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Environmental outlooks: municipal waste

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Context

The Topic Centre has prepared this working paper for the European Environment Agency (EEA) under its 2006 work programmes as a contribution to the EEA's work on environmental outlooks.

Disclaimer

This **ETC/RWM working paper** has not been subjected to European Environment Agency (EEA) member country review. Please note that the contents of the working paper do not necessarily reflect the views of the EEA.

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Executive summary

This paper presents the ETC/RWM project, *Environmental outlooks*, which estimates waste generation in the EU for the years 2005-2020 and the associated environmental pressures from the management of this waste.

The projections of municipal waste that were published in the ETC/RWM Working paper 2005/1 used as explanatory variables the number of households, population and final private consumption. In the projection presented in this paper, the primary explanatory variable is either the total final private consumption or three sub-categories of final private consumption, namely food, beverages, and clothing. The economic baseline from which the projected socio-economic variables are drawn is developed for DG TREN, and provides an EU-25 energy and transport reference case to 2030.

Generation of municipal waste in the EU-25 is projected to increase by 25% by 2020. However, large differences exist between countries and between the 'old' and 'new' Member States. In the EU-15, the generation of municipal waste is projected to increase by approx. 22% by 2020 compared to 2005. Except for a few countries (the Netherlands and Luxembourg), the projected increase in the generated waste for the individual countries ranges between 12% and 33% by 2020. Waste generation in the 10 'new' EU Member States is projected to grow faster than the EU-15, and increase by 50% from 2005 to 2020. However, the variations between countries are also significant. Slovenia is expected to have a considerably lower growth (5%) than Poland, the Czech Republic, Hungary, and Malta who all have a projected growth of more than 60% in 2020 compared to 2005. Another important observation is that the new EU-10 generates less than 10% of the waste generated in the EU-25, and this rate has been decreasing since 1995.

This also implies that a relative decoupling of waste generation from both GDP and final private consumption expenditure may be expected for the EU-15 and EU-10 as a whole. Between 2005 and 2020, the GDP is expected to grow by 35% in the EU-15 and by 75% in the EU-10. Due to variations in the projected national waste generation and economic development, the degree of the decoupling may vary.

In the EU-25, landfill of municipal waste fell from 64% in 1995 to 45% in 2004. As incineration only rose from 15% to 18% in the period, recycling and other recovery operations must have increased by around 16 percentage points. These trends are in part the result of dedicated policies to increase recycling and recovery of packaging waste (the Packaging Directive of 1994) and to divert particularly biodegradable waste from landfill (the Landfill Directive of 1999). It is projected that the decrease in landfilling will continue but also that the growth in waste generation may be so high that it offsets this decrease.

The estimation of greenhouse gases from waste management shows that the direct emissions from landfill first will decrease and then stabilise till 2020, while the direct emissions from incineration and material recovery will increase. Further reductions of greenhouse gases from landfills are foreseen, since from 2009 all landfills in the EU that accept biodegradable waste have to be equipped with methane emission reduction systems following Annex 1 of the Landfill Directive. The extent of the reduction is difficult to estimate because the Landfill Directive does not provide standards or capture targets for such methane emission reduction systems.

The results presented allow a quantification of the time delay between the introduction of waste policies and the effects on greenhouse gases from waste management. Recycling and incineration have no time-lag, while the time-lag for landfilling is estimated in the order of 10-15 years with existing methane capture and reduction technologies.

One of the strengths of the model for greenhouse gas estimations presented here is its consistency across the 25 EU Member States. The methodology is the same (a modification of the IPCC methodology), and it has a consistent data origin (NIR and Eurostat data). Consistent assumptions have also be made to correct for national assumptions that deviate from the IPCC recommendations, such as the assumed maximum gas recovery rate of 20% of methane from landfills. This percentage is considered by IPCC experts a maximum technically achievable recovery rate, and has been used, regardless of the values reported by countries in their NIR and CRF.

Moreover, the estimations modify slightly the IPCC are based by introducing carbon massbalances as quality assurance test for the estimated emissions.

There are numerous aspects to be improved. It is for instance important to stress that the indirect emissions from the waste sector are not yet accounted for. Indirect emissions are for instance savings of CO_2 emissions in other sectors, such as energy production as a consequence of increasing incineration with energy recovery, and manufacturing virgin materials as a consequence of increasing recycling. Indirect greenhouse gas emissions are necessary in order to get a complete picture of these emissions from the waste sector, and are therefore to be included soon in the calculations.

1. Introduction

The EEA's contribution to policy-making in the field of waste and resource management will be further developed by increasingly focusing work on analysing future trends rather than past historical developments. This implies a greater emphasis on modelling of future waste generation and material flows.

Decoupling of environmental pressures and economic growth is one of the overall aims of the Sixth Environmental Action Programme. More specifically, the programme aims at breaking the linkages between economic growth and resource use. For waste the objective is to achieve a significant, overall reduction in the volumes of waste generated. Apart from these relatively general objectives, no quantitative reduction targets have been set at EU level.

In 2002, the development of a macro-level model on prospective analysis began. As a first priority, the work concentrated on developing a model in order to provide an assessment of the likely, future trends of selected waste quantities and material flows. In 2005, the projections were published in the European Environment Outlook, and the methodology was further presented in an ETC/RWM Working Paper.

The work was taken a step further in 2005 with the aim of projecting the output of a climate change indicator from management of municipal waste for the EU-25. The indicator chosen was methane production from municipal waste in landfills. The IPCC Guidelines describe in detail how to model greenhouse gas emissions from waste management (composting, incineration, landfilling), and are the point of departure for the reporting of countries to the UNFCCC. In order to estimate the climate change indicator, an environmental model has been developed (in a series of interlinked Excel workbooks).

An external, peer review of the waste and material flows model was undertaken in 2005, which resulted in a re-estimation of the model parameters for a number of waste streams. Due to the difference in modelling (explanatory variables), the 2005-projections showed a slower growth in municipal waste in the New EU-10, Bulgaria, Romania and EEA2 than in EU-15, which was questionable as economic growth is expected to be larger in the New EU-10, Bulgaria and Romania. As a consequence, the model assumptions were reassessed in 2006. Moreover, several model parameters have been re-estimated due to new data on municipal waste, paper and packaging.

In particular, new data on municipal waste published by Eurostat is a complete set of Structural Indicators for municipal waste for the period 1995-2004 for all 27 Member States. When using these data, the main explanatory variable was changed and is now the final private consumption (or sub-categories hereof). In the 2005-projections different explanatory variables were applied for the 29 countries with the number of households as the main explanatory variable (and to some extent the population and final consumption).

In 2006, the environmental model for greenhouse gas emissions was extended to include modules on incineration and recycling of municipal solid waste, and all emissions were converted to CO_2 equivalents. Only direct emissions from these treatment activities are included so far.

To date, several activities have been initiated with a view to disseminate the results of the project to EEA Eionet member countries, the European Commission, waste management stakeholders and the scientific community.

In 2007, the environmental model will be further extended to include *indirect* emissions from recycling and incineration of municipal waste. Moreover, a quality control of the calculated emissions based on a carbon massbalance will be undertaken, and the model will also be expanded to include the two new Member States, Bulgaria and Romania..

Finally, as part of a new EEA/ETC study (7.2.5 Recycling society and its environmental effects) an environmental model for the management of construction and demolition waste will be developed, which is similar to the one for municipal waste.

2. Baseline scenario: economic outlook

The baseline scenario used in this context has been developed by the NTUA for the DG TREN, and provides an EU-25 energy and transport reference case to 2030. The baseline scenario represents current trends and policies as implemented in the Member States up to the end of 2004, (CEC 2006).

The key economic and demographic assumptions for the baseline scenario are presented in Table 2.1.

Table 2.1. Baseline scenario: key assumptions

						Annual % change			
EU25	**1990**	**2000**	**2010**	**2020**	**2030**	**'90-'00**	**'00-'10**	**'10-'20**	**'20-'30**
Population (Million)	440.8	452.9	464.1	469.3	469.4	0.3	0.2	0.1	0.0
Average household size (persons)	2.6	2.4	2.3	2.1	2.0	-0.8	-0.8	-0.6	-0.5
Gross Domestic product (*)	7294.7	8947.0	10946.8	13656.3	16051.4	2.1	2.0	2.2	1.6
Households expenditure (*)	4254.7	5192.0	6327.8	7822.6	9163.7	2.0	2.0	2.1	1.6
Gross Value Added (*)	6796.9	8332.2	10230.4	12785.3	15009.0	2.1	2.1	2.3	1.6
EU15									
Population (Million)	365.7	378.1	390.7	397.5	398.7	0.3	0.3	0.2	0.0
Average household size (persons)	2.6	2.4	2.2	2.1	2.0	-0.8	-0.7	-0.7	-0.5
Gross Domestic product (*)	6981.9	8572.2	10391.5	12835.7	14948.8	2.1	1.9	2.1	1.5
Households expenditure (*)	4074.3	4972.5	5997.3	7329.2	8496.5	2.0	1.9	2.0	1.5
Gross Value Added (*)	6517.5	8001.9	9742.6	12065.2	14042.0	2.1	2.0	2.2	1.5
New EU-10									
Population (Million)	75.0	74.9	73.4	71.8	70.6	0.0	-0.2	-0.2	-0.2
Average household size (persons)	2.9	2.7	2.4	2.3	2.3	-0.9	-0.8	-0.4	-0.3
Gross Domestic product (*)	312.8	374.8	555.3	820.6	1102.7	1.8	4.0	4.0	3.0
Households expenditure (*)	180.4	219.5	330.4	493.4	667.2	2.0	4.2	4.1	3.1
Gross Value Added (*)	279.4	330.3	487.9	720.0	966.9	1.7	4.0	4.0	3.0

Note: * = billion EUR in 2000-prices.
Source: CEC (2006)

During the period 2005 to 2030 the population in the New EU-10 is expected to decrease by 5 million, and increase by 20 million in the EU-15. During this period, there will also be a decrease in the average household size throughout the EU-25, while the number of households will increase.

The baseline scenario assumes an average, annual GDP growth from 2000 to 2030 of 1.9% for the EU-15, and 3.7% for the New EU-10, (CEC 2006). The average for the EU-25 is 2% p.a. In comparison, the baseline scenario from 2003 assumed an average, annual growth rate of 2.3 % for the EU-15 and 3.5 % for the New EU-10, (Mantzos and Zeka-Paschou 2002). Hence, in light of the modest economic development in recent years, the anticipated growth in GDP for the EU-15 has been adjusted downwards. At the same time the anticipated growth in the New EU-10 has been adjusted upwards.

The growth in private final consumption is projected to be slightly lower than the GDP growth in the EU-15, while the reverse is true for the New EU-10.

3. Quantities of municipal waste: the baseline projection

3.1. The projection model

The use of resources and generation of waste relate to a number of economic activities, and different economic activities generate different streams and quantities of resources and waste. Looking at past developments in such streams, economic activities and the size of population, links between amounts of resources/waste, economic activities and population are analysed. If the links have been reliable in the past, given forecasts of economic activities and the population, the links may be used for the generation of projections/scenarios for the development in the use of resources and the amounts of waste.

Mathematically, the general equation tested on past observations is:

$$\log(w_i) = a_{0i} + a_{1i} \cdot (s_i \cdot \log(A1_i) + (1 - s_i) \cdot \log(A2_i)) + a_{2i} \cdot \log(pop) + a_{3i} \cdot T + d \cdot Dummy$$

Eq. (1)

where w_i is the amount of waste (or resources) of waste stream (or resource) *i*, $A1_i$ and $A2_i$ are two different economic activities, e.g., the private consumption of categories of goods or the production within various branches, pop is the size of the population and T is time. T is included in the equation to catch trend-wise changes in the amount of waste. Such trends may occur due to structural changes, i.e. changes in the relative size of waste generating activities, or changes in the waste collection systems, what is included in the individual waste streams and how much of the waste generated is collected. Past trends may be extended into projections. However, large historical trends are not likely to continue in the long run. If they are to continue, this requires some specific explanation. Therefore, the module includes a possibility to phase out the trend over a specified period. Finally, the equation includes a dummy-variable that is zero in some years and one in other years. Dummy-variables may be included to correct for data breaks or outlayers.

The parameters $s_i, a_{0i}, a_{1i}, a_{2i}$ *and* a_{3i} are estimated on past observations. Interpreting parameters, s_i is the share of waste stream *i* linked to the economic activity $A1_i$, and $(1 - s_i)$ is the share linked to activity $A2_i$, i.e., s_i is a figure between 0 and 1. If it is known what share of the waste stream is related to activity $A1_i$, s_i may be restricted to this value. If time series for the share are available the two equations relating the waste streams to $A1_i$ and $A2_i$, respectively might be formulated. However, if the share is not known, but only that the waste stream is related to two activities, the aggregated data for the waste stream are used to estimate s_i. Restricting s_i to either 1 or 0 implies that the waste stream is only linked to one economic activity, and Eq. (1) reduces to Eq. (2). The parameter a_{1i} is the elasticity of waste stream *i* with respect to the activity level, i.e., if the activity level increases by 1%, the amount of waste increases by $a_{1i}\%$. a_{i2} is the elasticity with respect to changes in the population and a_{i3} is a trend-wise annual change in the amount of waste.

$$\log(w_i) = a_{0i} + a_{1i} \cdot \log(A_i) + a_{2i} \cdot \log(pop) + a_{3i} \cdot T + d \cdot Dummy \qquad \text{Eq. (2)}$$

Equations (1) and (2) contain two sets of level variables $A1_i, A2_i$ and pop. Reasonable free estimations of parameters to both sets of variables are difficult to obtain and not easy to interpret. Therefore, in order to estimate Eq. (1) or Eq. (2), a number of parameter restrictions are imposed. However, the equation is formulated in the module as Eq. (1) and the parameter values (restricted or not) are specified in an input sheet.

Assuming that $a_{1i} = 1.0$ Eq. (2) reduces to:

$$\log\left({w_i}/{A_i} \right) = a_{0i} + a_{2i} \cdot \log(pop) + a_{3i} \cdot T + d \cdot Dummy \qquad \text{Eq. (3)}$$

i.e., the waste coefficient depends on the size of population and time.

Assuming $a_{2i} = 1.0$ Eq. (2) reduces to:

$$\log\left({w_i}/{pop} \right) = a_{0i} + a_{1i} \cdot \log(A_i) + a_{3i} \cdot T + d \cdot Dummy$$

i.e., the waste per inhabitant depends on the level of activity and time. This may be somewhat difficult to interpret. An easier equation to interpret is that the waste per inhabitant depends on the activity level per inhabitant and time. To obtain this formulation, the parameter restriction on Eq. (2) is $a_{2i} = 1.0 - a_{1i}$ and Eq. (2) reduces to:

$$\log\left({w_i}/{pop} \right) = a_{0i} + a_{1i} \cdot \log\left({A_i}/{pop} \right) + a_{3i} \cdot T + d \cdot Dummy \qquad \text{Eq. (4)}$$

Furthermore, imposing the restriction $a_{2i} = 0.0$ on Eq. (3), or $a_{1i} = 0.0$ on Eq. (4) and leaving out dummy-variables, the equations reduce to an annual change in the waste coefficient, or in the amount of waste per inhabitant:

$$\log\left({w_i}/{A_i} \right) = a_{0i} + a_{3i} \cdot T \qquad \text{or} \qquad \log\left({w_i}/{pop} \right) = a_{0i} + a_{3i} \cdot T \qquad \text{Eq. (5)}$$

Taking first differences in Eq. (5), it is seen that a_{3i} is the annual % change in the waste coefficient, or in the amount of waste per inhabitant:

$$\Delta \log\left({w_i}/{A_i} \right) \quad or \quad \Delta \log\left({w_i}/{pop} \right) = a_{3i}$$

i.e., if $a_{3i} = 0.02$, the waste coefficient, or amount of waste per inhabitant increases by 2% p.a.

Finally, if $a_{3i} = 0.0$ in Eq. (5), the equation reduces to assuming a constant waste coefficient, or amount of waste per inhabitant:

$$\log\left({w_i}/{A_i} \right) \quad or \quad \log\left({w_i}/{pop} \right) = a_{0i} \qquad \text{Eq. (6)}$$

If a_{0i} is estimated on past values, it represents the average waste coefficient or amount of waste per inhabitant. An alternative is to set a_{0i} equal to the value in the last observable year. This may be preferable if it is evaluated that the quality of waste data has improved over time, or that the most recent value best mirrors the future waste coefficient.

Testing the various specifications, Eq. 1 is, in general, estimated imposing the parameter restrictions given in Table 3.1. However, the inclusion of one or two activity variables is mainly decided from a priory consideration, i.e., for most of the waste streams, s_i is priory restricted to one or zero. Free estimation of s_i is tested only for waste streams linked both to private consumption categories and to the production within sectors. In the module (and in the following pages), the variable $A1_i$ is the private consumption, or some categories thereof, and $A2_i$ is the gross value added within some sectors. That is, if a waste stream is linked to private consumption, only, s_i is restricted to one and if a waste stream is linked to gross value added in some sectors, s_i is restricted to zero.

A general problem with modelling streams of waste is the limited number of historical observations. Given few historical observations, the number of parameters that may be freely estimated is also limited, and for a number of waste streams, this also limits the number of equations tested.

Table 3.1. Combinations of parameter restrictions in Eq. (1)

Equation \ parameter	s_i	a_0	a_1	a_2	a_3
eq. (1)	free	free	free	free	free
eq. (2)	1.0	free	free	free	free
eq. (3)	1.0	free	1.0	free	free
eq. (4)	1.0	free	free	$1-a_1$	free
eq. (4) alternative	1.0	free	free	$1-a_1$	0.0
eq. (5) activity	1.0	free	1.0	0.0	free
eq. (5) population	1.0	free	0.0	1.0	free
eq. (6) activity	1.0	free	1.0	0.0	0.0
eq. (6) population	1.0	free	0.0	1.0	0.0

In general, dummy variables are defined to be zero in projections, but may in the module be used for including exogenous evaluated changes in specific waste streams. If a dummy variable becomes one in the projection and the coefficient to this is 0.02, the waste stream increases by 2% in the year the dummy variable changes from zero to one.

