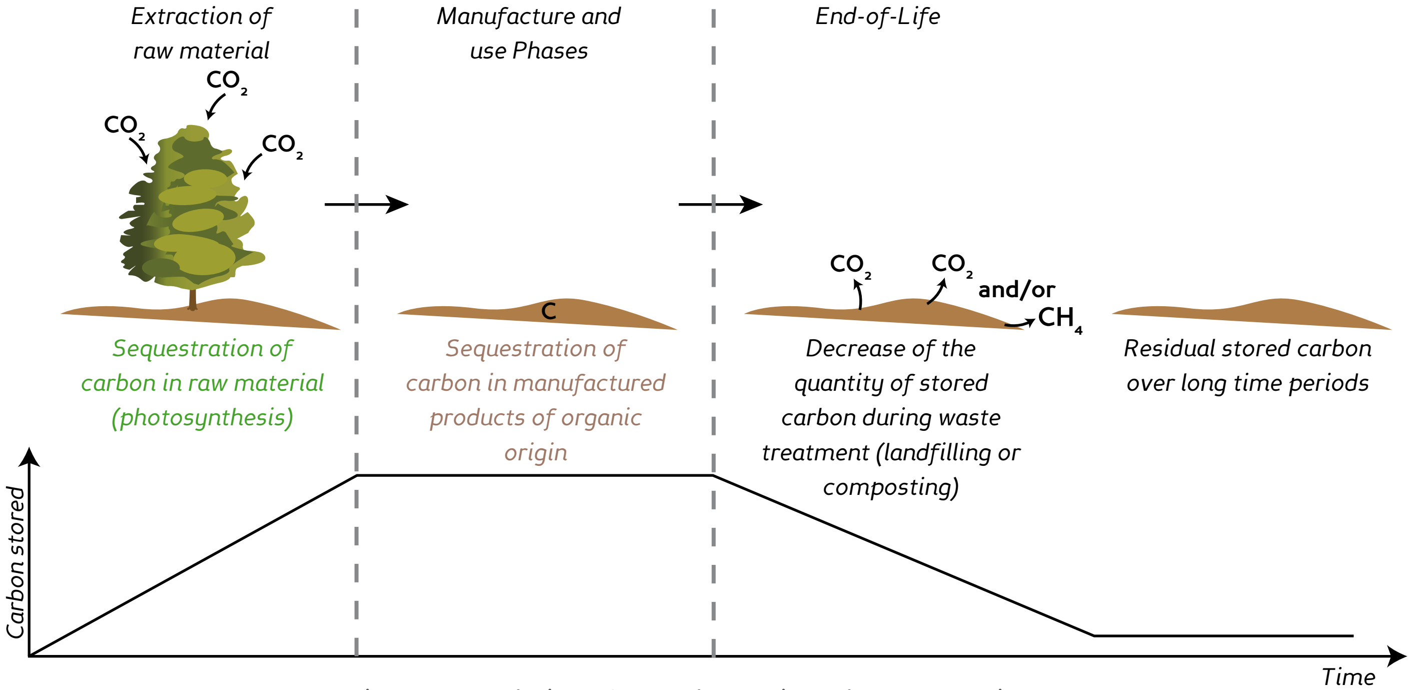


Figure 1 – Evolution of stored organic carbon versus time

Organic wastes and compost contain organic matter whose carbon has been sequestrated during the production of the raw material (via photosynthesis) and the product manufacturing (wooden board production for instance). During landfilling or composting, the organic matter contained in such products decomposes and part of its carbon is emitted as CO_2 and/or CH_4, back to the atmosphere.

However, part of the organic matter does not decompose completely or very slowly and part of its carbon thus remains in soils.

In landfills, wood and paper decay very slowly and accumulate in the landfills (long-term storage). Carbon fractions in other waste types decay over varying time periods. Lignin does not decompose to a significant extent because of the anaerobic conditions. Cellulose and hemicellulose

1. This factor is highly variable from one region to another (food habits, waste sorting efficiency etc.). It explains the significant discrepancies that one might observe between the models of the different countries.

decompose, but the extent of their decomposition depends on the environmental conditions in the landfill (e.g. pH and moisture). In addition, the presence of lignin actually prevents some cellulose and hemicellulose biodegradation.

