Supporting Document for the determination of diffuse methane emissions from landfill sites

1 Introduction

At the 13th Article 19 meeting in Luxembourg in November 2003 Germany agreed to compose a supporting document on the methodologies for determination of diffuse emissions from landfill sites for the European Pollutant Emission Register (EPER). Member States were requested to submit any information on methodologies they use or are planning to use before 12 March 2004. Nine Member States answered[1] in different ways.

The methodologies of eight Member States are listed in the table in chapter 3.

The document submitted by the Netherlands includes a comparison of different methodologies and it is briefly summarized in chapter 4 of this paper.

The results of the first EPER reporting concerning landfills are presented in chapter 5.

2 Background

According to the EPER Decision (2000/479/EC), facilities undertaking an activity listed in Annex I of the IPPC Directive and exceeding the specific threshold values laid down in Annex I of the EPER-Decision have to report their emissions into air and water. The emissions can be determined by measurement, calculation or estimation.

Landfills can fall under activity 5.4 (*Landfills receiving more than 10 tonnes per day or with a total capacity exceeding 25 000 tonnes, excluding landfills of inert waste*) and 5.1 (*Installations for the disposal or recovery of hazardous waste as defined in the list referred to in Article 1 (4) of Directive 91/689/EEC, as defined in Annexes II A and II B (operations R1, R5, R6, R8 and R9) to Directive 75/442/EEC and in Council Directive 75/439/EEC of 16 June 1975 on the disposal of waste oils (3), with a capacity exceeding 10 tonnes per day*) of Annex I IPPC Directive. They have to report both emissions to water and emissions to air according to EPER.

Regarding landfills, besides emission to water two different emission paths into the environment can be distinguished:

- emissions to air resulting from point sources (e.g. gas engines),
- emissions to air resulting from diffuse emissions from the landfill body.

During the first EPER reporting period it has become obvious that there were some problems and grey areas in determining diffuse emissions to air from landfills in several Member States.

Concerning air emissions from landfills, usually methane (CH_4) and carbon dioxide (CO_2) are the substances for which exceeding EPER threshold values is probable. Nevertheless, further gases such as

[1] Austria, Belgium, France, Germany , Ireland, Netherlands, Portugal, Slovakia, United Kingdom

nitrogen oxides (NO_x) and sulphur oxides (SO_x) can be emitted to air[2] by landfills. Especially for activity 5.1, further emissions into air are possible, such as heavy metals, carbon monoxide (CO), hexachlorobenzene, dioxins, polycyclic aromatic hydrocarbons, chlorine and inorganic compounds, fluorine and inorganic compounds, and particulate matter (PM10)[2]. Each Member State has to check if the above mentioned emissions arise and if so, how they could be quantified.

3 Methodologies by Member States

In the following, only **diffuse emissions of methane (CH_4)** from landfills are regarded, because they are most frequent and most determination problems were known here.

[2] see "Guidance Document for EPER implementation", appendix 4, table 1

Table 1: Methodologies to determine methane emissions by Member States

Member State	Methodology	Methodology based on	Specifications
Austria	- different approach for residual and non residual waste - residual waste: *methodology of Tabasaran and Rettenberger* [described in BAUMLER et al. 1998] o to determine the total amount of landfill gas emissions for one year, the amounts generated by waste disposed in the last 31 years are summed up. o after subtracting the collected gas and multiplying by the CH_4 content of landfill gas (approximately 55%) the emitted quantity of CH_4 from residual waste was obtained. - non residual waste: *methodology of Marticorena* [described in BAUMLER et al. 1998] o the deposited non residual waste was split up into two groups and the incidental quantity of gas was calculated for each group. 1. Well bio-degradable waste (half-life period: 1-20 years) 2. Hardly bio-degradable waste (half-life period: 20-100 years) o after calculating the total emitted gas of each group the values were summed up, o multiplied with the collecting factor and the share of CH_4 in the generated gas. - recovered methane is substracted from total emissions	first order decay model	residual waste - amount of landfill-gas produced in the year of disposal and in the 30 years after disposal are taken into account. non residual waste - very hardly bio-degradable waste was not relevant.
Belgium	- first order decay model to take into account the various factors which influence the rate and extent of methane generation and release from landfill - the overall methodology follows the *Tier 2 IPCC* methodology (equation 5.1, IPCC GPG) $S_{P,Y} = Q_Y * DOC * k * C * \exp^{(-k * \Delta t)}$ where : $S_{P,Y}$ = biogas generation rate at year P (m^3) Q_Y = the quantity of waste disposed year Y (Mg) DOC = initial degradable organic carbon (kg/Mg) k = biodegradation rate constant (% / yr) C = % of DOC really degraded (%) Δt = the time since initial disposal (Y-P) (yr) - recovered methane is subtracted from total emissions	first order decay model according to IPCC approach (Tier 2)	the model assumes that : - the waste decomposes during 25 years - there is an aerobic period of 1 year with no methane production - the landfill gas contains 55 % of CH_4 and 45 % of CO_2 - there is a CH_4 oxidation in the upper layer (10 %) - the DOC reduction reflects the increased sorting of municipal waste - DOC, k, and C are constants which are defined for municipal and industrial waste