3.1.1. Forecast methodology

In analyses of past developments, the activity variables are taken from Eurostat, and the baseline scenario is used in forecasts. However, the two sets of data have different classifications and base-years. The Eurostat data are in constant 1995-prices and the baseline scenario is in constant 2000-prices. Two sets of activity data are used: household consumption expenditure by category of goods and Gross Value Added by sectors.

Forecast of Household Consumption Expenditure
The baseline scenario only forecasts total private consumption expenditure. But in the development analyses of the amount of waste, for some waste streams, the amount is linked to the consumption of categories of goods, e.g., municipal waste is linked to the consumption of food, beverage and clothing.

To forecast categories of private consumption, the share of the category in total private consumption is simply calculated and it is assumed that past trends in shares continue in the future, i.e.:
Share of category *f* at time *t*: $Sf_t = Cf_t / Ct_t$

Average change in share of *f* in the observation period $Apf = \sqrt[n]{Sf_t / Sf_{(t-n)}}$

Future share of *f*: $Sf_{t+1} = Sf_t \cdot Apf$

Future consumption of *f*: $Cf_{t+n} = Ct_{t+n} \cdot Sf_{t+n}$

where Cf_t is the consumption of category *f*, Ct_t is total private consumption and Apf is the average annual change in this past share.

This is a very simple way to generate forecasts of categories of private consumption, not taking into account differences in income and price elasticities of the different categories of private consumption. However, with only forecasts of total private consumption, and lack of a demand system, simple alternatives are difficult to find.

The problem of different price base-years in the historical data and the Baseline scenario is solved by transforming the Baseline scenario into 1995-prices using the 1995-values in the two base-year calculations, i.e., the ratio:

$$Ct_{1995(Eurostat)} / Ct_{1995\,(DG-TREN-baseline)}$$

Using this for the calculation of consumption by categories of goods, it is implicitly assumed that the development in prices for each category of goods is equal to the price development for the total private consumption.

The categories of final consumption expenditure of households by consumption purpose (COICOP 2-digit) used for the projection of municipal waste are:

fcps	Total final consumption expenditure
fcp01	Food and non-alcoholic beverages
fcp02	Alcoholic beverages, tobacco and narcotics
fcp03	Clothing and footwear

Forecast of Production by sectors

The baseline scenario includes a sector classification that differs from the classification in Eurostat (b_a17_k) used for analyses of past developments. However, the following links may be established between the two classifications:

Eurostat b_a17_k	Code	LREM-baseline
Agriculture etc	a, b	Agriculture
Energy and mining	c, e	Energy
Manufacturing	e	Industry
Construction	f	Construction
Wholesale, Hotels, Transport	g, h, i	Trade
Finance, Real estade	j, k	Market services
Public administration	l, m, n, o, p	Non-market services

Concerning price-levels, the baseline scenario is translated to constant 1995-prices using the GVA-price in the two sources for 1995. Hereby, it is implicitly assumed that from 1995 to 2000, the price development in the individual branches was identical.

3.2. Model parameters for municipal waste

The projections from 2005 used mainly the number of households but also the population and the final private consumption as explanatory variables (Skovgaard et al. 2005). In the new, revised projection, the primary explanatory variable is the final private consumption or the three categories (food, beverages, and clothing). The model parameters are shown in Tables 3.2 and 3.3.

The trend-wise annual changes in the amount of waste, a_{i3}, are phased out after 5 years for all countries, except Bulgaria.

Table 3.2. Model parameters for municipal waste, EU-15

Country	Eq. no.	No of obs.	Act. Var.	a_0	a_1	a_2	a_3	s	d	R^2	DW
AT	Eq. 1	10	fcp01-fcp03	-4.080	1.127	-0.13	0.0212	1	-0.133	0.992	2.465
BE	Eq. 5	10	fcp01-fcp03	0.410	0	1	-0.0030	1	-0.050	0.794	2.938
DE	Eq. 1	11	fcps	-1.515	0.694	0.306	-0.0058	1	-0.081	0.921	2.826
DK	Eq. 5	11	fcp01-fcp03	-1.644	0	1	0.0198	1		0.904	1.823
ES	Eq. 5	9	fcp01-fcp03	-1.301	0	1	0.0193	1		0.020	1.220
FI	Eq. 5	10	fcp01-fcp03	-0.569	0	1	0.0057	1	0.098	0.863	1.000
FR	Eq. 5	10	fcp01-fcp03	-0.792	0	1	0.0105	1		0.995	1.779
GR	Eq. 2	9	fcp01-fcp03	-4.448	1	0	0.0265	1		0.946	0.818
IE	Eq. 5	10	fcp01-fcp03	-4.462	0	1	0.0408	1	-0.106	0.970	1.274
IT	Eq. 1	10	fcps	-1.946	0.571	0.429	0.0038	1	-0.015	0.975	2.164
LU	Eq. 2	10	fcps	-2.102	1	0	-0.0141	1		0.986	1.675
NL	Eq. 1	11	fcp01-fcp03	-1.385	0.988	0.013	0	1		0.951	1.941
PT	Eq. 1	9	fcp01-fcp03	-1.038	0.719	0.281	0	1	0.063	0.972	1.254
SE	Eq. 5	11	fcp01-fcp03	-1.883	0	1	0.0181	1		0.919	1.478
UK	Eq. 1	10	fcps	-0.975	0.393	0.607	0	1	-0.040	0.964	0.846

Table 3.3. Model parameters for municipal waste, New EU-10, Bulgaria, Romania and EEA2

Country	Eq. no	No of obs.	Act. Var.	a_0	a_1	a_2	a_3	s	d	R^2	DW
CY	Eq. 1	10	fcps	-1.824	0.663	0.337	0.000	1		0.908	1.352
CZ	Eq. 2	10	fcps	-0.914	1.000	0.000	-0.013	1	0.172	0.782	1.976
EE	Eq. 1	10	fcps	-0.173	0.559	0.441	-0.007	1	0.162	0.768	2.383
HU	Eq. 2	10	fcps	1.114	1.000	0.000	-0.026	1	0.037	0.558	1.434
LT	Eq. 1	10	fcps	1.419	0.367	0.633	-0.024	1	-0.075	0.901	2.349
LV	Eq. 1	9	fcps	-0.828	0.297	0.703	0.000	1	0.466	0.953	2.654
MT	Eq. 2	10	fcps	-7.868	1.000	0.000	0.053	1		0.994	1.183
PL	Eq. 2	10	fcps	1.781	1.000	0.000	-0.039	1	0.226	0.962	2.933
SI	Eq. 1	10	fcps	1.392	0.345	0.655	-0.028	1	0.276	0.975	2.911
SK	Eq. 2	7	fcps	3.361	1.000	0.000	-0.051	1	0.238	0.887	2.777
BG	Eq. 5	8		-0.554	0.000	1.000	-0.002	1	-0.204	0.809	1.322
RO	Eq. 1	4	fcps	-0.555	0.605	0.395	0.000	1		0.419	2.990
NO	Eq. 1	8	fcps	-2.262	0.676	0.324	0.000	1	0.071	0.534	1.101
CH	Eq. 5	6		-2.391	0.000	1.000	0.020			0.928	1.046

3.3. Data sources

The per capita municipal waste generation for the periods 1950-1994 and 2004-2020 are estimated on the basis of different assumptions. Data for the period 1995-2004 stem from Eurostat. The method of estimation or source of data is presented in Table 3.4.

Table 3.4. Generation of municipal waste, method of estimation and source of data

Period	Method	Comment/source
1950 - 1994	*For the model on estimation of environmental pressures from the management of waste (section 5):* Estimation of municipal waste per capita generation based on the development in GDP.	GDP, 1950-1960: data is based on information from the Eurostat New Cronos database. However, the UK is the only country with a complete set of data for this period. Thus, the UK annual growth in GDP is used to estimate the development in waste generation for the EU-15. For the New EU-10 and Bulgaria, Romania is assumed a constant growth of 1.5%. GDP, 1960-1994: data is based on information from the ‘annual macroeconomic database’ (AMECO) from the European Commission (hosted by DG ECFIN). For the New EU-10, Bulgaria and Romania data are only available from 1991, and as a result for the period 1961-1990 is assumed a constant growth of 1.5%. Population: Eurostat/UN
1980 - 1994	*For the waste and material flows model to project the generation of waste (section 3):* Econometric estimation of model parameters (Tables 3.2 and 3.3)	Generation of municipal waste: data reported from Member States to Eurostat. Data series are not complete (especially from 1980-1989), and for some countries data seem to be approximations. Private final consumption: Eurostat data Population: Eurostat/UN
1995 - 2004	Structural Indicators: Generation of municipal waste generation	Structural Indicators published by Eurostat Private final consumption and population: Eurostat data
2005 - 2030	Estimation of municipal waste generation per capita.	Projections of municipal waste (from the waste and material flows model). Private final consumption and population: DG TREN baseline scenario (CEC, 2006)

3.4. Waste generation, 2005-2030

The projected growth in the municipal waste generation in the 29 EEA member countries are presented in Tables 3.5 and 3.6.

In the EU-15, the generation of municipal waste is projected to increase by approx. 9% in 2010 compared to 2005, by 22% in 2020 and by 33% in 2030[1]. Except for a few countries (Austria, the Netherlands, Luxembourg and Portugal), the projected increase in waste generation is between 22% and 43%.

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[1] The annual growth rates are 1.6% p.a. till 2010; 1.4% till 2020 and 1.2% till 2030.

Waste generation in the New EU-10 is projected to grow faster than the EU-15, i.e. increase of 11% from 2005 to 2010, of 50% in 2020 and around 100% in 2030[2]. However, the variations between countries are significant. Slovenia and Latvia will have a considerably lower growth than Poland, the Czech Republic, Hungary, Malta and the Slovak Republic who all have a projected growth of more than 100% in 2030 compared to 2005.

Table 3.5. Projected growth in municipal waste generation in the EU-15, 2005-2030

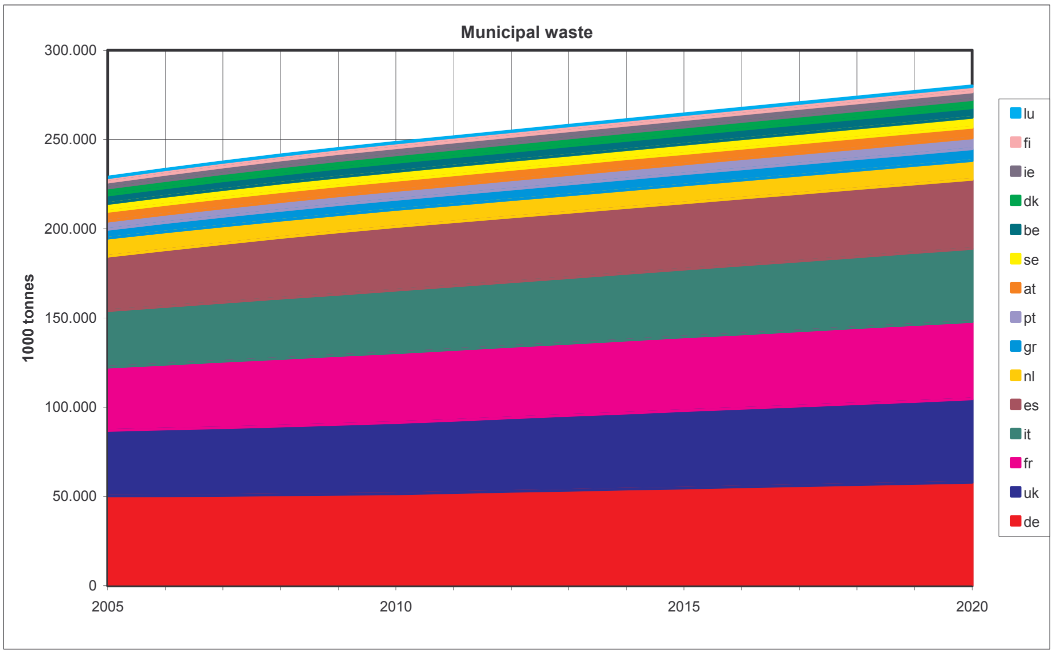
%	AT	BE	DE	DK	ES	FI	FR	GR	IE	IT	LU	NL	PT	SE	UK	EU-15
2005-10	7.0	6.6	2.5	9.0	17.0	6.5	10.6	15.7	18.2	10.4	13.7	-6.0	7.5	10.3	8.5	8.5
2005-20	12.1	15.1	15.2	16.4	27.0	16.5	22.7	33.1	30.1	29.0	72.4	3.7	31.4	22.3	27.1	22
2005-30	10.5	21.6	24.4	22.3	33.7	24.8	33.4	42.2	38.6	42.9	118.9	10.1	58.0	32.2	42.9	33

Table 3.6. Projected growth in municipal waste generation in the New EU-10, Bulgaria, Romania and EEA2, 2005-2030

%	CY	CZ	EE	HU	LT	LV	MT	PL	SI	SK	New EU-10	BG	RO	NO	CH
2005-10	13.0	13.7	14.1	15.9	7.4	6.8	22.0	7.9	-1.4	4.4	10	-5.9	19.4	8.5	10.3
2005-20	45.7	63.5	43.7	62.1	31.8	18.7	63.7	66.0	4.5	54.3	57	-15.4	56.4	28.6	35.4
2005-30	69.6	108.8	70.7	108.4	53.6	25.2	109.5	131.1	7.1	107.1	106	-24.3	93.3	47.5	65.9

The generation of municipal waste in the EU-15 from 2005 to 2020 is presented in Figure 3.1. From the figure it becomes evident that the five most populated countries produce the majority of waste in the EU-15, in fact about 80% of total generated waste arises in Germany, the United Kingdom, France, Italy and Spain.

Figure 3.1. Generation of municipal waste in the EU-15, 2005-2020



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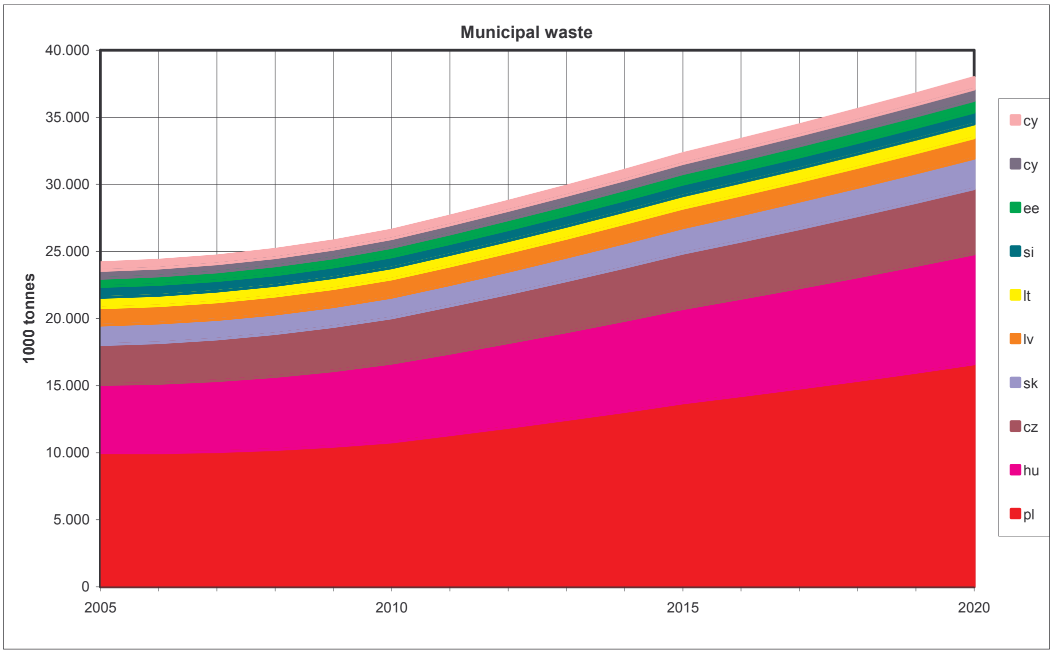
[2] The annual growth rates are 2% p.a. till 2010; and approx. 3% from 2005 to 2020, and 2005 to 2030, respectively.

A similar situation applies for the EU-10 where Poland and Hungary produces around 65% of the total waste generated in the New EU-10. As Poland and Hungary furthermore have a projected growth of 66% and 62% respectively between 2005 and 2020, the result is a rapidly growing curve as shown in Figure 3.2.