In the same way, **after compost spreading**, part of the carbon present in compost is not mineralized but retained in the soil. Indeed, the stable organic matter has a turnover of 100 to 1 000 years and thus a fraction of the carbon is bound in soil for long periods.

In both cases, the result is that a fraction of biogenic carbon contained in organic waste/compost remains stored in soils.

1.3. Biogenic carbon vs fossil carbon

Carbon sequestration only concerns biogenic carbon.
There are two distinct organic carbon cycles: the short-term cycle (biogenic carbon) and the long-term cycle (fossil carbon).

- Biogenic carbon is involved in the short-term organic carbon cycle which reflects carbon interactions between the atmosphere and the biosphere. Carbon, as CO_2, is first absorbed during the green plants growth (photosynthesis). Temporarily sequestrated, it is then emitted as CO_2 again, when plants decompose. Assuming a sustainable biosphere, while plants are decomposing, others are growing and CO_2 emitted by the previous is thus absorbed by the latter. A neutral equilibrium of carbon is resulting.
- Fossil carbon is involved in the long-term organic carbon cycle. Instead of decaying, part of the organic matter is being buried and incorporated into fossil fuels deposits or sediments. This process is very slow since it extends over geological timescales (thousands and millions of years). The residence time of carbon in geological reservoirs is estimated at more than 200 millions years.

Figure 2 describes the impact of landfilling and compost spreading in both biogenic and fossil carbon cycles. It shows that:

- In the case of biogenic carbon, landfilling and compost spreading avoid carbon emissions, by extending carbon sequestration in the soils;
- Whereas in the case of fossil carbon, landfilling has no impact. It does not avoid any carbon emission since fossil carbon, initially extracted from soil, simply returns to the soil.

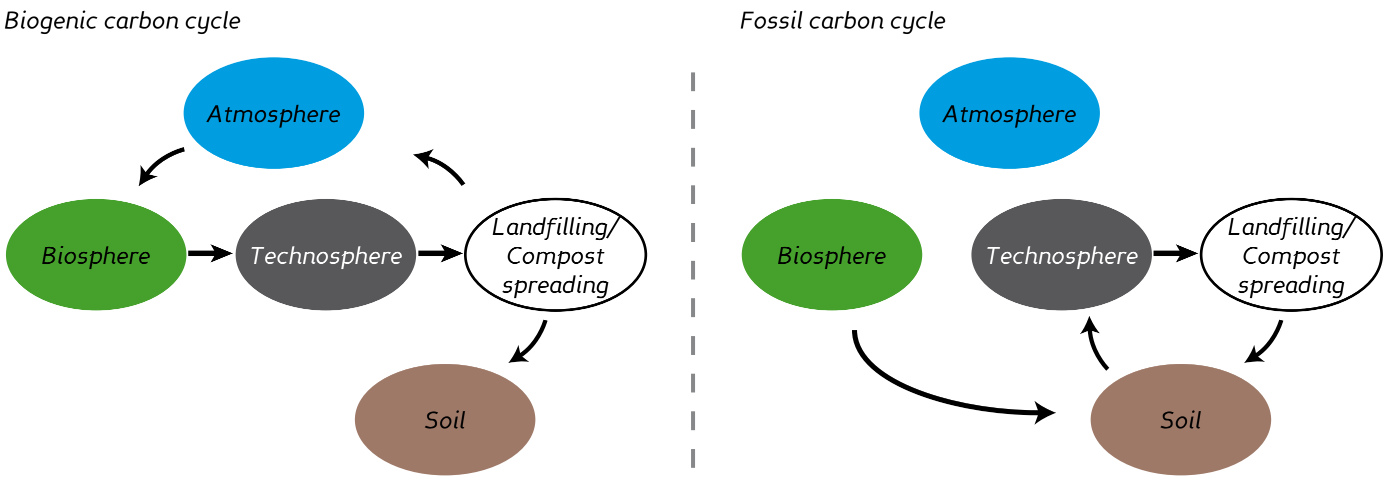


Figure 2 – Biogenic Carbon Cycle versus Fossil Carbon Cycle
The size of the arrows is not proportional to the involved carbon quantities.

2. Estimating carbon sequestration

From a mass balance standpoint, carbon sequestration can be considered as a negative emission.

By convention, only the biogenic carbon that is stored for longer than the time horizon adopted for global warming (100 years) can be considered as having been sequestrated.