Member State	Methodology	Methodology based on	Specifications
Ireland	*LandGem (USEPA)* - simple first order decay equation which needs the following information: o the design capacity of the landfill, o the amount of refuse in place in the landfill, or the annual refuse acceptance rate for the landfill, o the methane generation rate (k), o the potential methane generation capacity (L_o), o the concentration of total non-methane organic compounds (NMOC) and speciated NMOC found in the landfill gas, o the years the landfill has been in operation, and o whether the landfill has been used for disposal of hazardous waste (co-disposal).	first order decay model	-
Netherlands	*TNO – First order model* - landfill gas formation in a certain amount of waste is assumed to decay exponentially in time $\alpha_t = \varsigma 1.87 A C_0 k_1 e^{-k_1 t}$ where: α_t = landfill gas formation at a certain time [m^3/yr] ς = dissimilation factor [-] A = amount of waste in place [Mg] C_o = amount of organic carbon in waste [kg/Mg waste] k_1 = model parameter first order model [yr^{-1}] t = time elapsed since depositing [yr] *Afvalzorg – Multi phase model* - takes into account typical fractions of slow, moderate and fast degadables $\alpha_t = \varsigma \sum_{j=1}^{3} 1.87 A C_{0,i} k_{1,i} e^{-k_{1,i} t}$ For both models: recoverd and oxidised methane is substracted from total emissions	first order decay model	- two models are available

Member State	Methodology	Methodology based on	Specifications
Portugal	- theoretical first-order kinetic model of methane production (*USEPA/LandGEM*) $Q_{CH4} = L_0 R (e^{-kc} - e^{-kt})$ where: Q_{CH4} = methane generation rate at time t, m^3/yr L_0 = methane generation potential, m^3 CH_4/Mg of refuse R = average annual refuse acceptance rate during active life, Mg/yr e = base log, no units k = methane generation rate constant, yr^{-1} c = time since landfill closure, years (c = 0 for active landfills) t = time since the initial refuse placement, yr - from methane generation rate in m^3/yr two different methods lead to methane mass emissions	first order decay model	- model was designed to estimate landfill gas generation and not landfill gas emissions
United Kingdom	*GasSimLite, Realease 1.01* - multi-phase, first order decay equation $C_t = C_0 - (C_{0,1}e^{(-k_1 t)} + C_{0,2}e^{(-k_2 t)} + C_{0,3}e^{(-k_3 t)})$ And $C_x = C_t - C_{t-1}$ where: C_t = mass of degradable carbon degraded up to time t (Mg) C_0 = mass of degradable carbon at time t = 0 (Mg) $C_{o,i}$ = mass of degradable carbon at time t = 0 in each fraction (1, 2, 3, rapidly, moderately and slowly degradable fractions respectively) (Mg) C_x = mass of carbon degraded in year t (Mg) t = time between waste emplacement and LFG generation (yrs) k_i = degradation rate constant for each fraction of degradable carbon (per yr)	first order decay model	- calculates the landfill gas generation rate for bulk gases (CH_4, CO_2, H_2) using the waste quantity, breakdown/ composition, the rate of decay, moisture content and the emission ratio of CH_4 to CO_2; - deals with the three degradable fractions separately and aggregates the amount of carbon converted to landfill gas