Figure 3.2. Generation of municipal waste in the New EU-10, 2005-2020

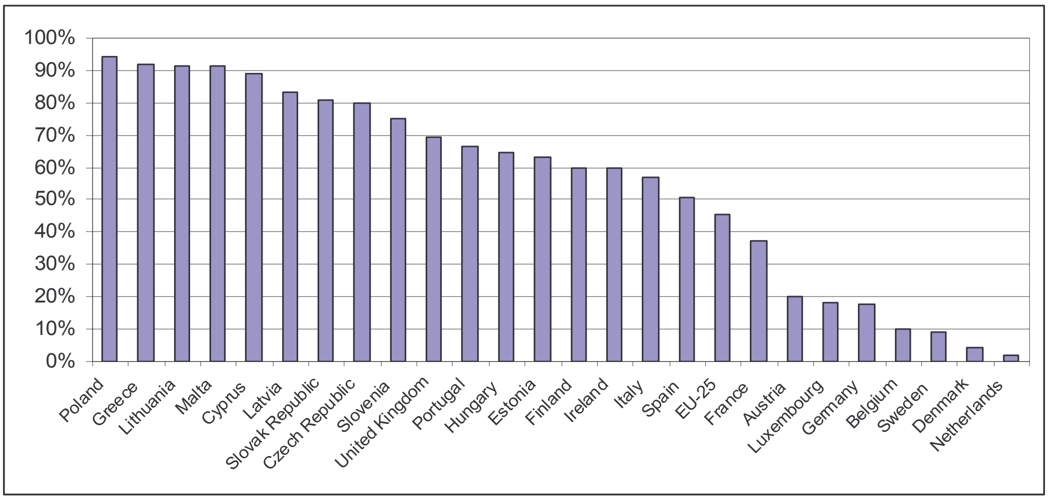


4. Management of municipal waste: the baseline projection

4.1. Management of municipal waste

Waste management practises vary greatly across the EU-25, although landfill of municipal waste is the predominant option. As shown in Figure 4.1, the majority of countries landfilled more than 60% of the generated municipal waste in 2004. In the EU-25, 45% of the generated amount of municipal waste was landfilled in 2004.

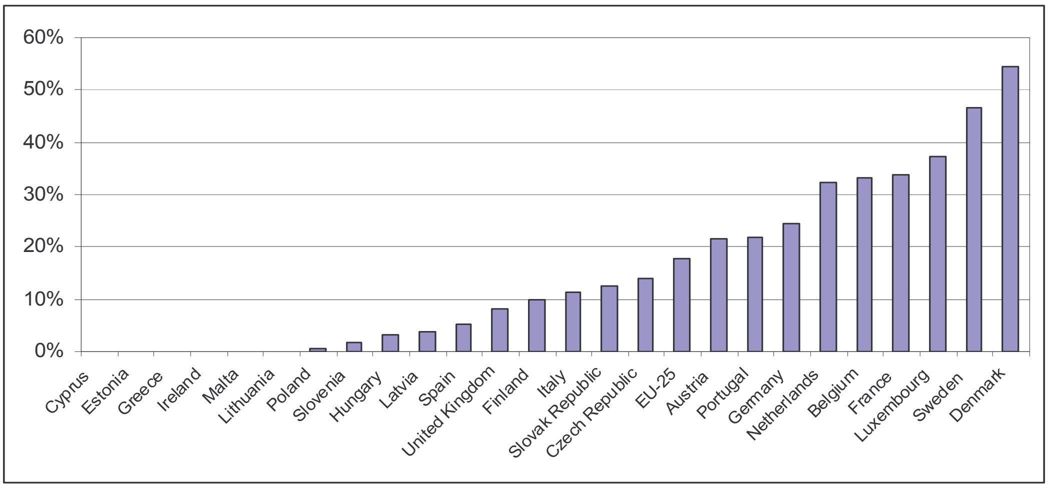
Figure 4.1. Landfill of municipal waste in the EU-25, 2004



Note: Calculated as landfilled waste over generated waste.
Source: Eurostat Structural Indicator data

An almost reverse picture can be shown for incineration, where 13 countries have either no incineration or incinerate less than 10% of the generated waste. The recent trends show an increase in the incineration of waste, one reason being the introduction of bans on the landfilling of certain waste streams. e.g. waste with organic contents. In 2004, 18% of the generated amount of waste was incinerated in the EU-25.

Figure 4.2. Incineration of municipal waste in the EU-25, 2004



Note: Calculated as incinerated waste over generated waste.
Source: Eurostat Structural Indicator data

4.1.1. Landfilling of municipal waste

In order to estimate the amount of municipal waste landfilled during the 70-year period 1950 to 2020, a series of assumptions has been made.

For the period 1950 to 1964, all generated municipal waste in the period is assumed to be landfilled. The estimate is a ´best estimate'. Between 1965 and 1995, linear interpolation is used to reach the rates of landfill that have been estimated using the structural indicator data from Eurostat in 1995. Between 1995-2004, Eurostat structural indicators for the generation and landfill have been used to estimate the rates of landfill. The rates of municipal waste landfilled are calculated as a shares of municipal waste generated. In a few cases, the landfill shares reported in NIR (1990 – 2003) are used instead.

The projected, future landfilling of municipal waste has been estimated under the assumption that in the countries where the Directive will have an effect[3], they will landfill the maximum amount of biodegradable municipal waste possible within the targets of the Directive. The countries where the Directive's targets on biodegradable waste are assumed not to have an effect, because targets are met already, will landfill biodegradable waste equal to the landfill rate in 1995[4]. In estimating the future management of municipal waste it is also attempted to take into account if a country has a four-year derogation from the Landfill Directive (cf. section 4.2), and the policy measures in place to divert waste from landfill. The residual waste (total projected generated municipal waste minus the biodegradable fraction) will be managed as it was in 2003.

The projections are also based on the assumption that most EU-15 and a few EU-10 Member States will meet the targets in reductions of biodegradable waste in landfill as required in the Landfill Directive. In 2004, the majority of new Member States landfilled more than 80% of the generated municipal waste, and some old Member States landfilled more than 60%. Hence, in order to reach the targets for the landfilling of biodegradable municipal waste in these countries, additional policy interventions will be necessary.

The rates of landfill applied in the baseline projection are presented in Annex III.

4.1.2. Incineration of municipal waste

The incineration rates have been estimated in a way similar to the landfilling of municipal waste.

For the period 1950 to 1964, incineration is assumed to be nil for all countries. Between 1965 and 1995, linear interpolation is used to arrive at the rates of incineration that have been estimated using the structural indicator data from Eurostat in 1995. Between 1995-2004, Eurostat structural indicators incineration have been applied. The rates of municipal waste incinerated are calculated as a shares of municipal waste generated. The assumptions regarding projections (2005-2020) are based on incineration plants planned or under construction.

It is assumed that the incineration is with energy recovery (relevant for the estimation of GHG emissions).

The rates of incineration applied in the baseline projection are presented in Annex III.

4.1.3. Material recovery of municipal waste

Material recovery is calculated as the residual of municipal waste generated minus municipal waste landfilled and incinerated. Hence, material recovery covers recycling, com-

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[3] Finland, Greece, Ireland, Italy, Portugal, Spain, and United Kingdom. France for 2016 only.

[4] 1995 is the reference year for the Landfill Directive.

posting, other types of recovery operations (except incineration with energy recovery) such as mechanical and biological treatment (MBT). For some countries, this residual results in unrealistic high recycling rates, and in these cases the recycling rate has been corrected downwards resulting in an upwards correction of the landfill rates.

4.2. Biodegradable municipal waste

The biodegradable fraction (organic waste, paper & cardboard, and textiles) makes up a considerable share of municipal waste, and with a few exceptions this fraction comprises some 60-70% of the generated municipal waste in countries. Hence, the amount of biodegradable municipal waste (BMW) landfilled is of major importance for the total amount of municipal waste landfilled.

The Landfill Directive[5] defines progressive targets for the diversion of BMW away from landfill. All targets are based on the historical quantity generated in 1995, or the latest year before 1995 for which standardised data are available. The main implication of this approach is that there is an absolute limit placed on the quantity of biodegradable municipal waste (in tonnes) that can be landfilled by the specific target dates. Thus, if BMW quantities continue to grow, increasing quantities will need to be diverted from landfill. The targets set out in the directive for the diversion of BMW from landfill are shown in Table 4.1.

Table 4.1. Targets for diversion of BMW from landfill

Year to achieve target	On the basis of biodegradable municipal waste generated in 1995[1], biodegradable municipal waste going to landfill must be reduced to:
16 July 2006	75 %
16 July 2009	50 %
16 July 2016	35 %

Note 1: Or the latest year before 1995 for which standardised Eurostat data are available.
Source: Council Directive 99/31/EC of 26 April on the Landfill of waste

A derogation of not more than four years for each of the targets (i.e. 2010, 2013 and 2020) is available for Member States which in 1995, or the latest year for which standardised Eurostat data are available, landfilled more than 80% of their collected municipal waste. Greece, the United Kingdom and Ireland (CEC 2005, DoEHLG 2006) will postpone attainment of the targets by four years. The same applies to the New EU-10, where it is assumed that all the new Member States will use the four-year derogation.

Since the amount of generated BMW in 1995 constitutes the reference, an increase in generation of BMW will per se induce stricter targets than the ones presented in Table 4.1.

The current status in the EU-15 for meeting the targets is presented in Figure 4.3. The figure shows the amount of BMW landfilled in 2003 compared to the generation of BMW in 1995. It becomes evident that Greece is far from meeting the 75% target even with the derogation to 2010. The UK and Ireland have initiated a wide range of measures and the full effect of these measures is not yet measurable. Portugal and Spain were landfilling 83% and 80% respectively, thus having some way to go still to meet the 75% target. Information for Belgium is not complete. The remaining Member States have already met the 2006-target and are well on the way to meeting the 2009 and 2016 targets.
The European Commission concludes that ‘Having analysed the [national] strategies [for the reduction of biodegradable waste going to landfills for the EU-15] it is unclear whether the landfill reduction targets will be achieved for those Member States where this

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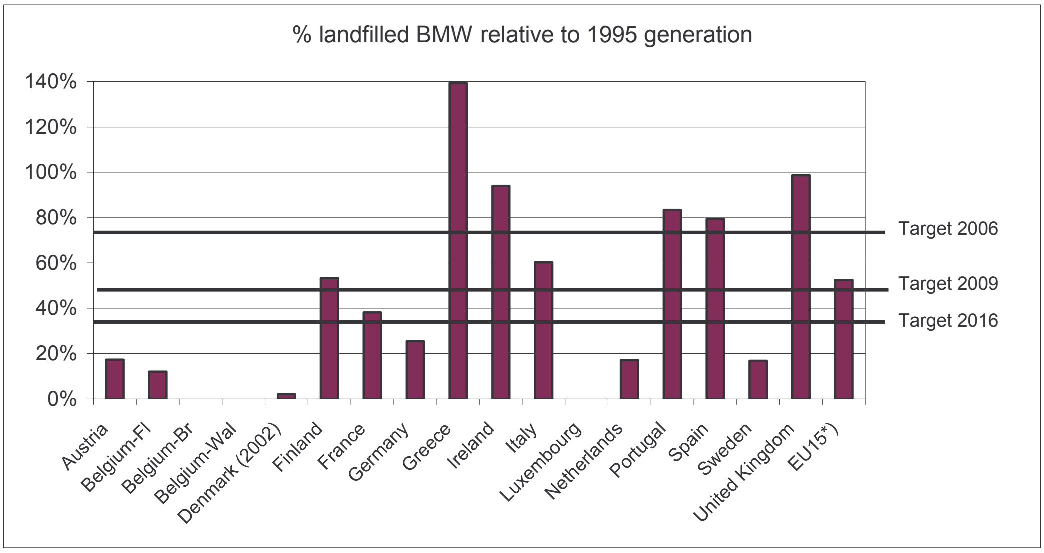
[5] Council Directive 1999/31/EC of 26 April 1999 on the Landfill of waste (OJ L 182, 16.7.99, p. 1)

is not already the case. It looks like additional efforts will be necessary to achieve the targets', (CEC 2005).

Figure 4.3. BMW distance to target, 2003



Note *): Excluding Luxembourg and the regions Wallonia and Brussels.
Source: CEC (2006).

5. Environmental pressures: the model

The following sections describe the methodology used to develop the environmental indicator, greenhouse gas (GHG) emissions from the treatment of municipal waste. In 2005, the first part of the model was built, consisting of the emissions of methane from landfills. Landfills are regarded by analysts on greenhouse gas inventories as the most complex of the waste sector. In 2006, the GHG model has been completed with carbon dioxide (CO_2), nitrous oxide (N_2O), methane (CH_4) emissions, and with all main waste management options (landfill, incineration, and recycling - including composting). Moreover, all emissions have been converted to CO_2 equivalents, so the figures can be compared. The so-called characterisation factors used for establishing these comparisons are presented in Table 5.1. The time horizon used is 100 years.

Table 5.1. Global Warming Potentials used for characterisation of greenhouse gas emissions

Species	Chemical formula	Lifetime (years)	Global Warming Potential (time horizon)		
			20 years	100 years	500 years
CO_2	CO_2	variable	1	1	1
Methane *	CH_4	12 ± 3	56	21	6.5
Nitrous oxide	N_2O	120	280	310	170

Note: * The GWP for methane includes indirect effects of tropospheric ozone production and stratospheric water vapour production.
Source: UNFCC (2006)

5.1. Selection of the environmental indicator: greenhouse gas emissions

The emission of greenhouse gasses from the waste sector in Europe has recently been characterised in Gugele et al. (2005 and 2006), using the data reported by the EU Member States to the UN Secretariat for Climate Change, as part of the countries' commitment to the United Nations Framework Convention on Climate Change (UNFCCC) and the Kyoto Protocol.

Since 1996, uniform data collection and estimation procedures have been proposed and regularly updated by an international expert group on emissions from waste at the Intergovernmental Panel on Climate Change. These procedures are the so-called 'IPCC Guidelines'. The last available version of the guidelines is from 2006 (IPCC, 2006).

The IPCC Guidelines describe in detail a methodology to model greenhouse gas emissions from waste management (composting, incineration, landfilling), and are the point of departure for the reporting of countries to the UNFCCC. Some countries use the method proposed in the IPCC guideline, and other countries have chosen to develop alternative, yet IPCC-compliant modelling methods that national experts believe match better national waste generation and management characteristics.

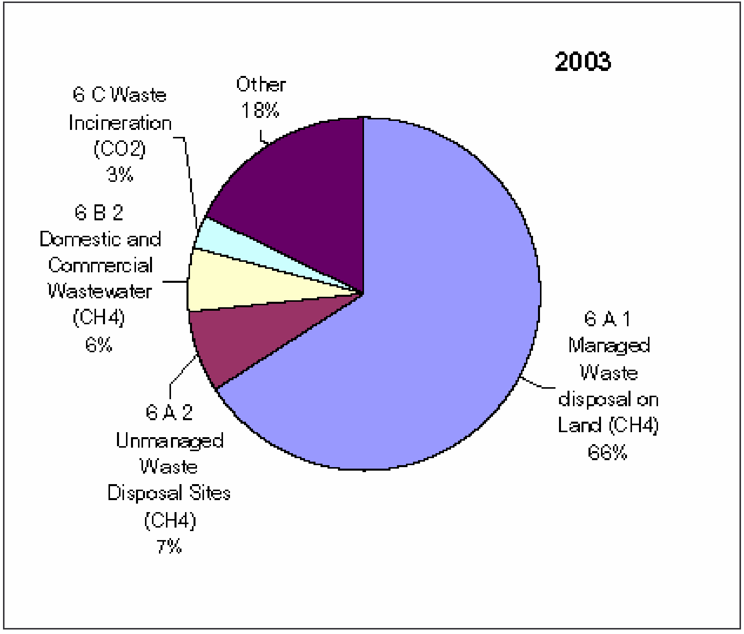
Using either the IPCC proposed method or national methods, all EU Member States report their estimates of greenhouse gas emissions from waste management yearly in to the UNFCCC in the form of the so-called National Inventory Reports (NIR) and a worksheet called Common Reporting Format (CRF).

The Member States' NIR and CRF submitted in 2005 are the main source of information for the outlooks. The information contained is produced by national experts, it is homogeneous, internationally accepted, and in most cases well documented. The information contained takes 1990 as the reference year, i.e., it provides in the best cases information for the period 1990-2005.

According to Gugele et al. (2005), the emissions from waste management contributed in 2004 to approx. 2.6% of the total greenhouse gas emissions in the EU-25. The total emissions from waste management have decreased by 33% from 141 million tonnes[6] CO_2-equivalents in 1990 to 97 million tonnes CO_2-equivalents despite an increase in waste generation in the same period, mostly as consequence of the implementation of national and EU policies oriented towards diversion of waste from landfill.

The greenhouse gases covered in the IPCC reporting are CO_2, N_2O, CH_4, and carbon monoxide (CO). The first three are the main contributors from the waste sector, since incomplete combustion, the main source of carbon monoxide, is not a main source from the waste sector. The conversion factors have been presented in Table 5.1. The key sources of greenhouse gas in waste management are illustrated in Figure 5.1 below.

Figure 5.1. Greenhouse gas emissions from the waste management sector in the EU-15, 2003



Source: Gugele et al., (2005)

Figure 5.1 shows that CH_4 emissions from landfills account for about 75 % of waste-related greenhouse gas emissions in the EU-15. Gugele et al. (2005) estimate that this percentage is larger in the New EU-10 due to larger use of landfilling for waste disposal in these countries compared to the EU-15.

In addition to CH_4, landfills also produce biogenic CO_2 and non-methane volatile organic compounds (NMVOCs) as well as smaller amounts of N_2O, NO_x and CO. Decomposition of organic material derived from biomass sources (e.g. crops, wood) is the primary source of CO_2 released from waste. These CO_2 emissions are not included in national inventories, because the carbon is of biogenic origin and it is therefore assumed that they stem from uptake of atmospheric CO_2.

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[6] In the context of Greenhouse Gas Inventory publications, e.g. IPCC Guidelines, the International System is used, and therefore 1 tonne will be 1Mg (M, Mega=10^6), 1000 tonnes will be 1Gg (G, Giga= 10^9), and 1 million tonnes will be 1Tg (T, Tera, 10^{12}).