Avoided emissions are calculated by converting tonnes of sequestrated carbon to avoided tonnes of carbon dioxide equivalents, by multiplying by the molecular weight ratio for carbon dioxide to carbon (44/12).

2.1. Estimating carbon sequestration in landfills
Five positions are presented here:

IPCC 2006

As proposed in the *2006 IPCC Guidelines for National Greenhouse Gas Inventories*, Landfill C sequestration is estimated and reported as an information item within the Waste Sector Inventory, but is accounted for in the Agriculture, Forestry and other Land Use Inventory. The Waste Sector guidelines explain how to estimate the amount of biogenic carbon that is long-term stored in landfills.

$$DOC_{m\ long\text{-}term\ stored\ T} = W_T \times DOC \times (1 - DOC_f) \times MCF$$
(Equation 1)

W_T: mass of waste disposed in year T (Gg)
DOC: degradable organic carbon in disposal year (Gg C/Gg waste)
DOC_f: fraction of DOC than can decompose in the anaerobic conditions in the landfill (fraction)
MCF: CH_4 correction factor for year of disposal (fraction)

Carbon sequestration can then be calculated by multiplying $DOC_{m\ long\text{-}term\ stored\ T}$ by 44/12.
To ensure consistency between the amount of sequestrated carbon calculated and the amount of emitted methane reported, the use of Equation 1 imposes the use of the IPCC Waste model to estimate methane emissions.

USEPA 2006

In its study entitled "*Solid Waste Management and Greenhouse Gases, A Life Cycle Assessment of Emissions and Sinks*" (2006), USEPA estimates carbon sequestration that will result from landfilling organic waste, based on experiments conducted by Dr. Morton Barlaz of North Carolina State University in 1998. These Carbon storage factors (CSF) have been updated in 2008 (See Table 1).

SWICS 2009

SWICS has developed its approach to carbon sequestration in its study entitled "*Current MSW Industry Position and State-of-the-Practice on LFG Collection Efficiency, Methane Oxidation, and Carbon Sequestration in Landfills*" (Version 2.2, Revised January, 2009). Here as well, the approach proposed is based on the research work performed by Dr. Morton Barlaz and the USEPA. SWICS proposes the following carbon storage values for refuse placed in landfills, taking into account the update performed by Dr. Morton Barlaz in 2008:

Table 1 – Carbon storage factors (CSF) from SWICS's study

	Amount of Carbon Stored TeqC/Wet Ton	Avoided CO_2 emissions $TeqCO_2$/Wet Ton
Paper and Paperboard		
Old Corrugated Containers	0.24	0.89
Old Newsprint	0.40	1.46
Office Paper	0.04	0.16
Coated Paper, Magazines and 3rd Class Mail	0.25	0.93
Food		
	0.02	0.08
Yard Trimming		
Grass	0.08	0.28
Leaves	0.28	1.01
Branches & wood	0.34	1.25
Municipal Solid Waste		
15% moisture	0.10	0.36
20% moisture	0.10	0.36
25% moisture	0.09	0.32

PROGNOS 2008

PROGNOS proposes emission factors for landfilling of residual waste both with and without the accounting of the carbon sink. In its calculations, PROGNOS considered that the carbon sink equals 300 kgCO2 equivalent per tonne of landfilled waste.

RECORD 2008

In 2008, RECORD, - a French network open to all public or privately owned organizations in which industry, public bodies and researchers can engage in collaborative research projects -, has published a study entitled "Application of the Bilan Carbone method to waste management activities" in which a literature review of carbon storage factors is made. The results of this work are presented in the Table below