Member State	Methodology	Methodology based on	Specifications
France	*Ademe* - step by step approach which distinguishes between different cases of available or not available site data - takes into account typical fractions of slow, moderate and fast degradables and four different age categories - multiplication of the amount of waste (Mg/yr) during a special time period depending of the age of the waste with a specific factor for the methane production (m^3/Mg) for this age - summation of the methane production of the time periods - recovered methane is subtracted from total emissions	first order model or estimated from measured flow of landfill gas	- tool is not mandatory - instead of using a mathematically model it is preferable to use site data - tool distinguishes between cells for which data (measurements) of gas flows and CH_4 content are available or not
Germany	- adaption of *IPCC tier 1-approach and elements of tier 2-approach* for the estimation of CH_4 emissions from landfill sites $ME = M * DOC * DOC_F * F * D * C$ where: ME: methane emission (Mg/a) M: amount of the annual dumped waste relevant for gas production (domestic waste, unconditioned residential waste or similar waste) DOC: fraction of biological degradable carbon in the waste (Mg C per Mg waste) DOC_f: fraction of the carbon which is transformed into landfill gas under landfill conditions F: factor for calculation of carbon transferred into methane D: fraction of the not gathered or biological oxidized methane C: methane concentration in the landfill gas	model according to IPCC approach (Tier 1)	- only landfills with domestic and residential waste - CO_2 emissions below threshold value - only landfills which are still under deposition - regarding waste deposited during the last 10 years - three categories for the fraction of the not gathered or biological oxidized methane - contains elements of Tier 2 approach

4 Comparison of methane emission models to methane emission measurements by the Netherlands

The paper submitted by the Netherlands [JACOBS, SCHARFF] draws a comparison of methane emission models and emission measurement techniques. Data of an exemplary landfill were taken into account to attempt to tackle the problem. In order to calculate the methane emission of this landfill, 6 different models were used in the case study:

1. First order model Netherlands (TNO)
2. Multi phase model Netherlands (Afvalzorg)
3. GasSim (Environment Agency UK and Golder Associates) including
   3.a) Multi phase
   3.b) LandGEM
4. EPER Model France (Ademe)
5. EPER Model Germany (Federal Environmental Agency (UBA) and State Institute for Environmental Protection Baden-Württemberg)
6. LandGEM (US EPA)

The results calculated by the 6 models for the exemplary landfill reveal a more or less wide variation shown in Table 2.

Table 2: CH_4 emissions prognoses for exemplary landfill obtained by type of model

Model		Methane emission prognosis ($m^3CH_4*h^{-1}$)
First order		853
Multi phase		483
GasSim	Multi phase	883
	LandGEM	2765
EPER France		192
EPER Germany		375
LandGEM (US EPA)		4760

These results were compared with the results of 5 different measurement techniques determined in another project. For the exemplary landfill the average measured emission was 515 $m^3CH_4*h^{-1}$. Comparing this value with the modelled values the first order (TNO), GasSim multi phase, the LandGEM and LandGEM US EPA model seem to overestimate the emission rate. The multi phase (Afvalzorg), German EPER and French EPER seem to have a tendency to underestimate the emission rate whereas the multi phase model (Afvalzorg) shows the smallest deviation to the measured emission.

In conclusion, no recommendation for one preferable model was given because the comparison is based on one single landfill site which is probably not representative. For other landfills with different waste, composition results may be inaccurate.

5 Results of the first EPER reporting

For the first EPER reporting EU-wide 813 facilities according to activity 5.3/5.4 *Installations for the disposal of nonhazardous waste (>50t/d) and landfills (>10t/d)* reported methane emissions. Germany

and United Kingdom were the two Member States with the most facilities (301 and 291 respectively). The variation of number of facilities is wide between Member States (see Table 3). Even regarding the total amount of emissions the landfills of Germany and United Kingdom belong to the three highest emitters. However, Italy shows the highest value of methane emissions from landfills in EU.

Table 3: Number of facilities for activity 5.3/5.4 with methane emission

5.3/5.4 Installations for the disposal of nonhazardous waste (>50t/d) and landfills (>10t/d)				
Area	**Number of facilities**	**Share of facilities in EU**	**Methane emission [kg/a]**	**Share of emission in EU**
Austria	31	3,8%	34.068.000	1,7%
Belgium	4	0,5%	10.679.000	0,5%
Denmark	0	0,0%	-	0,0%
Finland	15	1,8%	16.400.000	0,8%
France	28	3,4%	20.932.000	1,0%
Germany	301	37,0%	493.592.000	24,6%
Greece	0	0,0%	-	0,0%
Hungary	0	0,0%	-	0,0%
Ireland	48	5,9%	67.377.000	3,4%
Italy	51	6,3%	702.206.000	35,0%
Luxembourg	2	0,2%	2.745.000	0,1%
Netherlands	0	0,0%	-	0,0%
Portugal	4	0,5%	16.884.000	0,8%
Spain	37	4,6%	65.739.000	3,3%
Sweden	1	0,1%	2.300.000	0,1%
United Kingdom	291	35,8%	574.180.000	28,6%
EU	813	100%	2.007.102.000	100%