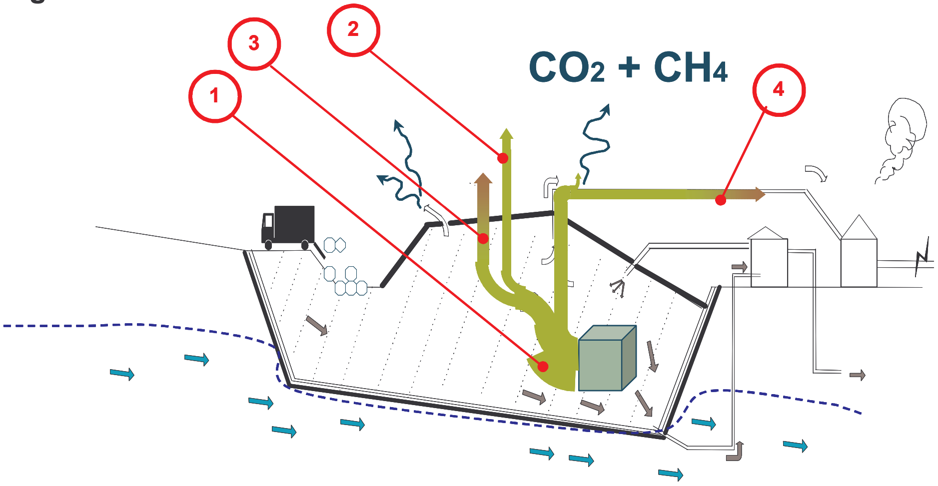
5.2. The model for estimating environmental pressures from waste management

In the model developed here and in contrast to common GHG inventories, all carbon inputs and outputs are registered, be these biogenic or anthropogenic. In order to ensure this, the model is based on a carbon massbalance. In a landfill, for instance, one can distinguish four sources of carbon emissions:

1. Direct emission of CO_2 from anaerobic biodegradation
2. Direct emission of CH_4 from anaerobic biodegradation
3. Emission of CO_2 from CH_4 oxidised in the top layers
4. Emission of CO_2 from recovered CH_4 which is oxidised by flaring (with or without energy generation).

These four sources are illustrated in Figure 5.2.

Figure 5.2. Sources of carbon emissions in a landfill



Source: ETC/RWM compilation

No methodology is provided for N_2O emissions from landfills due to their small significance. N_2O and CH_4 emissions, however, are modelled for the recycling processes, even though the IPCC Guidelines (IPCC, 2006) indicate that the CH_4 and N_2O emissions from composting and anaerobic digestion are usually small, often negligible. This is to be able to incorporate evidence from countries that may have registered CH_4 and N_2O from poorly managed composting plants and fugitive CH_4 emissions from biogas facilities with biogas recovery.

The environmental model includes methane emissions from landfills, the key source of greenhouse gases from waste, and CO_2 emissions from incineration, composting and recovery of materials, according to the following principles:

1. Landfilling module: follows the IPCC guideline, and adds CO_2 emissions on the basis of a carbon massbalance.
2. Incineration module: follows a massbalance of carbon, as suggested by the IPCC guideline, but is further specified in the model for all combusted materials (and not only an average of the mixed waste).
3. Material recovery module:
    a. 2006: uses emission factors from the Gabi 4 LCA database.
    b. 2007: to be modified to be based on a massbalance of carbon, and not only on emission factors (as the IPCC guideline indicates), and will cover emission factors for composting, anaerobic digestion (both in the IPCC) and paper and plastic recycling/material recovery (not included in the IPCC guideline).

Methane emissions from landfills have a singular characteristic compared to aerobic greenhouse gas emissions. Contrary to greenhouse gas emissions from waste incinerators and composting plants, landfill greenhouse gas emissions are characterised by the large time-lag of emissions. Biodegradable waste landfilled today may start gas production next year, reach a peak in 4-10 year's time, and prolong its production for up to 50-60 years. Modelling emissions with a time-lag is a challenge, but it is a more appropriate approach for the calculation of projections compared to e.g. assuming immediate emissions after deposition in a landfill.

It is also most relevant in connection with a ex-ante evaluation of the effects of the fulfilment of EU's waste policy objectives.

5.3. Use of NIR and CRF 2005 data in the model

All EU-25 countries are covered by the study. The NIR and CRF 2005 provide information of the period 1990-2005 at best. The studies by Gugele et al. (2005, 2006) include figures and tables giving an overview of the methodologies, and data completeness of the NIR and CRF 2005 from EU-15. The information from the New EU-10 will be taken directly from the NIR and CRF of these countries.

If the NIR and CRF 2005 were not available for some countries, the NIR and CRF 2004 has been used.

The data contained in the waste section in the NIR and CRF is consists of two parts:

1) Data on amounts of landfilled biodegradable waste (activity data): these data may be based on measurements (of % of biodegradable material in landfilled waste, and of total weights landfilled), or be estimated from other data such as population, per capita generation, and waste management practices. So far, only municipal waste is included in the model.

2) Modelling data: are mathematical parameters representing physicochemical processes in landfills and incinerators, and help to model greenhouse gas emissions from waste containing carbon and nitrogen. These parameters can be for instance biodegradation and oxidation rates, gas recovery conditions in landfills, combustion conditions, or flue gas cleaning equipment in incinerators.

Both parts are necessary for estimating the greenhouse gas emissions from landfill and incineration of waste.

Specifically, the information from the NIR and CRF used has been the coeficcients of the IPCC model, that is, those describing landfill types, waste composition, percentage of biodegradable waste, and methane recovery ratios. The source is the NIR and CRF 2005 of the EU-25 Member States.

Data on the generation and management of waste (so-called *activity data* in national inventories) are from Eurostat, as presented in section 4.1.

5.4. Modelling landfill emissions

5.4.1. IPCC Guidelines and their application in EU Member States

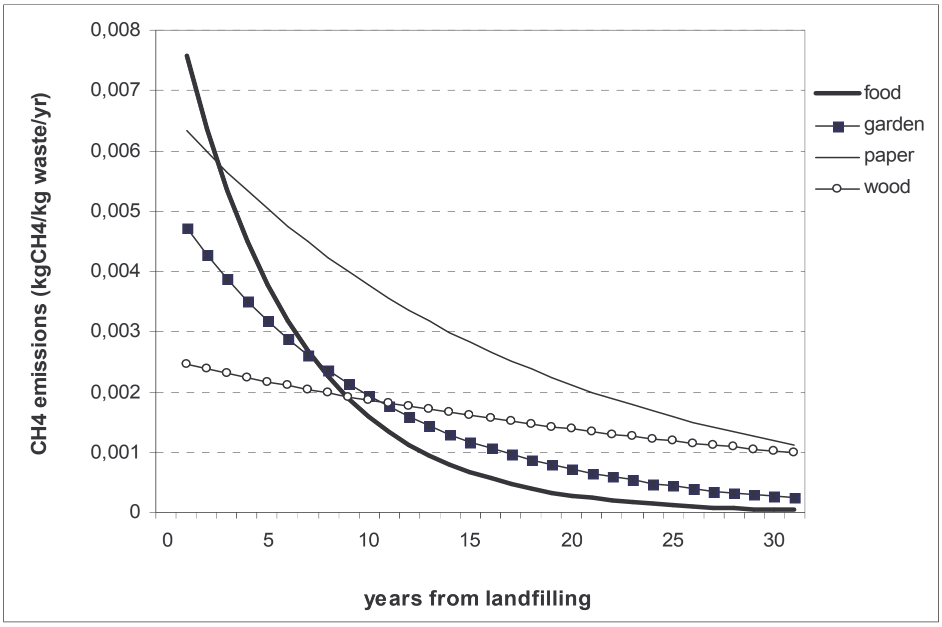
The 1996 and 2006 IPCC Guidelines distinguish two tiers for modelling landfill emissions. Tier 1 is a time-independent methane emission model where all emissions from a given waste are attributed to the year when waste was landfilled. Tier 2 allows to calculate the emissions and to display emission trends over time following a first order decay (FOD) model, and is more accurate to actual behaviour by not assigning all emissions to a single year. According to the IPCC Guidelines, it is considered good practice to use a first order decay (FOD) model, that is, Tier 2.

The two tiers are explained in detail in Annex II. The description is essentially an excerpt of the description of the model given in the IPCC Guideline (Aitchison et al, 1997 and Jensen and Pippatti, 1996, and IPCC 2006).

All EU-15 Member States apart from Greece and Luxembourg apply in the inventories for 2005 the Tier 2 methods in order to estimate CH_4 emissions from landfills, in line with the IPCC good practice guidance. While the method used in Luxembourg is not indicated, Greece applied a simplified, time-independent massbalance method due to the lack of detailed national data.

Applying the Tier 2 method does not mean using exactly the equations and parameters proposed in the IPCC Guideline. Tier 2 indicates only that the estimation of the methane emissions from landfills must follow a first-order decay equation, which in plain words means that the amount of methane emitted is a function of the amount of biodegradable material remaining in the landfill at a given moment in time. This is expressed mathematically by a differential equation which, when integrated, results in an exponential, time dependent function, as illustrated in Figure 5.3 for 1kg of different waste materials with different degradation rates.

Figure 5.3. Example of methane emissions evolution over time using a first-order decay model



Note: The degradation of 1kg of different waste materials is presented, each material having a specific organic content and degradation rate (represented by the half-life degradation times, which in the example of this figure are food: 4 years, garden waste: 7 years, paper waste: 12 years, wood: 23 years).

Source: ETC/RWM compilation

Countries apply various models and assumptions when reporting to the UNFCCC. Gugele et al. (2005) report that in 2004/2005 three Member States used a country-specific emission model in accordance with the Tier 2 method (Denmark, United Kingdom and Belgium) and four Member States (Sweden, Austria, France and Finland) applied country-specific methods (or rather values) in accordance with the Tier 2 method. The remaining Member States applied the Tier 2 methodology (including default values) as proposed by the IPCC good practice guidance and the IPCC Guidelines.

5.4.2. Data used in the model

In the model, the time-dependent methodology developed by IPCC has been used to model emissions in all EU-25 Member States, using the background information provided, and regardless of the method used in these countries for NIR and CRF reporting.

As mentioned above, landfill modelling is complex because of the time dimension: waste landfilled today results in emissions of methane in the next 30-50 years, depending on the waste type and the conditions in the landfill. The IPCC Guidelines has a series of coefficients, which are technical parameters that help modelling the generation of GHG from:

1) landfills (methane and CO_2)
2) waste incineration plants (mostly CO_2)
3) Biological treatment – including anaerobic digestion, composting and mechanical-biological treatment (mostly methane and nitrous oxide)

The IPCC coefficients are used as default values, but national data can be used instead if reported by Member States in the NIR. When the coefficients are not available, they are estimated based on IPCC default values. All assumptions are reported.

The modelling of landfill emissions will be undertaken using a two-string approach:

1) Use of the NIR and CRF 2005 data exclusively (for the emission coefficients). Activity data (waste amounts generated and percentage landfilled, incinerated and recycled) are from Eurostat.
2) Progressive refinement of data by contact to national experts where conflicts are observed. In many industrialised countries, waste management has undergone large changes during the last decade. Waste prevention and reuse policies have aimed at reducing the amount of waste generated. Increasingly, alternative waste management practices to waste disposal on land have been implemented to reduce the environmental impacts of waste management. Also, landfill gas recovery has become more common as a measure to reduce methane emissions from landfills.
3) This procedure is to be repeated in the future updates of the model (planned in 2007, 2008).

5.5. Assumptions made in the model

For the time being, landfilling, incineration and composting of municipal waste is modelled. Other relevant biodegradable fractions not covered are:

- Sewage sludge
- Industrial biodegradable waste

In 2006, the processes of anaerobic digestion, and mechanical-biological treatment have not been included. This is planned for 2007.

In addition to the assumptions presented in section 4, the baseline scenario also includes assumptions regarding the composition of municipal waste and the recovery of methane gas.

5.5.1. Waste composition

Unless otherwise specified, data on the composition of landfilled waste is acquired from the NIR and CRF reporting to UNFCCC. The information provided in the NIR is, in most cases, based on the assumption that the composition of waste has not changed in the period 1950-2005, and will not change in the period 2005-2030. This information has been incorporated in the model, but it is to be reviewed and refined with own assumptions in 2007.

It is important to notice that the figures reported in NIR and CRF consider municipal waste as a sum of household and household-like waste *and* industrial biodegradable waste (which is potentially inconsistent with the definition used by OECD and Eurostat). Therefore, it has been necessary to check and in some cases correct these figures in order to remove the industrial biodegradable waste.

The data used for the corrections in municipal waste composition are:

- Composition of generated waste: OECD (2004)
- Recovery rates, Source collection rates (paper, glass, biodegradable waste): OECD (2004), the EU Commission's reporting on the Landfill Directive

In addition, the waste materials reported in the NIR/CRF, especially from 2006, diverge slightly from our model. The fractions not included in the model are for instance 'sanitary household waste', 'unspecified biodegradable waste', and 'nappies'. These fractions are essentially a mixture of known biodegradable materials: food, garden, wood, paper, or textiles. Therefore, it has been chosen to keep in the model the division into known biodegradable materials: food, garden, wood, paper, and textiles, rather than include in it unspecified fractions. The fractions reported not matching these known materials have been divided after the following qualified estimation:

- 'sanitary household waste': 33 % paper, 33 % textile, 33 % plastic
- 'unspecified biodegradable waste': 50 % food waste, 50 % inert waste
- 'nappies' is assumed to be composed of 95 % paper, 5 % plastic

Furthermore, the values obtainable in the NIR/CRF are often aggregated values for total organic (food and garden) waste. Hence, in the calculations the amount of organic waste is calculated as food waste. Food waste and garden waste contain the same amount of degradable organic carbon (DOC), but have different half-life values. This implies that in the calculations, the speed in which the waste degrades is somewhat overrated. The total amount of methane generated is, however, the same.

The composition of municipal waste in each country remains constant throughout the period 1950-2030. The composition varies from country to country and corresponds to the information given in the NIR. Countries which explicitly report the composition variation in the years 1990-2003 in the NIR/CRF, this reporting has been included.

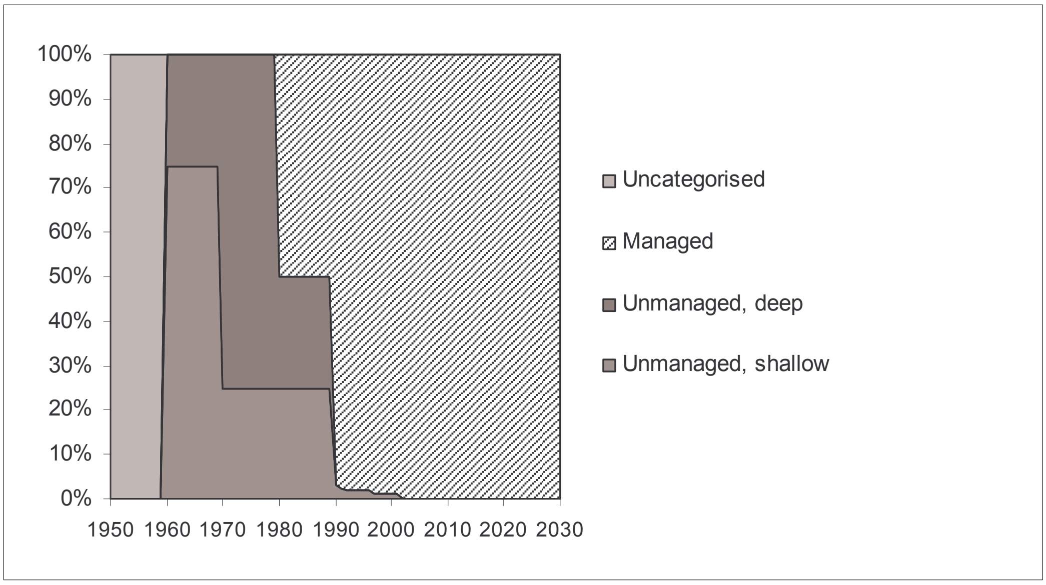
Some complementary sources of information on waste composition such as reports related to the construction and operation of waste management (e.g. incineration) plants have not fully been explored. In such reports, waste characterisation is a fundamental step, and the information could be used to validate currently collected data.

Moreover, the consumption patterns change over a period of 70 years, and thereby the composition of waste. One example is plastics which probably makes up a larger share today (and in the future) than it did in the 1950s. This change in composition will be examined to the extent possible.

5.5.2. Methane generation potential and methane recovery in landfills

In the model, the methane correction factor (MCF) is used to take into account that different types of landfills have different potentials for creating anaerobic conditions and subsequently develop methane. In the NIR/CRF reports, however, only data for the years 1990-2003 are available. While the landfill types applied in the years ahead can be assumed to consist manly of managed landfills the landfill types in the past are more diverse. Hence, it has been necessary to make assumption of MCF values in the time span 1950-1990. It is generally assumed that prior to the use of managed landfills, landfilling was performed at a mix of shallow and deep unmanaged landfills. It is assumed that when going back in time the share of shallow unmanaged landfills will increase. This trend has been incorporated in the assumed composition of landfill types in the period from 1950-1990. In the model, the MCF factors/landfill types are assumed to change gradually every 10 years. Figure 5.4 illustrates the assumed evolution of landfill types (and MCF values) reported in Finland's NIR.

Figure 5.4. Assumed evolution of landfill types (and MCF values) in Finland



The maximum gas recovery rate assumed feasible is 20% of the total generated. This percentage is considered a maximum technically achievable recovery rate, and has been used as the maximum, regardless of the values reported by countries in their NIR and CRF. According to the experience of Oonk (2006) and Villumsen (2005) as reported in IPCC (2006), the maximum recovery values in European landfills lie between 20% for landfills in operation and 37% for closed, controlled landfills.

In the modelling possible recovery levels in future years have been assumed for all countries not currently recovering landfill gas.