Table 2 – Carbon storage factors from RECORD's report

	Amount of carbon stored (TeqC/Wet Ton)	Avoided CO2 emissions $TeqCO_2$/Wet Ton	Source
Paper			
Newspaper	0.391	1.43	USEPA 2006
Office Paper	0.046	0.17	USEPA 2006
Magazines	0.245	0.90	USEPA 2006
Mixed paper	0.200	0.73	USEPA 2006
Paper	0.147	0.54	ERM 2006
Paper/Newspaper	0.214	0.78	AEA 2001
Newspaper/Magazines	0	0.00	Fridriksson 2002
Other papers	0	0.00	Fridriksson 2002
Newspaper	0.229	0.84	Finnveden 2000
Paper	0.235	0.86	Lobo et al. 2006
Value selected by RECORD	*0.198*	*0.73*	
Cardboard			
Corrugated cardboard	0.245	0.90	USEPA 2006
Corrugated cardboard	0.207	0.76	Finnveden 2000
Mixed Cardboard	0.161	0.59	Finnveden 2000
Cardboard	0.234	0.86	Lobo et al. 2006
Value selected by RECORD	*0.224*	*0.82*	
Food Discards			
Food Discards	0.024	0.09	USEPA 2006
Food Discards	0.064	0.23	ERM 2006
Food Discards	0.038	0.14	AEA 2001
Food Discards and garden waste	0	0.00	Fridriksson 2002
Food Discards	0.06	0.22	Finnveden 2000
Food Discards	0.069	0.25	Lobo et al. 2006
Value selected by RECORD	*0.036*	*0.13*	
MSW			
Value selected by RECORD	*0.063*	*0.23*	

2.2. Estimating carbon sequestration in soils after compost spreading

Three positions are presented here.

USEPA 2006

In its study entitled "Solid Waste Management and Greenhouse Gases, A Life Cycle Assessment of Emissions and Sinks" (2006), USEPA explains that its research efforts did not yield any primary data that could be used to develop quantitative estimates of the soil carbon sequestration benefits of compost. Therefore, it decided to use a simulation model able to be applied to the issue of soil carbon sequestration from compost application. CENTURY is a Fortran model of plant-soil ecosystems that simulates long-term dynamics of carbon, nitrogen, phosphorus, and sulfur. It tracks the movement of carbon through soil pools and can show changes in carbon levels due to the addition of compost. In addition to this soil carbon restoration effect, USEPA considers the impact of compost on humus formation. Indeed, USEPA reports that some studies considering other compost feedstocks (e.g. farmyard manure, legumes) have indicated that the addition of organic matter to soil plots may increase the potential for sequestration of soil organic carbon.

USEPA proposes the following carbon storage factor for compost application. This factor takes into account carbon sequestration from both the soil restoration and the humus formation.

Table 3 – Carbon storage factors from USEPA's report

	Soil carbon sequestration TeqCO$_2$/ Waste Ton
Food Discards	0,26
Yard Trimming	0,26
Mixed organics	0,26

AEA Technology 2001

AEA Technology details the phenomena of carbon sequestration in soils in case of compost application and purposes a quantification in its study entitled "Waste Management options and climate change" (2001). According to this study, **8,2% of the carbon contained in compost would remain sequestrated after 100 years**.

PROGNOS 2008

PROGNOS proposes emission factors for compost production from biowaste and application both with and without the accounting of the carbon sink. In its calculations, PROGNOS considered a storage rate of carbon of 24%, corresponding to 52 kgCO2 equivalent per tonne of collected and composted biowaste.

Boldrin A. et al 2009

A. Boldrin et al of Departement of Environmental Engineering of the Technical University of Denmark and E. Favoino of Suola Agraria del Parco di Monza have both recently published an article entitled *"Compost and compost utilization : accounting of greenhouse gases and global warming contributions" in Waste management & research* (Volume 27, Issue 8 , November 2009).

They purpose the following formula to calculate the avoided CO2 emissions due to carbon sequestration:

$$CO_{2,bind} = C_{input} \times C_{bind} \times 44/12$$

CO_2,bind : sink of CO_2 (kg)
C_{input}: C content in compost (kg)
C_{bind}: fraction of C which is stable

According to different studies, the article reminds that the **C still bound to soil after 100 years has been estimated to be 2-14% of the input in compost, depending on the soil type and the crop rotation**.

Table 4 – Carbon storage factors from Boldrin A. and Favoino E.'s article

	Carbon content (kg/Wet ton)	Carbon bound in soil (kg/Wet Ton)	Avoided CO_2 emissions $TeqCO_2$/Wet Ton
Compost from food waste	63-386	1-54	4-198
Compost from garden waste	56-202	1-28	4-103