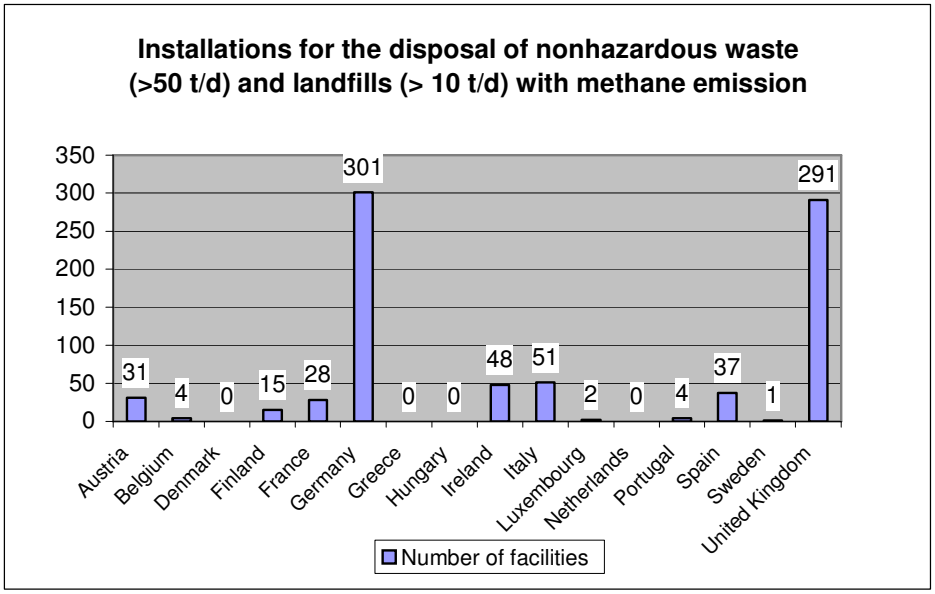

Figure 1: Number of facilities for activity 5.3/5.4 with methane emission per Member State

Concerning other emissions to air several additional pollutants are reported. But compared to methane which is reported by 12 Member States, the number of Member States which reported these pollutants

is much lower (see Table 4). Only carbon dioxide and nitrogen oxides were reported by more than one or two Member States.

Table 4: Number of emission reports per pollutant emitted to air for activity 5.3/5.4

Emission to Air	Number of Member States
Ammonia	1
Arsenic and its compounds	1
Cadmium and its compounds	1
Carbon dioxide, CO_2	4
Carbon monoxide, CO	2
Chlorine and inorganic compounds (as HCl)	2
Chromium and its compounds	1
Copper and its compounds	1
Dinitrogenoxide (N_2O)	2
Dioxines and furans (PCDDs and PCDFs)	1
Hydrofluorocarbons	1
Mercury and its compounds	2
Methane, CH_4	12
Nickel and its compounds	2
Nitrogen oxides, NO_x	5
Non methane volatile organic compounds (NMVOC)	2
PM10	2
Sulphur hexafluoride	1
Sulphur oxides (SO_x)	2
Zinc and its compounds	1

6 Conclusion

In order to determine diffuse methane emissions from landfill sites for EPER Member States used different models. Most of the determination models are based upon a first order decay. However, necessary modelling parameters differ systematically and cannot be compared directly.

A study from the Netherlands comparing several methane emission determination models with measurement results of an exemplary landfill revealed a certain range of results. While the results of 4 models differ less than a factor of 2 from an average measured value, three models lead to bigger variations. To gain more representative results the models should be compared for more than one landfill.

7 List of References

BAUMELER, BRUNNER, FEHRINGER, KISLIAKOVA, SCHAMAYER: Reduktion von Treibhausgasen durch Optimierung der Abfallwirtschaft (CH_4). Schriftenreihe der Energieforschungsgemeinschaft im Verband der E-Werke Österreichs; Wien 1998

JACOBS, J.; SCHARFF, H.: Comparison of methane emission models to methane emission measurements. NV Afvalzorg