5.5.3. Material recovery

The following emission factors have been used to calculate the emissions from material recovery (recycling) processes:

Table 5.2. Emission factors used for material recovery processes

	Composting	Paper & cardboard	Plastic	Glass	Metals	Wood	Textile
CO_2	Unitary CO_2 emissions from the recycling of the different materials (gCO_2/g material)						
2006	2.06E-02	3.07E-01	2.35E-01	4.68E-01	1.26E+00	-1.38E-03	3.44E-01
CH_4	Unitary CH_4 emissions from the recycling of the different materials (gCH4/g material)						
2006	2.49E-03	1.73E-03	2.30E-04	5.35E-05	9.96E-04	-2.9E-06	4.59E-04
N_2O	Unitary N_2O emissions from the recycling of the different materials (gN2O/g material)						
2006	0.00E+00	4.46E-07	3.21E-07	3.96E-06	3.84E-06	1.81E-08	3.77E-07

Source: Gabi4 LCA database.

5.5.4. Incineration

The emission factors have used to calculate the emissions from incineration processes are based on a massbalance of carbon. The emission factors used are presented in Table 5.3.

Table 5.3. Emission factors used for incineration processes

	Food	Garden	Paper	Wood	Textile	Plastics	Inert
Dry matter content of the materials in waste	0.4	0.35	0.9	0.85	0.8	1	0.9
Carbon content of the materials (Gg C/Gg dry weight waste)	0.38	0.49	0.46	0.5	0.5	0.75	0
Calorific value of the materials (GJ/Mg)	2	5	15	15	16	30	0

Source: Gabi4 LCA database.

6. Environmental pressures from the management of municipal waste: baseline scenario

As mentioned in the previous section, the baseline scenario has been designed to present the likely, future management of municipal waste. This scenario assumes that most countries will meet the targets of the Landfill Directive. The biodegradable fraction makes up a very large share of the total municipal waste (60%-70%) in most countries, and the national policies implemented to meet the Landfill Directive targets are therefore bound to a significant effect on the amount of waste landfilled as well as the emission of methane.

6.1. Municipal waste generated and landfilled

Figure 6.1 illustrates the evolution of municipal waste generation in the EU-25, in the period 1980-2020. The overall picture of the EU-25 is a constant increase in the waste generation. By 2020, the EU-25 Member States are expected to have doubled their generation of municipal waste compared to 1980. For a few countries, however, the waste generation may decrease or even stabilise in the period.

Figure 6.1. Municipal waste generation and landfilling in the EU-25

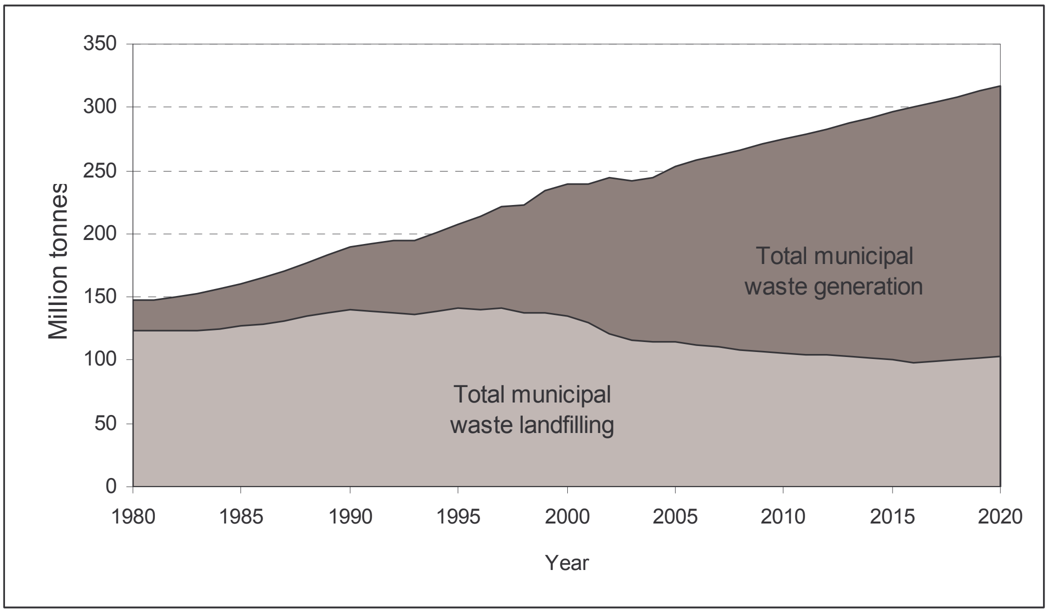


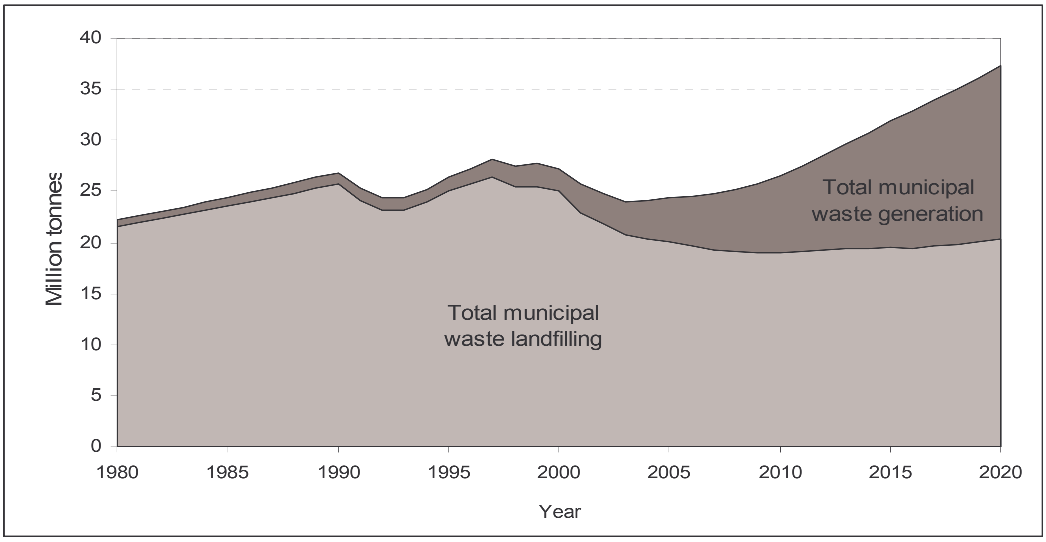
Figure 6.1 also depicts the total amount of municipal waste landfilled in the European Union. In the period before 1980, the share of the municipal waste that was disposed of in landfills was very high in most countries, close to 90%. In the late 1980s and beginning of the 1990s, several countries in Europe began introducing policies to reduce the use of landfills as outlet for municipal waste, and with the adoption of the Landfill Directive in 1999, all countries are required to introduce policies to divert biodegradable municipal waste away from landfills. Since then, the amount of landfilled waste has decreased gradually, and is expected to continue to decrease until 2016. From 2017 on, a slight increase in landfilling may occur, as the increase in the projected generation of waste may offset the decreased landfill rates.

Figures 6.2 and 6.3 show the generation and landfilling of municipal waste in the New EU-10 and EU-15 respectively. In the New EU-10 almost all waste was landfilled up to

1990. This situation continues after 1990, when countries such as Skovakia, Slovenia and Hungary started to divert waste from landfills. However, since then all three countries experienced fluctuations in the landfilling rates. In Poland the landfill rate has remained constant at 97-98% between 1995 and 2003, but from 2004 a slight decrease is now observed. The landfill rate for the New EU-10 fell from 90% in 1995 to 83% in 2004, (Eurostat, SDI).

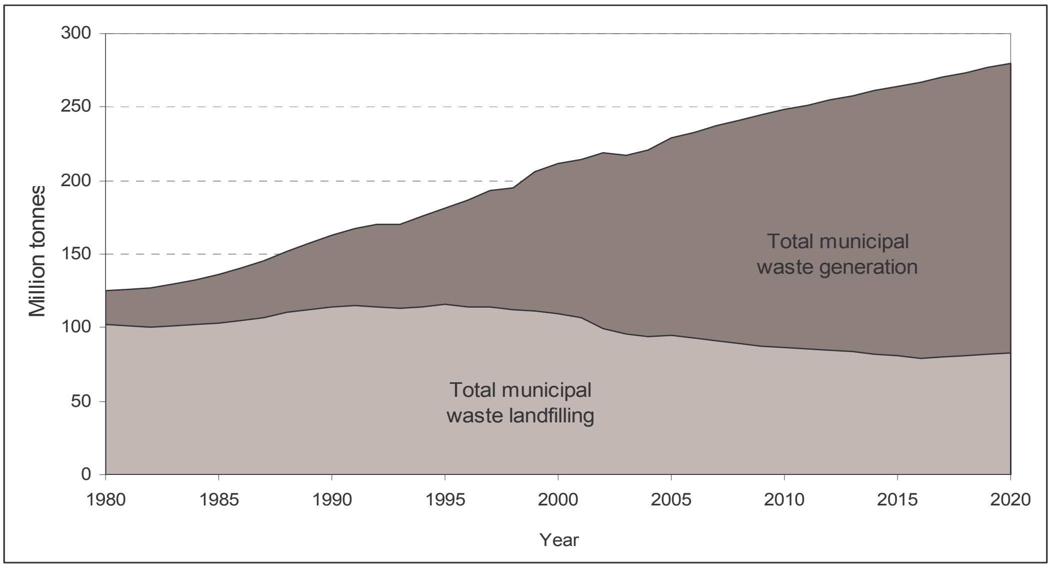
The generation of municipal waste in the EU-10 is projected to grow considerably over the 15 years between 2005 and 2020, a growth of about 50%. This may result in an increase in the landfill of waste from 2012, unless further efforts to reduce landfilling or to stabilise waste generation are initiated.

Figure 6.2. Municipal waste generation and landfilling in the New EU-10



Most municipal waste was also landfilled in the EU-15 until 1990. It is assumed that the average landfill rate between 1950 and 1990 was 100% for all countries except Belgium, Denmark, Luxembourg, the Netherlands and Sweden (assumed rate of 80%), and Austria, Finland, France and Germany (assumed rate of 90%).

Figure 6.3. Municipal waste generation and landfilling in the EU-15



The break of the landfilling-curve from 1990 is partly due to the interpolation between 1990 and 1994 to reach the actual landfill rates in 1995. However, is was also during the first half of the 1990s that several initiatives were taken in the EU Member States to increase recovery and recycling. Of particular relevance is the German Packaging Ordinance in 1991 which led to the ‘Green dot’ system, and later in 1994 the EU Packaging Directive.

From 1995 on, there is a smooth decrease in the amount of landfilled municipal waste till 2017, where a marginal increase can be observed in the projection. This increase is related to the method used for projection of landfilled waste, calculated as an estimated fixed percentage of municipal waste generation, which increases in this period. Between 1995 and 2004, the total amount of landfilled waste over generated waste in the EU-15 dropped from 60% to 41% (Eurostat, SDI).

From Figures 6.2 and 6.3 it is interesting to see that the absolute amount of landfilled waste is projected to decrease, although not considerably. Comparing it with the increase in projected municipal waste, this is an example of ‘absolute decoupling’ between the two, at least in the period up to 2020.

6.2. Direct GHG emissions from the management of waste

6.2.1. GHG generation and emissions from landfills

Until the 1990s, methane emissions followed pace with municipal waste generation. Increased waste generation and the almost exclusive use of landfills as disposal form led to increasing methane emissions. In the beginning of the 90s, as mentioned above, a reduction of the use of landfills for municipal waste disposal begins to take place. In addition to this decrease, new initiatives were put into practice to reduce methane emissions, one of them being the installation of collection and flaring/burning equipment for the methane generated in landfills. Methane from landfill gas is a fuel with similar properties to natural gas, and can be used to operate electricity generators. If the content of methane in landfill gas is too low to make electricity generation profitable, methane can be flared, converting it into carbon dioxide. Below certain concentrations, not even extraction is economically feasible. The methane content in landfill gas varies with the landfill’s lifetime. It is low in the start, increases rapidly in the first months and keeps high (50-55% CH_4 in the gas) in the first 5-10 years. Afterwards, it decreases gradually.

The origin of methane in landfill gas is the degradation under anaerobic conditions of the carbon contained in food, garden, paper, wood and textile waste. This carbon was once in the atmosphere in the form of carbon dioxide, and was stored into these materials via photosynthesis and the food chain. Therefore, if these waste materials were degraded aerobically, the carbon contained in them would be released as carbon dioxide at some point. Carbon dioxide emissions from these materials are therefore called ‘CO_2-neutral’, and have a net contribution to global warming equal to zero.

However, if the biodegradation takes place anaerobically, as happens inside landfills, carbon is also released in the form of methane, and there is a net contribution to anthropogenic global warming because methane is 21 times more powerful than carbon dioxide as greenhouse gas. Therefore, it is good practice in relation to GHG emission management to capture as much of methane from landfills as possible, and convert it to carbon dioxide, be it with electricity generation (if possible and feasible), or simply by flaring.

Figure 6.4 builds on Figure 6.1, and depicts the estimation of methane generation (measured in CO_2-equivalents), recovery and net emission from municipal waste landfills in the EU-25, expressed in CO_2-equivalents. The estimated evolution in the amounts of methane recovered and used as fuel/flared is presented with a dotted line.

The difference between the curves of methane generation and net methane emissions is caused by a combination of the following two factors:

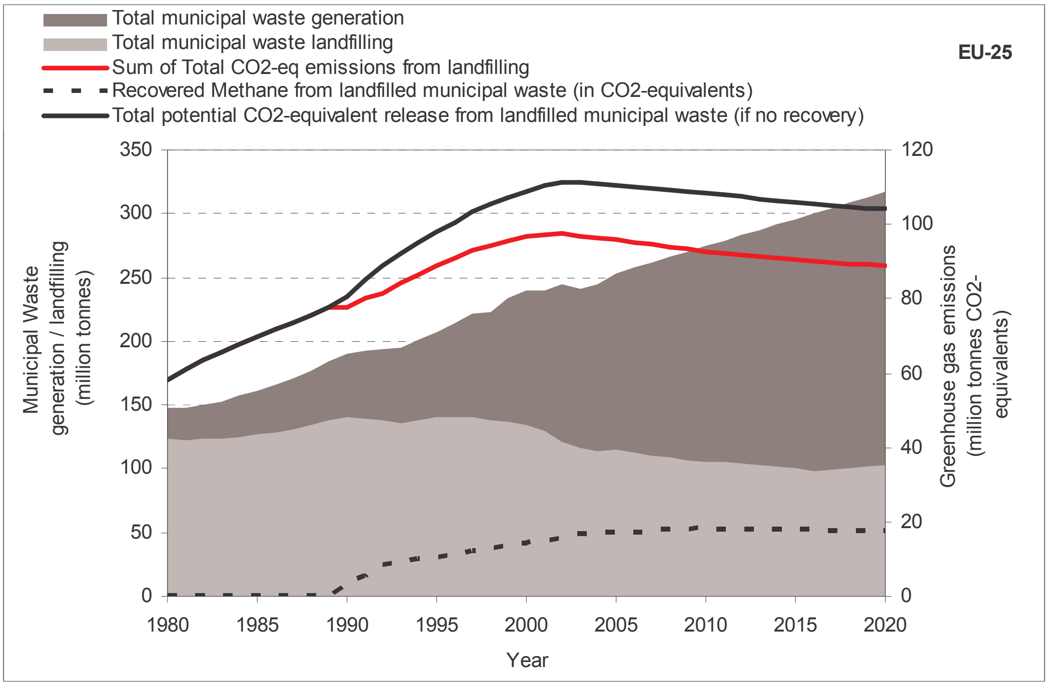
1) methane recovery, as described above

2) methane oxidation by aerobic bacteria in the top layers of the landfill (about 10% in the best cases).

The stabilisation and progressive reduction of the total methane generation curve is not caused by any of these two factors, but instead of:

1) a reduction of the total amounts of biodegradable municipal waste landfilled.
2) a modification of the structure of landfills to reduce the potential for methane generation, e.g. reduction of humidity, thickness, and temperature inside the landfill.

Figure 6.4. Generation and landfilling of municipal waste, and emissions of greenhouse gases from landfilling of municipal waste, EU-25



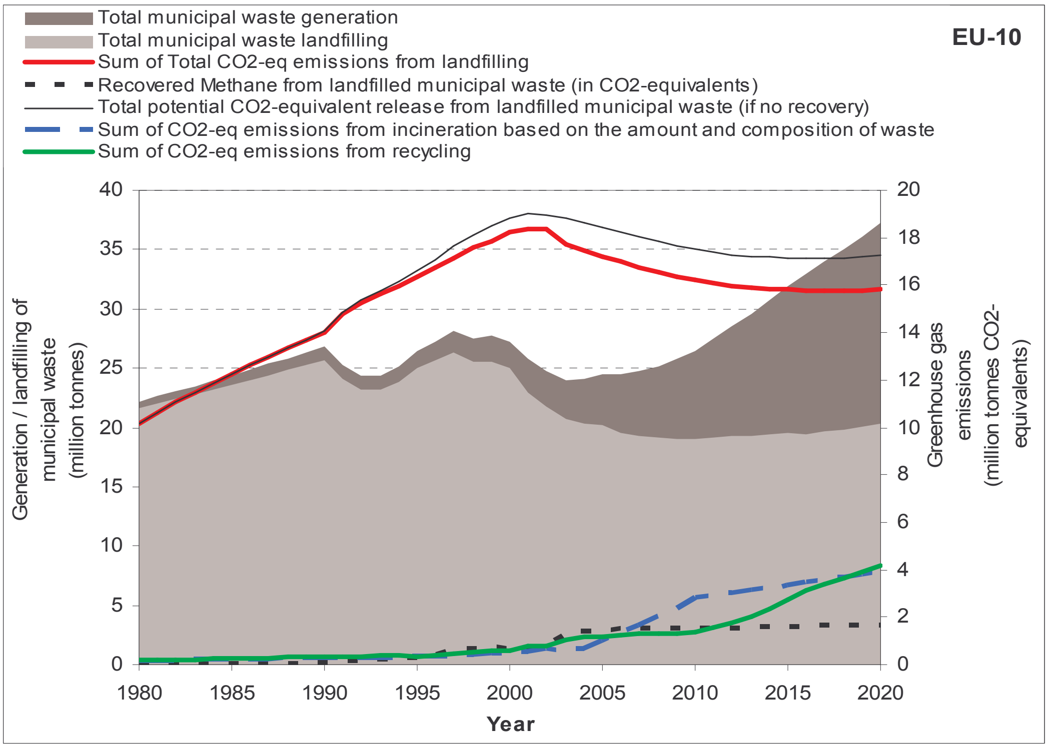
Notes: Left hand side axis: municipal waste generation and landfilling in the EU-25 (shaded profiles, as in Figure 6.1). Right hand side axis: generation, recovery and net emissions of greenhouse gases from municipal waste landfilling in the EU-25 (black and red curves).