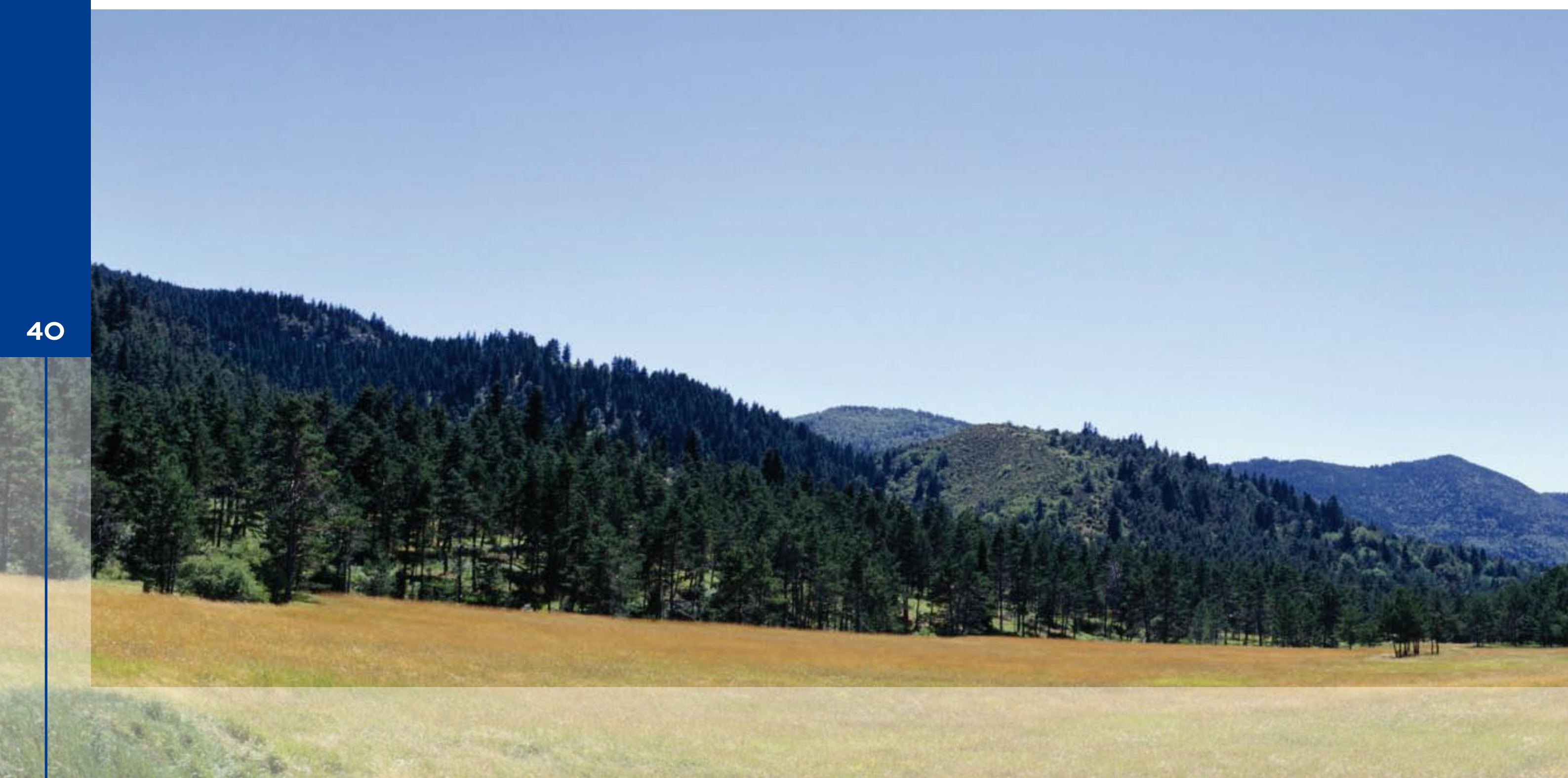
3. EpE position regarding the incorporation of carbon sequestration in the protocol

Carbon sequestration in landfills and soils has been and continues to be a subject of debate which requires further research.

In an annual reporting approach, such as the one described by the EpE Protocol, taking into account carbon sequestration is a challenging task because of the confrontation of two time horizons. On the one hand, carbon sequestration is most often based on a 100 years time horizon whereas on the other hand, the time period for reporting is typically one year. However, this carbon, that will only be considered as sequestrated if stored for more than 100 years after its disposal in the soil, is effectively present in the soil right from the first year.