Figure 6.4 allows following the dependency and time delay between the reduction of the landfilling of biodegradable municipal waste, which reaches a top around 1990, and the stabilisation and reduction of the total net methane emissions [in Figure 6.4, “sum of total CO2-eq. emissions from landfilling”], which for the EU-25 takes place around the year 2000.

A detailed discussion of any correlation at this high aggregation level (EU-25) is, however, very uncertain, because the changes in the amounts of landfilled waste or recovered methane are decided at national level, and are therefore best analysed on a country-per-country level.

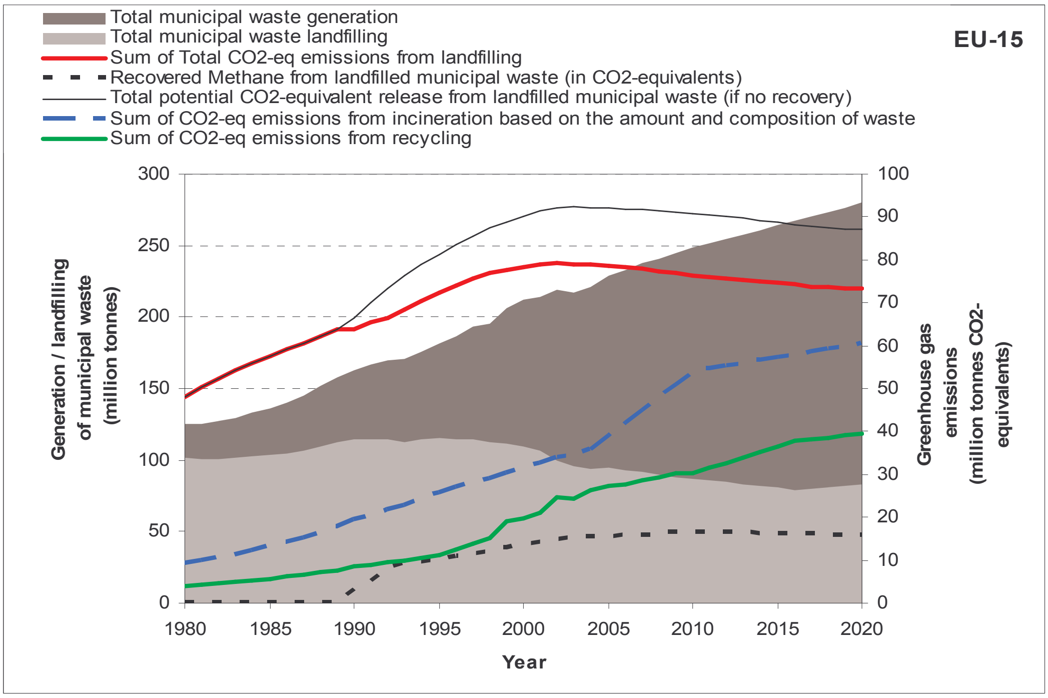
In Figures 6.5 and 6.6 the parameters are disaggregated to the new New EU-10 and EU-15. The figures show that efforts towards reduced landfilling and increased recovery of methane have been taken earlier in the EU-15 than in the New EU-10. As a result, the total net emission of methane in the EU-15 peaked in the early 1990s, whereas the peak in the New EU-10 seems to be early 2000.

Figure 6.5. Generation and landfilling of municipal waste, and emissions of greenhouse gases from landfilling, incineration and material recovery of municipal waste, New EU-10



Notes: Left hand side axis: municipal waste generation and landfilling in the New EU-10 (shaded profiles). Right hand side axis: generation, recovery and net emissions of greenhouse gases from municipal waste treatment in the New EU-10 (thin lines). The figure mentions CO2-eq emissions from recycling, but it would be more appropriate to characterise it as CO2-eq emissions from material recovery.

Figure 6.6. **Generation and landfilling of municipal waste, and emissions of greenhouse gases from landfilling, incineration and material recovery of municipal waste, EU-15**



Notes: Left hand side axis: municipal waste generation and landfilling in the EU-15 (shaded profiles). Right hand side axis: generation, recovery and net emissions of greenhouse gases from municipal waste treatment in the EU-15 (thin lines). The figure mentions CO2-eq emissions from recycling, but it would be more appropriate to characterise it as CO2-eq emissions from material recovery.

6.2.2. Emissions from incineration

As illustrated in figures 6.5 and 6.6, as a result of the increasing amounts of waste incinerated in Europe, the CO_2 emissions from this management option are increasing. It is important to stress that these are total direct carbon emissions. As a result, (a) the savings of CO_2 emissions in other sectors such as energy supply as a consequence of increasing energy supply from incineration are not calculated, and (b) both biogenic and anthropogenic carbon are included.

Sensu stricto, only the emissions from plastics are anthropohgenic, since the other carbon sources in waste are from biodegradable fractions.

6.2.3. Emissions from recycling

As illustrated in figures 6.5 and 6.6, the CO_2 emissions from this management option are increasing as a result of the increasing amounts of waste recycling in Europe. Similar considerations to those above indicated for incineration are necessary here: the calculated CO_2 emissions are total direct carbon emissions. Hence, (a) the savings of CO_2 emissions in other sectors such as manufacturing of raw materials as a consequence of increasing recycling are not accounted for in the model, and (b) both biogenic and anthropogenic carbon are included.

In 2007, the model for material recovery is to be modified and be based on a massbalance of carbon, and not only on emission factors (as the IPCC guideline indicates), and will cover emission factors for composting, anaerobic digestion (both in the IPCC) and paper and plastic recycling (not included in the IPCC guideline).

6.3. Analysis of parameters by Member State

Figure 6.7 depicts the total generation of municipal waste in the EU-25 in the period 1980-2020, specified by Member State. The largest producers are also the most populated Member States in the European Union: United Kingdom, Spain, Italy, the Netherlands, Poland, Germany and France.

Figure 6.7. Total generation of municipal waste, 1980-2020, per EU Member State, million tonnes

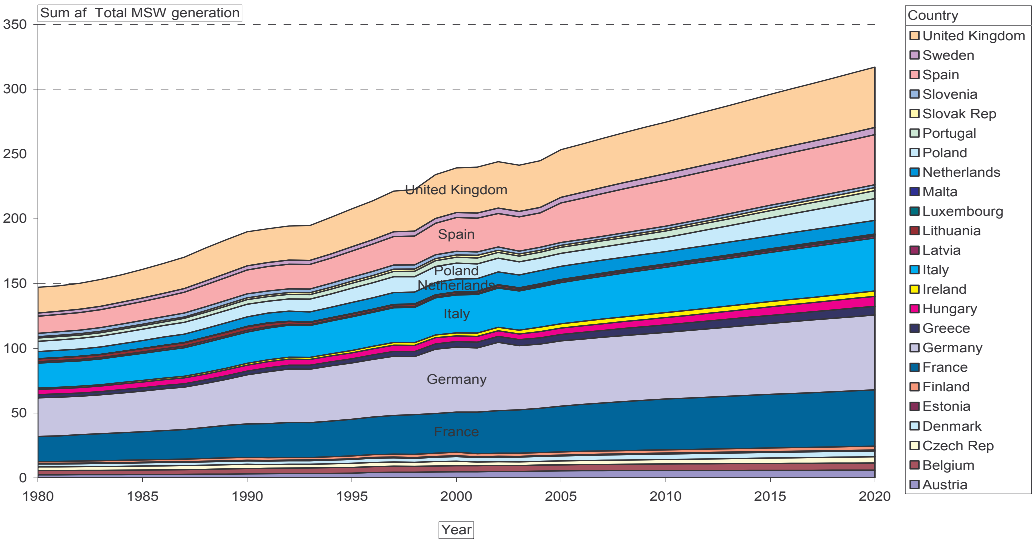


Figure 6.8 shows the total landfilling of municipal waste in the EU-25 in the period 1980-2020, specified by Member State. The largest ‘landfilling countries’ were the same as the largest municipal waste producers in the 80s, but the efforts of landfill diversion of some differences can be observed after 2000, for instance in France, Germany, and the Netherlands, just to mention a few of the most notorious examples in terms of total weight.

Figure 6.8. Total landfilling of municipal waste, 1980-2020 per EU Member State, million tonnes

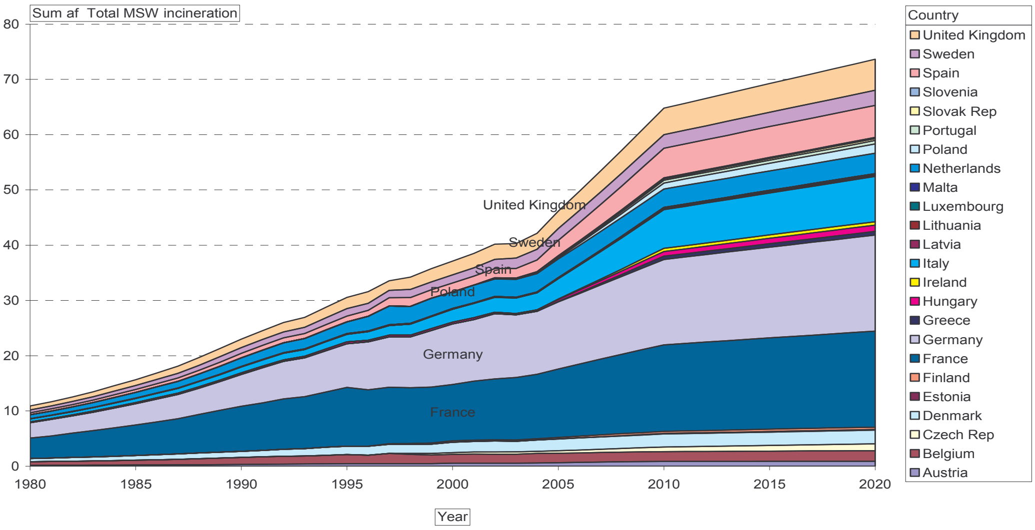


Figure 6.9 illustrates the total methane generation from municipal waste in the EU-25, specified by Member State. The curve is closely correlated to Figure 6.8 (total municipal waste landfilled), as already discussed above: United Kingdom, Spain, Italy, Poland,

Germany and France are the Member States where most methane is generated in municipal waste landfills.

Figure 6.9. Total methane generation from landfills of municipal solid waste, 1980-2020, per EU Member State, million tonnes CH_4

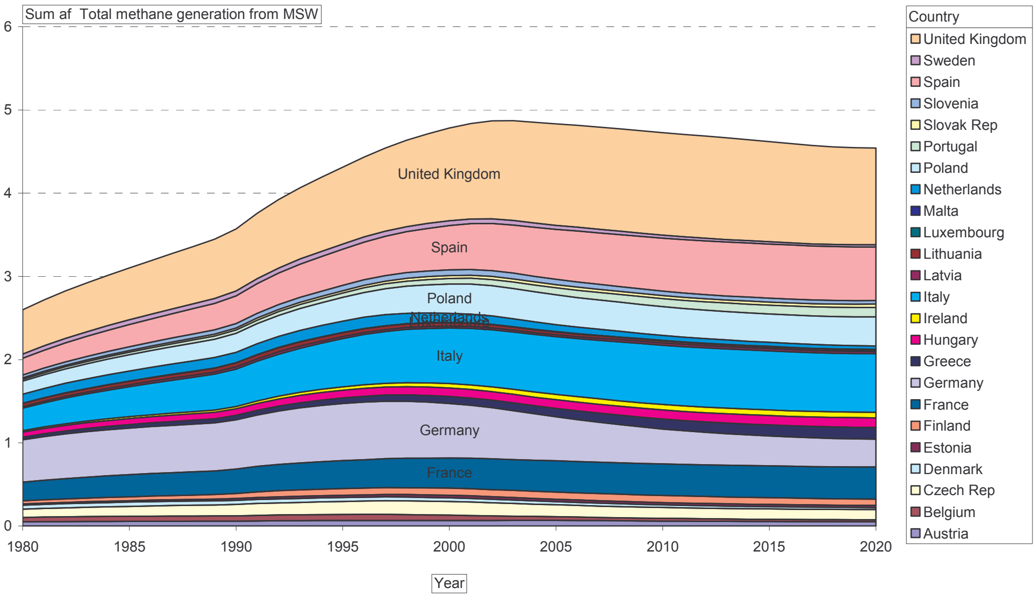


Figure 6.10 presents the total recovery of methane from municipal waste landfills in the EU-25, specified by Member State. According to the current information, the Member States with largest landfill methane recovering capacity are United Kingdom, Italy, Germany and France, with Greece probably playing also a role in the future.

It should, however, be noted that data on methane recovery is scarce. Consequently, the estimation of recovery rates is rather uncertain. The prominent recovery of methane by the UK is based on UK reporting to UNFCCC stating a very high recovery percentage (60%). The validity of the values reported to the UNFCCC has not been checked. Because of this, interpretation of Figure 6.10 should be made with caution. This assumption will be checked and refined in 2006.

Figure 6.10. Total recovery of methane from landfills of municipal solid waste, 1980-2020, per EU Member State, million tonnes CH_4

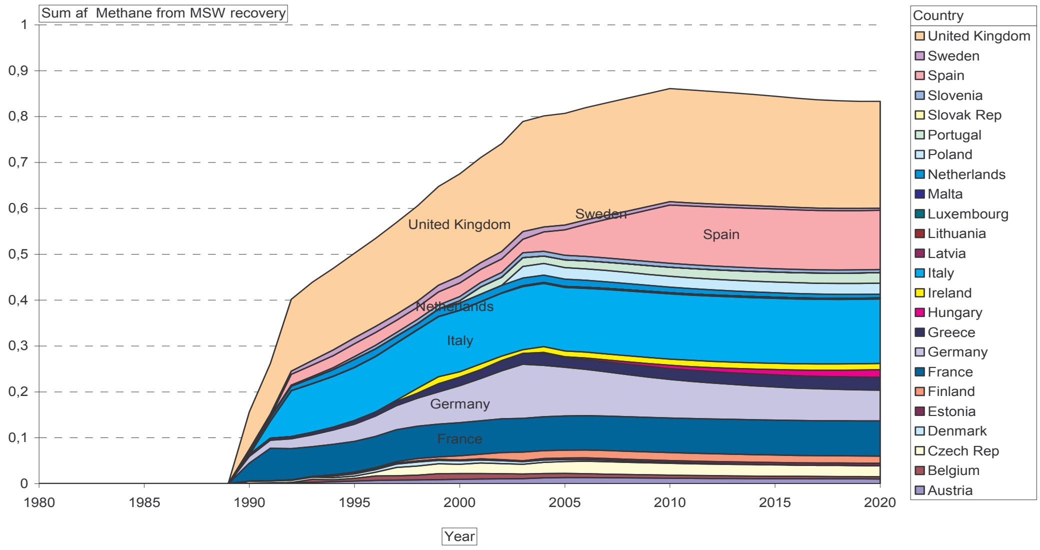
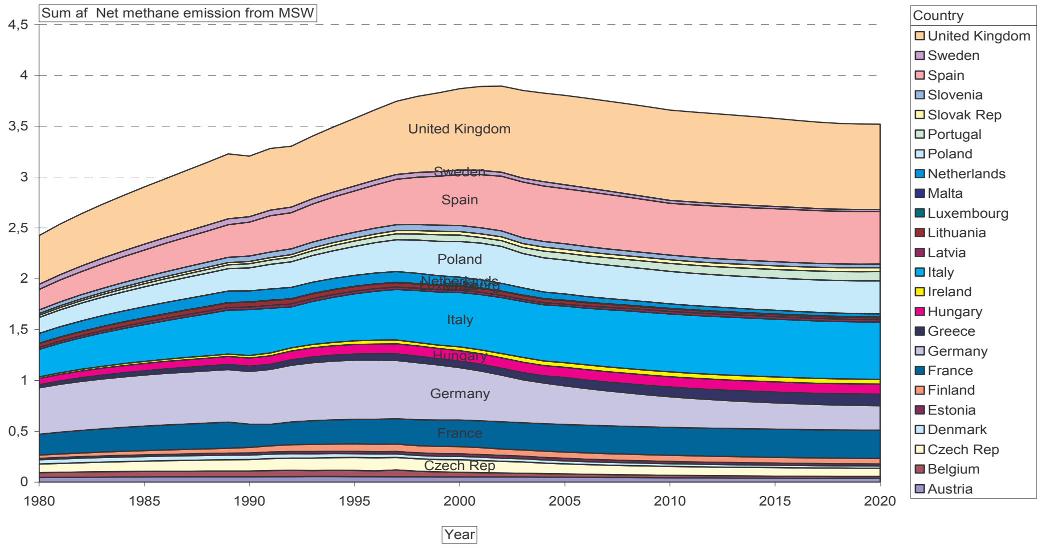


Figure 6.11 presents the net emission of methane from municipal waste landfills in the EU-25, specified by Member State.

Figure 6.11. Net methane emissions from landfills of municipal solid waste, 1980-2020, per EU Member State, million tonnes CH_4



7. Potential improvements of the model

7.1. Mass balance of carbon and of waste

Following the IPCC methodology, as it has been done until 2006, does not guarantee that all calculations match with respect to the fact that what comes in has to come out or be stored. In some sectors such as recycling, but also in incineration, the emissions of CO_2 using the IPCC guideline are made using emission coefficients, which not necessarily lead to a matching massbalance of carbon. Therefore, one of the first exercises of 2007 will be to ensure that the massbalance of carbon is strictly followed.

The general data on waste management needs to be adjusted also: Currently, the recycling percentages have been assumed to be the residual of the reported percentages of incineration and landfilling. This may not be fully true. The recycling percentages have to be reviewed for each material, the technologies for recycling have to be checked, and the amount of residual from recycling that actually goes to landfill again has to be added to the landfilled amount.

7.2. Definition of a new scenario: a recycling society

The Thematic Strategy on the prevention and recycling of waste (Com(2005)666 final) has as a general goal to reduce the environmental impacts from generation and management of waste. The long term goal, as expressed by the Commission (Com(2005)666 final, page 6) is for the EU to become a recycling society.

The Commission, the Council and the Parliament are asking for input to define the Recycling Society, making standards for recycling, input to life-cycle thinking, and an assessment of the implications of the material approach. Other EU-institutions have been asked to contribute with proposals for standards for recycling and end-of-waste definitions (JRC-IPTS), and life-cycle thinking (JRC-IES). However, at present no institution has been asked to contribute with inputs to define and quantify the implications of the vision of a ‘recycling society’.

As a first step in the process of defining more precisely a 'recycling society', focus will be placed on selected waste streams or economic sectors. Municipal waste as well as construction and demolition waste are very dominant waste streams in the EU and would be relevant to include in the study.

One of the tools that could present quantitatively a recycling society scenario and the greenhouse gas emissions associated to it is this project.

It is therefore planned for 2007 to use the existing model to analyse and quantify a recycling society scenario for the EU25.

The overall objective of the study is to define for certain waste streams and sectors realistic, quantitative target levels of recycling in a Recycling Society in a short term (2015), medium term (2025) and long term (2050). The targets would be defined both in relation to tonnes of waste, and environmental pressures in the form of greenhouse gas (GHG) emissions. Thus, the targets would be related to the recycling rate in percent and in absolute tonnes as well as to waste streams that are the most important to recycle if the objective is to reduce environmental pressures.

7.3. Inclusion of indirect effects

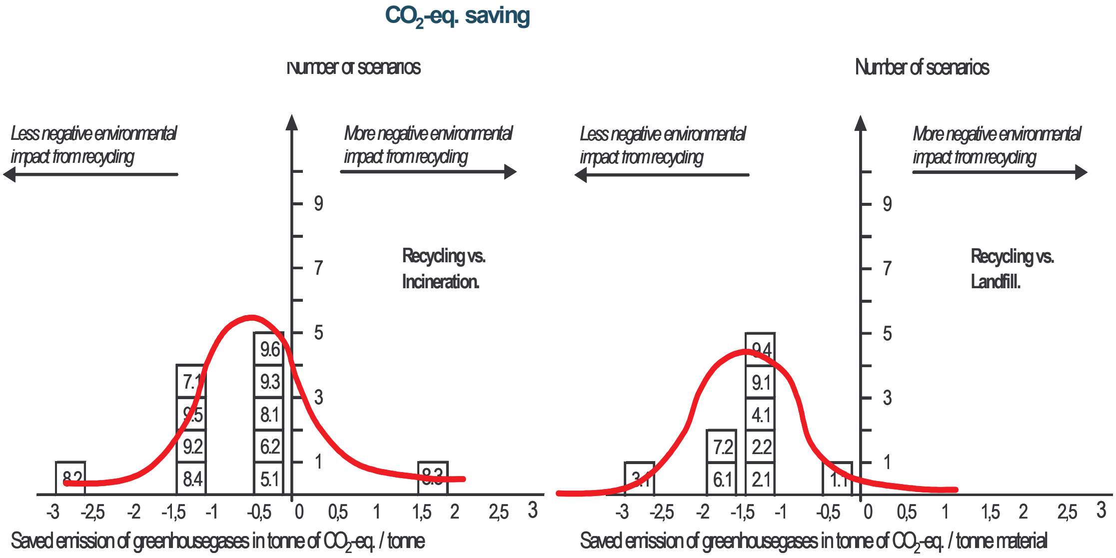
In 2007, it is planned to include in the accounting of greenhouse gases the potential benefits/increases in emissions that the waste sector causes on other sectors such as energy production (from incineration of waste and combustion of landfill gas), or manufacturing (reduced production of recyclable materials on account of an increased supply of recyclable materials such as plastics, paper, wood, metals, glass). The latter does not only affect the biodegradable materials.

Such information has been analysed in so-called Life-Cycle Assessments (LCAs). In 2005, a complete review of existing studies of this kind was published (IPU and DTCW, 2005), and this information is intended to be used in the projections to quantify alternative future scenarios.

Life-cycle information is necessary in the quantification of projected scenarios (such as the above mentioned recycling society scenario) because such scenarios imply a change with respect to the scenario used as reference (baseline scenario). In order to capture all effects of a change (for instance, from 20% to 30% recycling of paper), a methodology using a broad view has to be used. Currently, input-output based on NAMEAs (National Accounting Matrices including Environmental Accounts) and LCA are the only methodologies providing such information. Of these two, LCA is the only one providing the degree of detail required.

Figure.7.1 provides an illustration of the type of information currently provided by LCA studies. The figure depicts the distribution of the reported benefits of recycling over incineration of paper (left) and recycling over landfilling of paper (right). Some studies report large benefits, some other report less. The red lines are an illustration of a distribution function that would represent quantitatively this spreading of result. This is the information that would be used, for instance, to quantify the indirect CO_2 savings of recycling of an extra 10% paper.

Figure 7.1. **LCA information on the benefits of recycling in terms of CO_2 savings**



7.4. Modelling of one waste stream: paper

A vast amount of information on the environmental pressures of the paper cycle is already available in-house as the DTC has conducted several studies on the subject, e.g. a review of LCAs on paper, and two studies applying LCA-based indicators to prioritise waste materials based on their environmental impacts (including paper and cardboard).

The projections on paper seem reliable in the sense that historical data on paper consumption stem from the same source, CEPI, and that complete time series are available for most countries since 1983.

Estimation of environmental pressures from management of paper and cardboard relies heavily on the assumptions made on the source of energy.

With a few exceptions, paper and cardboard comprises some 25-45% of municipal waste during the period 1995-2002[7]. Municipal waste comprises 14% of total waste generated in Western Europe, (OECD 2001), and some 17-20% of the waste streams included in the WMF model.

7.5. Inclusion of more environmental pressures

The model includes emissions of CH_4, CO_2 and N_2O (the main greenhouse gases from the waste sector). The improvements in the modelling in 2006 have focused on a quality control of these emissions, rather than expanding the modelling to include other gases.(NO_x, SO_x, dioxins, particulates ($PM_{4/10}$). This is still the preferred option for 2007: to ensure few, but high-quality emission indicators rather than a wide spectrum of discussable quality emissions.

GHG air emissions cover mainly the pressures from the use of energy (for transport, recycling, primary production), incineration, and methane from landfill and other biowaste treatments. These emissions have mostly global effects.

The production of projections on greenhouse gas emissions is additionally of high political relevance at the moment in the EU. Since 1990, Member States have reported both inventories of their emissions and projections to 2020, but there was no requirement to document how these projections were made. From 2006, MS are required to document transparently how their projections of greenhouse gases are made, including those from the waste sector. Many MS will therefore benefit from the data and methodological assumptions reported in this project.

The estimation of environmental pressures from toxic substances (such as dioxins) is one of the less developed areas of the life-cycle/environmental impact methodology. Even though tools for the estimation of some toxic effects exist, they are very dependent on local conditions and hence difficult to model. As a consequence, there is a lack of international consensus for the use of methodology and parameters. The project team suggest therefore to keep the activity of expanding the emission types on hold in 2007, and use all energies on the production of high-quality greenhouse gas emission projections.

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[7] WMF model data

8. Abbreviations

AC	Accession Countries: AC2 Bulgaria and Romania
BMW	Biodegradable municipal waste
CH_4	Methane
CO	Carbon monoxide
CO_2	Carbon dioxide
CRF	Worksheet called Common Reporting Format for the UNFCCC
DOC	Degradable organic carbon
EEA2	Norway and Switzerland
New EU-10	New EU Member States
EU-15	Old EU Member States
FOD	First Order Decay
GHG	Greenhouse gas (e.g. carbon dioxide, methane)
GVA	Gross value added in the production sector
GWP	Global Warming Potential
IPCC	Intergovernmental Panel on Climate Change
MCF	Methane correction factor
MSW	Municipal (solid) waste
MSWF	Fraction of municipal waste disposed to landfills
MSWT	Total municipal waste generated (million tonnes /year)
N_2O	Nitrous dioxide
NIR	National Inventory Reports for the UNFCCC
NMVOCs	Non-methane volatile organic compounds
OX	Oxidation factor
SWDS	Solid Waste Disposal Site
UNFCCC	United Nations Framework Convention on Climate Change
WMF model	EEA/ETC-RWM model for projections of waste and material flows

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I. Annex: Modelling of methane gas emissions from landfills in the IPCC Guidelines

The description below is essentially an excerpt of the description of the model given in the IPCC Guideline (Aitchison et al, 1997 and Jensen and Pippatti, 1996), including some modifications to the method as suggested by Svardal (2004).

The Revised 1996 IPCC Guidelines and the 2000 IPCC Good Practice Guidance describe two methods for estimating CH_4 emissions from landfills: the mass balance method (Tier 1) and the First Order Decay (FOD) method (Tier 2).

The use of the mass balance method is strongly discouraged as it produces results that are not comparable with the more accurate FOD method.

The most significant factors affecting CH_4 generation are:

Waste disposal practices. Waste disposal practices of concern for CH_4 emissions vary in the degree of control of the placement of waste and management of the site. In general, waste disposal on land will result in CH_4 production if the waste contains organic matter. Managed disposal (controlled placement of waste), in particular, tends to encourage development and maintenance of anaerobic activity.

Waste composition. The composition of waste is one of the main factors influencing both the amount and the extent of CH_4 production within landfills. Municipal waste typically contains significant quantities of degradable organic matter. Different countries and regions are known to have municipal waste with widely differing compositions.

Physical factors. Moisture content is an important physical factor influencing landfill gas production. Moisture is essential for bacterial growth and metabolism, as well as for transport of nutrients and bacteria within the landfill. The moisture content of a landfill depends on the initial moisture content of the waste, the extent of infiltration from surface and groundwater sources, and the amount of water produced during the decomposition processes. Temperature, pH, and nutrient availability will affect the growth rate of the bacteria. Under anaerobic conditions, landfill temperatures are generally between 25-40^{o}C. These temperatures can be maintained within the landfill regardless of the ambient surface temperatures. Outside of these temperatures, CH_4 production is reduced. Optimal pH for CH_4 production is around neutral (pH 7.0). Important nutrients for efficient bacterial growth include sulphur, phosphorus, sodium and calcium. The significance of these physical factors to CH_4 generation can be demonstrated within controlled laboratory conditions.

I.1. Tier 1: Massbalance method

This method is a mass balance approach that involves estimating the degradable organic carbon (DOC) content of the solid waste, i.e., the organic carbon that is accessible to biochemical decomposition, and using this estimate to calculate the amount of CH_4 that can be generated from the waste. It is the most widely accessible, easy-to-apply methodology for calculating country-specific emissions of CH_4 from landfills. It requires the least amount of data to perform the calculations, and it can be modified and refined as the amount of data available for each country increases. This approach was provided as the default methodology in the 1995 IPCC Guidelines (Jensen and Pipatti, 1995). The revised 1996 methodology described here modifies the 1995 IPCC Guidelines in three important ways:

- Rather than distinguishing between “landfills” and “open dumps,” the methodology uses a continuum of solid waste disposal sites, characterised by the degree of waste management and depth through the parameter ‘Methane correction factor (MCF). Managed landfills: 1.0; Unmanaged - deep (>5m waste): 0.8; Unmanaged - shallow (<5m waste): 0.4; Default value - uncategorised landfills: 0.6.
- Default degradable organic carbon (DOC) values are provided for different waste streams so that countries can calculate the DOC content of their waste rather than relying on single default values: The DOC values are (% by weight): paper and textiles: 40%, garden and park waste, and other (non-food) organic putrescibles: 17%, Food waste: 15%, wood and straw waste excluding lignin: 30%.
- Emphasising the fact that this methodology estimates CH_4 generation rather than emission, and that oxidation often occurs in the upper layers of the waste mass and in site cover material, a CH_4 oxidation factor (OX) is included in the equation (currently equal to 0, pending the availability of further data). The determination of annual CH4 emissions for each country or region can be calculated from Equation 1:

EQUATION 1

$$\text{Methane emissions (M tonnes/yr)} = (\text{MSWT} \times \text{MSWF} \times \text{MCF} \times \text{DOC} \times \text{DOCF} \times \text{F} \times 16/12 - \text{R}) \times (1-\text{OX})$$

where:

- MSWT = total municipal waste generated (M tonnes /yr)
- MSWF = fraction of municipal waste disposed to landfills
- MCF = methane correction factor (fraction)
- DOC = degradable organic carbon (fraction)
- DOCF = fraction DOC dissimilated
- F = fraction of CH4 in landfill gas (default is 0.5)
- R = recovered CH4 (M tonnes /yr)
- OX = oxidation factor (fraction - default is 0)

Total municipal waste (MSWT) can be calculated from Population (thousand persons) x Annual municipal waste generation rate (Mtonnes/thousand persons/yr).

I.2. Tier 2: First-order reaction method

If conditions are constant, the rate of methane production depends solely on the amount of carbon remaining in the waste. This means that emissions of methane from waste deposited in a disposal site are highest in the first few years after deposition, and then gradually decline as the degradable carbon in the waste is consumed by the bacteria responsible for the decay. With a typical decay rate, it can take around 50 years for emissions of methane from waste deposited in landfills to decline to insignificant levels. Therefore, the first order decay method requires data to be collected or estimated for historic disposals of waste over the last 50 years.

The use of the IPCC FOD method require good quality country-specific activity data on current and historical waste disposal at landfills. These can be complemented with default parameter values. Data are needed on amounts and composition of waste (or country-specific data on degradable organic carbon content in waste or information of waste generation rates) disposed at the landfills. Tier 2 compliance is also possible with other mathematical modelling based on first order decay, with nationally developed key parameters, and which have been validated scientifically and have been well-documented. Key parameters in the FOD model are:

- The amount of organic carbon accessible to bacteria

- The half-life time(s) for the decay.

FIRST ORDER DECAY THEORY

The first-order decay method assumes that the decay of biodegradable carbon in the waste is governed by a first-order reaction, i.e. the rate of decay is directly proportional to the amount of carbon remaining in the disposal site. This is also known as exponential decay. In other words, the rate of decay declines exponentially as the reactant (in this case dissimilable degradable carbon) is used up. The first order decay reaction for the anaerobic decay of carbon in waste is:

EQUATION 2 - FIRST ORDER DECAY

$$d(DDOC)/dt = -k*(DDOC)$$

a differential equation which integrated gives:

$$DDOCm = DDOCm_0 * e^{-kt}$$

(exponential decay)

where

- $DDOCm$ = the mass of dissimilable degradable organic carbon in the disposal site at time t;
- $DDOCm_0$ = the mass of DDOC in the disposal site at time 0, when the reaction starts;
- k = the decay rate constant in y^{-1};
- t = time in years.

The decay rate k, determines the speed of the reaction, and is related to the half-life (t½, the time taken for the amount of DDOC in the disposal site to decay to half of its initial value). The relationship between the half life for decay and rate constant k is: $t½ = \ln(2)/k$

The $DDOCm_0$ can be calculated from the waste generation and waste composition in year T using Equation 3:

EQUATION 3 - MASS OF DISSIMILABLE DEGRADABLE ORGANIC CARBON (DDOC) AT TIME 0

$$DDOCm_0 = SW_T \bullet SW_F \bullet DOC \bullet DOC_f$$

where

- SW_T = waste generation of year T [MSW generation rate] x [population] + [industrial waste generation];
- $DDOCm_0$ = the mass of dissimilable degradable organic carbon (DDOC) in the disposal site at time 0, when the reaction starts;
- SW_F = fraction of waste disposed to landfills of year t;
- DOC = fraction of degradable carbon of year t.
- DOCf = fraction of degradable organic carbon that is dissimilatable under anaerobic conditions

The annual methane emissions from a landfill are therefore:

EQUATION 4 – TOTAL CH4 GENERATED IN A LANDFILL

$$\text{CH4 generated in year T} = \text{DOCm} \cdot \text{DOCf} \cdot \text{MCF} \cdot \text{F} \cdot 16/12 \cdot (1 - e^{-kt})$$

Where:

- T = inventory year
- DOCm = mass of degradable organic carbon (DOC) in the disposal site at the beginning of year T
- DOCf = fraction of degradable organic carbon that is dissimilatable under anaerobic conditions
- MCF = Methane Correction Factor, which accounts for the fact that unmanaged landfill produce less CH_4 from a given amount of waste than anaerobic managed landfill as part of the waste will decay under aerobic conditions.
- F = fraction of methane by volume in generated landfill gas
- 16/12 = conversion factor from C to CH_4
- k = the decay rate constant in y-1
- t = time in years

Following the corrections to the IPCC model suggested by Svardal (2004), dissimilable Degradable Organic Carbon (DDOC) is used in the equations and spreadsheet models. DDOC equals the product of DOCm (T) • DOCf (T) • MCF (T). The methane generation potential (Lo) is equal to DDOCm • F • 16/12. Using DDOCma (total deposited mass of DDOC in the landfill), the above equation can be used to calculate to total emission potential of the waste deposited in the landfills for a single year. Part of the CH_4 emissions can be oxidised in the cover of the landfill, or can be recovered for energy or flaring. The CH_4 actually emitted from the landfill will hence be smaller than the amount generated.