Besides, it is important to adopt a position that would be coherent with the approach considered for methane emissions from landfills. In the EpE Protocol, the emissions occurring in year n (reporting year) due to the waste disposed up to and including year n are taken into account; the Protocol does not consider the emissions that will occur on year n and afterwards originating from the waste disposed during the reporting year.

In the case of **carbon sequestration in landfills and soils through carbon spreading**, EpE's position would be to display the carbon stored as an information item only if available (for example if the reporting entity has made use of a first order decay model calculating this sequestration such as the IPCC model). **Under no circumstances, this sequestrated carbon should be subtracted from the direct emissions or presented as avoided emissions in the reporting entities' inventory.**



Bibliography

- [Barlaz 1998] Barlaz, M.A., 1998. Carbon storage during biodegradation of municipal solid waste components in laboratory-scale landfills. Global Biochem. Cycles 12(2): 373-380.
- [Barlaz 2008a] Barlaz, M.A., 2008. *Correction to Previously Published Carbon Storage Factors*, memo dated Feb.28, 2008
- [Barlaz 2008b] Barlaz, M.A., 2008. *Correction to Previously Published Carbon Storage Factors for Mixed Municipal Waste*, memo dated Oct.27, 2008
- [USEPA 2006] USEPA, 2006. Solid Waste Management and Greenhouse Gases: A Life-Cycle Assessment of Emission and Sinks.
- [IPCC 2006] IPCC, 2006. Guidelines for National Greenhouse Gas Inventories.
  Volume 5 Waste, Chapter 3, Solid Waste Disposal provides a methodology for estimating changes in carbon stored in solid waste disposal sites (landfills), which is reported as an information item in the Waste Sector (See also Volume 4, AFOLU, Chapter 12, Harvested Wood Products).
- [SWICS] Solid Waste Industry Climate Solutions Group (SWICS). Recommended Protocol for Estimating Greenhouse Reductions Due To Landfill Carbon Storage and Sequestration
- [SWICS 2009] Solid Waste Industry Climate Solutions Group (SWICS), 2009. Current MSW Industry Position and State-of-the-Practice on LFG Collection Efficiency, Methane Oxidation, and Carbon Sequestration in Landfills, Version 2.2, Revised January, 2009, SCS Engineers for SWICS
- [Boldrin et al. 2009] Boldrin A., Andersen J.K., Moller J., et al. 2009. Composting and compost utilization: accounting of greenhouse gases and global warming contributions.
- [RECORD, 2008] RECORD, 2008. Application de la méthode Bilan Carbone® aux activités de gestion des déchets, 133 p, n°07-1017/1A
- [ERM 2006] Fisher, K., Aumonier, S. 2006. Impact of Energy from Waste and Recycling Policy on UK Greenhouse Gas Emissions, ERM for DEFRA
- [Finnveden 2000] Finnveden G., Johansson J., Lind P., Moberg A., 2000. Life Cycle Assessment of Energy from Solid Waste
- [PROGNOS 2008] PROGNOS in cooperation with INFU, 2008. Resource savings and CO_2 reduction potential in waste management in Europe and the possible contribution to the CO_2 reduction target in 2020
- [Fridriksson 2002] Fridriksson GB, Johnsen T, Bjarnasóttir HJ, Slentnes H, 2002. Guidelines for the use of LCA in the waste management sector. Nordtest Project Nr. 1537-01
- [Lobo et al.2006] Lobo et al., 2006. Applications of simulations models to the diagnosis of MSW landfills: an example

Annex 4: Composting - N_2O and CH_4 Emission Factors[1]

Homogenized emission factors for direct N_2O emissions

Source	Emission factor g N_2O/t WW[2]	Emission factor kg CO_2e / t	% of initial N	Methodology	Substrate
ADEME05	24 [2.4-59.1]	7.3 [0.7-18.4]		Review of bibliography Default [min-max]	Biowaste
	210 [10.5-262]	65 [3.2-81.3]			MSW
Bar02	158	49			Biowaste
Bec01	7.15	2	0.02	Measurements in reactors	Greenwaste
	149.5	46	0.4		
	210.6	65	0.6		
CITEPA07	189	58.6			
Cl03	15	5		On-site measurements	MSW
	400	124			
ERM06	165	51			Paper, cardboard, park waste
He98	232	72	0.5	On-site measurements	Greenwaste
	1247.52	77	0.4	Measurements in reactors	
	382	118	0.7		
Heres07	69 [40-100]	21.4 [12.4 - 31]		Default [min-max]	Vegetable, fruit and garden waste (VFG)
IPCC06b	300 [60-600]	93 [18.6-185]		Default [min-max]	