EQUATION 5 - CH4 ACTUALLY EMITTED FROM A LANDFILL

$$\text{CH4 emitted in year T} = [\text{CH4 generated (T)} - \text{R(T)}] \cdot (1 - \text{OX})$$

Where:

- R (T) = Recovered CH4 in the inventory year T
- OX = Oxidation factor

II. Annex: Assumptions used for estimation of environmental pressures per country

Country	Data in NIR / CRF excel datasheets	Assumptions and estimations to cover non-reported data
Austria	Data on MSW composition, constant 1990-2002. Parameters for the model.	Landfilled waste shares 1990-2000: from Eurostat, not from the CRF.
Belgium	Not used, just generation data for cross checking in 1990-2003.	Model parameters from IPCC guideline. MSW composition and DOC (Degradable Organic Carbon) from IPCC guideline, (Western Europe).
Cyprus	No reporting to the UNFCCC has been made.	Data on generation of BMW in 1995: Eurostat
Czech Republic	Parameters: IPCC Guidelines Some of the values used for the parameters are quite different from the IPCC Guidelines, and can be discussed.	Estimated: ▪ Composition of MSW: from OECD, assumed constant composition. ▪ CH4 collection correction not needed because there is no information on industrial waste.
Denmark	All data available 1990-2005, including composition of non-MSW Assumption of constant waste composition of each fraction 1990-2005.	
Estonia	Total amounts of MSW 1993-2003. In Guideline 2006 (Estonian Env. Information Centre data): total amounts of industrial waste Some of the values used for the parameters are quite different from the guidelines, and can be discussed.	Estimated: ▪ Composition of MSW:1993-2003 assumed constant composition, taken from IPCC 2006 guideline 'Eastern Europe' (no info from OECD) ▪ 2) total gas recovery taken from NIR, assumed all coming from MSW
Finland	All data available 1990-2005, including composition of MSW and non-MSW. Assumption of constant waste composition of each fraction 1990-2005 based on 1990 composition.	Call with 'garden waste' substituted by 'other degradable waste', and a new half-life value of 13 years used, as indicated in the NIR 2005 FI. Values of industrial DOC in 1990-2003 from the NIR 2005 FI are used instead of an average DOC for industrial waste of 0.105 which would have been used instead and which underestimates emissions in 1990 and overestimates in 2003. NIR 2005 FI indicates a decrease in emissions of 30% from 1990 to 2003. That is only to be seen when the years before 1990 are included in the modelling.
France	Follows IPCC	
Germany	Parameters from the NIR and CRF. Methane recovery percentages extracted from CRF 2003 figure, after assumed constant, and linear increase in the period 1985-2003, following information in the NIR 2005 DE. The information on MCF in the NIR 2005 DE matches well with assumptions made.	Landfill share from Eurostat, composition from OECD.

Country	Data in NIR / CRF excel datasheets	Assumptions and estimations to cover non-reported data
Greece		Assumed dry temperate weather. Only the recovery percentages in the years 1999-2003 have been used for the projection of recovery in 2004-2020.
Hungary	Follows IPCC	
Ireland	Methane oxidisation is in CRF-file reported to be 1. This would imply that no methane emission takes place as everything is oxidised. This is not realistic. The value is set to 0.1.	Methane recovery trend has been estimated using available data. The results from the linear regression are used in the years where no information on methane recovery is available. (NB! no good correlation)
Italy	The time lag considered in the Italian CRF-file is 25 years. This value is rather unrealistic as the recommendation from IPCC is 0-6 months. A value of 6 moths is used.	Assumed dry temperate weather The methane recovery from SWDS is assumed to follow a linear increasing trend. Data is available for the period 1990-2003. A linear regression has been made to estimate the level of recovery for the period 2004-2030. Linear regression (based on the years 1992-2003)
Latvia		No information on delay time and oxidisation factor. These are set to 6 months and 0 respectively. No information on composition of MSW landfilled. The composition of landfilled MSW is assumed to equal the composition in Poland.
Lithuania		A very limited amount of data is available for Lithuania. Following assumptions have been made: ▪ Delay time: 6 months ▪ Oxidisation factor: 0 ▪ Fraction of methane in developed landfill gas: 0.5 Only unmanaged landfill sites are used at the moment. It is assumed to be 25% shallow and 75% deep No information on composition of MSW landfilled. The composition of landfilled MSW is assumed to equal the composition in Poland. There is no information on methane recovery. Assumed to be zero.
Luxembourg		A very limited amount of data is available for Luxembourg. The following assumptions have been made: ▪ Delay time: 6 months ▪ Oxidisation factor: 0 ▪ Fraction of methane in developed landfill gas: 0.5 There is no information on methane recovery. Assumed to be zero. Data on composition of MSW are from OECD statistics. No information on types of landfills used. It is assumed that at present and in future only managed landfills are used.

Country	Data in NIR / CRF excel datasheets	Assumptions and estimations to cover non-reported data
Malta		Malta has not reported to the IPCC. Thus, no data on parameters and landfills are available. Hence, several assumptions on key parameters have to be made: ▪ Delay time: 6 months ▪ Oxidisation factor: 0 ▪ Fraction of methane in developed landfill gas: 0.5 The present types of applied landfills are assumed to be unmanaged and consist of 50 % shallow and 50 % deep. It is assumed that no methane recovery is taking place. The composition of landfilled MSW is assumed to correspond to MSW landfilled in Italy. Assumed dry temperate weather.
Netherlands	Oxidation factor is set to 0.1. The Netherlands base calculations on a rather unrealistic value (0.58) which is not clearly documented (as required). Thus, the reported value is not used. The time lag considered is not specified. A time lag of 6 months is used. Landfilled MSW composition : the category 'other' is assumed to consist of 50% food waste 50% inert. The composition of Landfilled MSW is recalculated using the reported figures but excluding building waste and ashes as these are not included in MSW.	Assumed linear decrease in landfill share from 80% in 1989 to 29% in 1995. The methane recovery from SWDS is assumed to follow a linear increasing trend. Data is available for the period 1990-2003. A linear regression has been made to estimate the level of recovery for the period 2004-2030. Linear regression (based on the years 1990-2003)
Portugal	The oxidisation factor is by Portugal reported to be 0.0 or 0.1. It is chosen to use the default value (zero). The time lag considered in the Portuguese CRF-file is >=20 years. This value is rather unrealistic as the recommendation from IPCC is 0-6 months. A value of 6 months is used.	Assumed dry temperate weather. The methane recovery from SWDS is assumed to follow a linear increasing trend. Data is available for the period 1990-2003. A linear regression has been made to estimate the level of recovery for the period 2004-2030. Linear regression (based on the years 2000-2003).
Poland		No information on time lag available from Poland. 6 months is used. Information for recovery of methane is only given for one year (2003) where the recovery amounted to 6.9%. In order to estimate the level of recovery in future years an annual increase of 5 % is assumed.
Slovak Republic	The latest reported valued (2003) for the oxidisation factor is used: 0 A relatively low share of landfilled MSW in the mid-end 90s causes a conspicuous dive in the results graph	Landfilled MSW composition: the fraction 'non specified' is assumed to consist of 50% food waste, and 50% inert No information of managed vs. unmanaged disposal sites available. Data from Poland is used as a proxy

Country	Data in NIR / CRF excel datasheets	Assumptions and estimations to cover non-reported data
		No information on time lag available from Slovakia. 6 months is used. No information methane fraction in landfill gas available from Slovakia. A ratio of 0.5 is used. No SWDS are recovering methane.
Slovenia	Time lag is set to 6 months. NIRs from Slovenia indicate use of unrealistic time lags (23-39 years). The recommendation from IPCC is 0-6 months.	Fraction of methane in landfill gas is set to 0.47. According to the NIR the value varies slightly over time – this is not taken into account. Assumed dry temperate weather The methane recovery from SWDS is assumed to follow a linear increasing trend. Data is available for the period 1990-2003. A linear regression has been made to estimate the level of recovery for the period 2004-2020. Linear regression (based on the years 1996-2003)
Spain	Composition 1990-2003.	Assumed dry temperate weather. Landfill gas recovery: the figures in NIR are unrealistic. The figures used in the model are estimated from Willumsen (2003). These figures need to be refined in a later phase of the project.
Sweden	The composition of MSW landfilled is recalculated from CRF figures discarding the content of sludge. Furthermore, napkins are assumed to consist of 1/3 paper/cardboard, 1/3 textiles and 1/3 plastics	Linear regression on methane recovery trend (based on data from 1998-2003).
United Kingdom	The level of methane recovery reached in 2003 was 68 %. This is considered very high, and this value is kept in the prospective analysis.	Landfilled MSW composition: ‘miscellaneous’ is assumed to consist of 50% food waste, and 50% inert. Oxidation factor is set to 0.1. UK reports base calculations on a rather unrealistic value (0.9) which is not used

III. Annex: Landfill and incineration rates

In order to estimate the amount of municipal waste landfilled during the 70-year period 1950 to 2020, a series of assumptions has been made.

For the period 1950 to 1985, the average rate of landfilled municipal waste has been estimated and it is assumed to remain constant throughout the period. The estimate is a ´best estimate’. Between 1986 and 2004, two approaches have been used. In general, Eurostat Structural Indicator data are used. The estimates of municipal waste landfilled are calculated as a share of municipal waste generated. As the Eurostat Structural Indicator data cover the period 1995-2004, the figures from 1986-1994 have been estimated by means of linear interpolation. In a few cases, the landfill shares reported in NIR (1990 – 2003) are used.

The landfilling of municipal waste has been estimated under the assumption that in the countries where the Directive will have an effect[8], they will landfill the maximum amount of biodegradable municipal waste possible within the targets of the Directive. The countries where the Directive’s targets on biodegradable waste are assumed not to have an effect, because targets are met already, will landfill biodegradable waste equal to the landfill rate in 1995[9]. The residual waste (total municipal waste minus the biodegradable fraction) will be managed as it was in 2003.

The projections are also based on the assumption that most EU-15 and a few EU-10 Member States will meet the targets in reductions of biodegradable waste in landfill as required in the Landfill Directive. In 2004, the majority of new Member States landfilled more than 80% of the generated municipal waste, and some old Member States landfilled more than 70%. Hence, in order to reach the targets for the landfilling of biodegradable municipal waste in these countries, additional interventions (including policy) will be necessary.

The figures for incineration are based on Eurostat Structural Indicator data for the period 1995-2003, and on assumptions for the periods 1950-1994 and 2004-2020. The assumptions regarding projections (2005-2020) are based on incineration plants planned or under construction. The recycling rate is estimated as the residual of generation once landfill and incineration are subtracted. For some countries, this residual results in unrealistic high recycling rates, and in these cases the recycling rate has been corrected.

The landfill rates used are shown in Table III.1 municipal waste landfilled, 1950 – 2020. Likewise, the incineration rates are shown in Table III.2.

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[8] Finland, Greece, Ireland, Italy, Portugal, Spain, and United Kingdom. France for 2016 only.

[9] 1995 is the reference year for the Landfill Directive.

Table III.1 Municipal waste landfilled, 1950 – 2020

										Applied: estimated or assumed landfill rates				
	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	1950-1994	2006	2009	2016	2020
Austria	37%	27%	26%	25%	26%	25%	25%	26%	26%	24%	72%	16%	13%	13%	13%
Belgium	48%	46%	31%	23%	22%	17%	13%	13%	11%	10%	80%	9%	9%	9%	9%
Cyprus	100%	100%	100%	100%	100%	98%	96%	94%	92%	90%	100%	84%	80%	70%	65%
Czech Republic	100%	100%	100%	93%	85%	84%	78%	73%	72%	70%	100%	65%	60%	45%	42%
Denmark	17%	13%	11%	11%	11%	10%	7%	6%	5%	4%	80%	5%	5%	5%	5%
Estonia	99%	100%	100%	100%	100%	100%	79%	76%	66%	63%	100%	63%	60%	45%	42%
Finland	65%	67%	63%	63%	58%	61%	61%	64%	61%	60%	90%	60%	48%	38%	38%
France	45%	46%	46%	45%	44%	43%	41%	39%	38%	38%	90%	35%	33%	30%	30%
Germany	46%	41%	39%	36%	30%	27%	27%	21%	19%	17%	90%	16%	14%	13%	13%
Greece	100%	96%	91%	91%	91%	91%	91%	91%	92%	92%	100%	88%	80%	70%	70%
Hungary	84%	84%	84%	84%	84%	84%	83%	84%	84%	83%	100%	80%	75%	60%	55%
Ireland	92%	92%	91%	91%	90%	89%	87%	79%	72%	66%	100%	55%	47%	40%	40%
Italy	93%	83%	80%	77%	72%	67%	60%	53%	53%	53%	100%	57%	46%	37%	37%
Latvia	94%	94%	94%	93%	93%	93%	91%	87%	83%	83%	100%	70%	60%	45%	42%
Lithuania	100%	100%	100%	100%	100%	95%	89%	80%	78%	77%	100%	75%	72%	68%	63%
Luxembourg	27%	28%	24%	23%	22%	21%	20%	20%	19%	18%	80%	18%	18%	18%	18%
Malta	92%	92%	93%	90%	89%	89%	89%	89%	84%	80%	100%	78%	74%	65%	60%
Netherlands	29%	20%	12%	9%	7%	9%	8%	8%	3%	3%	75%	3%	3%	3%	3%
Poland	98%	98%	97%	98%	98%	98%	96%	96%	97%	94%	100%	90%	83%	65%	60%
Portugal	94%	94%	94%	95%	86%	72%	75%	73%	75%	73%	100%	70%	65%	55%	55%
Slovakia	80%	80%	80%	79%	79%	79%	79%	78%	78%	77%	90%	73%	68%	62%	57%
Slovenia	98%	96%	93%	90%	90%	90%	91%	89%	82%	78%	100%	70%	65%	50%	46%
Spain	86%	86%	84%	84%	80%	76%	73%	65%	63%	63%	100%	50%	45%	35%	35%
Sweden	35%	33%	31%	28%	25%	23%	22%	20%	14%	9%	80%	7%	5%	5%	5%
United Kingdom	83%	86%	86%	84%	82%	81%	80%	78%	74%	69%	100%	65%	60%	45%	45%

Source: For the period 1995-2004 the rates have been calculated: municipal waste landfilled as % of municipal waste generated, based on Structural Indicator data from Eurostat. For some countries national data or data reported to NIR have been used in selected years.

Table III.2 Municipal waste incinerated, 1950 – 2020

									Applied: estimated or assumed landfill rates			
	1995	1996	1997	1998	1999	2000	2001	2002	2003	1950-1994	2006	2009	2016 (2020)
Austria	12%	10%	11%	10%	10%	11%	11%	11%	11%	10%	14%	15%	15%
Belgium	36%	34%	39%	36%	33%	34%	35%	34%	36%	20%	35%	35%	35%
Cyprus	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Czech Republic	0%	0%	0%	6%	9%	9%	13%	14%	14%	0%	23%	25%	25%
Denmark	52%	50%	54%	53%	50%	53%	55%	56%	54%	20%	55%	55%	55%
Estonia	0%	0%	0%	0%	0%	0%	0%	0,3%	0,3%	0%	13%	15%	15%
Finland	0%	0%	5%	6%	8%	10%	9%	9%	9%	10%	14%	15%	15%
France	37%	35%	34%	33%	33%	33%	33%	34%	34%	10%	39%	40%	40%
Germany	18%	20%	20%	21%	21%	22%	23%	22%	23%	10%	29%	30%	30%
Greece	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	8%	10%	10%
Hungary	7%	7%	7%	7%	7%	8%	8%	6%	5%	0%	13%	15%	15%
Ireland	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	13%	15%	15%
Italy	5%	6%	6%	7%	8%	8%	9%	9%	9%	0%	18%	20%	20%
Latvia	0%	0%	0%	0%	0%	0%	4%	6%	3%	0%	13%	15%	15%
Lithuania	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	8%	10%	10%
Luxembourg	53%	52%	49%	46%	48%	43%	42%	43%	42%	20%	45%	45%	45%
Malta	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Netherlands	25%	30%	37%	33%	34%	31%	33%	32%	33%	20%	35%	35%	35%
Poland	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	9%	10%	10%
Portugal	0%	0%	0%	0%	14%	20%	22%	20%	22%	0%	25%	25%	25%
Slovakia	0%	0%	0%	0%	0%	0%	0%	10%	9%	10%	14%	15%	15%
Slovenia	0%	0%	0%	0%	0%	0%	0%	0%	1%	0%	9%	10%	10%
Spain	5%	5%	7%	7%	6%	6%	6%	6%	7%	0%	14%	15%	15%
Sweden	39%	37%	36%	38%	38%	38%	38%	40%	45%	20%	50%	50%	50%
United Kingdom	7%	7%	6%	7%	7%	7%	7%	8%	7%	0%	11%	12%	12%

Source: For the period 1995-2003 the rates have been calculated: municipal waste incinerated as % of municipal waste generated, based on Structural Indicator data from Eurostat. For some countries national data or data reported to NIR have been used in selected years.