Recommended values

Homogenized emission factors for direct CH_4 emissions

Source	Emission factor g CH_4/t WW[2]	Emission factor kg CO_2e / t	Methodology	Substrate
ADEME05	1240 [310-6190]	26 [6.5-130]	Review of bibliography Default [min-max]	MSW (65% dry)
CITEPA07	952	20		Biowaste
Cl03	400	8	On-site measurements	MSW
	1200	25		
	10000	210		
ERM06	30.3	0.64		Paper, cardboard, park waste
He98	6760	142	On-site measurements	Greenwaste
Heres07	170 [80-300]	3.6 [1.7-6.3]	Default [min-max]	Vegetable, fruit and garden waste (VFG)
IPCC06b	4000 [30-8000]	84 [0.63-168]	Default [min-max]	

Recommended values

1. Factors found in litterature, compiled thanks to a BIO Intelligence Service study carried out in 2007
2. WW = wet weight

Legend of above mentioned bibliographical sources :

- **ADEME05**: ADEME (2005), Impacts environnementaux de la Gestion Biologique des Déchets.
- **Bar02**: Barton, P. K. and Atwater, J. W. (2002), Nitrous Oxide Emissions and the Anthropogenic Nitrogen in Wastewater and Solid Waste Journal of Environmental Engineering 128(2):137-150.
- **Bec01**: Beck-Friis B., S. Smars, H. Jonsson, H. Kirchmann, (2001). Gaseous emissions of carbon dioxide, ammonia and nitrous oxide from organic household waste in a compost reactor under different temperature regimes. Journal of Agricultural Engineering Research, 78(4):423-430.
- **CITEPA07**: CITEPA (2007), Organisation et méthodes des inventaires nationaux des émissions atmosphériques en France (OMINEA), 4e Edition.
- **Cl03**: Clemens J., C. Cuhls, (2003). Greenhouse gas emissions from mechanical and biological waste treatment of municipal waste. Environmental Technology, 24(6):745-754.
- **ERM06**: Fisher, K., Aumonier, S. (2006) Impact of Energy from Waste and Recycling Policy on UK Greenhouse Gas Emissions, ERM for DEFRA.
- **He98**: Hellebrand H.J., 1998. Emission of nitrous oxide and other trace gases during composting of grass and green waste. Journal of Agricultural Engineering Research, 69(4):365-375.
- **Heres07**: Research determining indicator for methane and laughing gas composting plants. (Onderzoek bepalen kentallen methaan en lachgas composteerbedrijven), R-J Heres, Tauw BV, Deventer, 22 November 2007 (in Dutch).
- **IPCC06b**: IPCC (2006), Guidelines for National Greenhouse Gas Inventories: Chapter 4: Biological treatment of solid waste

Annex 5: Bibliography

General bibliography

- The Greenhouse Gas Protocol – A Corporate Accounting and Reporting Standard – Revised edition - 2004 - WBCSD / WRI – www.GHGprotocol.org
- Revised 1996 IPCC Guidelines for national Greenhouse Gas Inventories 2000 IPCC Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories
- Directive 2003/87/CE of the European Parliament and of the council of 13 October 2003 establishing a scheme for greenhouse gas emission allowance trading within the Community.
- Council Directive 96/61/EC of 24 September 1996 concerning integrated pollution prevention and control.
- Commission decision of 29 January 2004 establishing guidelines for the monitoring and reporting of greenhouse gas emissions pursuant to Directive 2003/87/EC of the European Parliament and of the Council
- 2000/479/EC: Commission Decision of 17 July 2000 on the implementation of a European pollutant emission register (E-PRTR) according to Article 15 of Council Directive 96/61/EC concerning integrated pollution prevention and control (IPPC) (notified under document number C(2000) 2004)
- Arrêté of July 28th 2005 of French Ministry of Ecology[1] and sustainable development relating to the verification and quantification of declared emissions within the frame of the GHG allowances trading scheme
- Methodological guide relating to the control of declarations of GHG emissions, prepared by the Ministry of ecology and sustainable development in application of article 62 of arrêté of February 2nd, 1998 modified.
- ADEME Bilan Carbone®[2] Method: www.ademe.fr/Outils/BilanCarbone
- ISO 14064 – 1:2006; Greenhouse gases -- Part 1: Specification with guidance at the organization level for quantification and reporting of greenhouse gas emissions and removals
- ISO 14064 – 2:2006; Greenhouse gases -- Part 2: Specification with guidance at the project level for quantification, monitoring and reporting of greenhouse gas emission reductions or removal enhancements
- ISO 14064 – 3:2006; Greenhouse gases -- Part 3: Specification with guidance for the validation and verification of greenhouse gas assertions

Waste industry specific bibliography

- VEOLIA PROPRETÉ, Measuring and reporting protocol (2009)
- Suez Environnement, Internal Protocol
- Séché Environnement, Internal Protocol
- Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories: Simplified Manual - Module 6: Waste
- UNFCCC, Consolidated baseline methodology for landfill gas project activities - ACM0001 (2004) E-PRTR : Supporting Document for the determination of diffuse methane emissions from landfill sites (2004)
- European Environment Agency : Waste Management in Europe and the Landfill Directive – Background paper from the ETC/RWM to the ETC/ACC workshop 'Inventories and Projections of Greenhouse Gas Emissions from Waste' (2005)
- CORINAIR, Emission Inventory Guidebook – Waste incineration (2001)
- AEA Technology, Waste management options and climate change, Study for DG Environment, European Commission (2001)
- COWI, A Study on the Economic Valuation of Environmental Externalities from Landfill Disposal and Incineration of Waste, Final Appendix Report for the European Commission (2000) European Commission – Joint Research center, Integrated pollution prevention and control, Reference

1. Ministère de l'Ecologie et du Développement Durable, France.
2. Bilan Carbone® is an ADEME registered trademark..

document on best available techniques for the waste treatments industry (BREF), August 2005

- ADEME : Calculation tool of emissions to air of CH_4, CO_2, SO_x, NO_x from waste storage sites and comparable – user manual (2003)
- Brinkmann (2004). Herziening levenscyclusanalyse voor GFT-afval, Brinkmann A.J.F. , E.H.M. van Zundert, R.J. Saft, Grontmij/ IVAM, De Bilt/ Amsterdam, November 2004 (in Dutch).
- Ewijk (2008). Environmental Analysis of VFG-Waste Digestion, paper for ORBIT 2008 mainly based on [9], H.A.L. van Ewijk, IVAM UvA BV, Amsterdam, August 2008.
- FNADE, Guidelines for filling in the regulatory questionnaire relating to annual pollutant discharge to water, air, waste and the ground towards operators of incinerators of non dangerous wastes and wastes from health activities with infectious risk (2004)
- Heres (2007). Research determining indicator for methane and laughing gas composting plants (Onderzoek bepalen kentallen methaan en lachgas composteerbedrijven), R-J Heres, Tauw BV, Deventer, 22 November 2007 (in Dutch).
- LandGEM, User's Manual Landfill Gas Emissions Model - Version 2.0 (1998)
- Environment Agency, GasSIM - landfill gas risk assessment tool (2002)
- US Environment Protection Agency, Solid Waste Management and Greenhouse Gases: A Life-Cycle Assessment of Emissions and Sinks (2002)
- ATILH, Guideline for collecting annual data on CO_2 emissions et check possibilities of those emissions values (2002)
- P. Bajeat, L'effet de serre dans les filières de gestion des déchets ménagers – Greenhouse effect in household waste management routes; Ademe seminar, 21 & 22 November 2002
- Prognos - IFEU (2008) : Resource savings and CO_2 reduction potentials in waste management in Europe and the possible contribution to the CO_2 reduction target in 2020
- Scharff H. et Jacobs J. Applying guidance for methane emissions estimation for landfills..Waste Management Volume 26. Issue 4. Page 417-429
- Gutierrez et al., Nitrous Oxide (N_2O) emissions from waste and biomass to energy plants, Waste manage Res 2005:23:133-147
- European Topic Center on Air and Climate Change Symposium proceedings, "Inventories and projections of greenhouse gas emissions from waste", 2-5 may, 2005, Copenhage

Additional bibliographic elements are available in the annex 2 of "Landfill greenhouse gases emissions models comparative analysis"

Entreprises pour
l'Environnement