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Context

The Topic Centre has prepared this working paper for the European Environment Agency (EEA) under its 2007 work programme 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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1. Executive summary

The EEA and the European Topic Centre on Resource and Waste Management have developed a model for projection of waste quantities and estimation of greenhouse gas emissions associated with the management of this waste. At present, the model is made for municipal waste. This model can be used to study the likely, future trends in European resource and waste management and whether the objectives of the Sixth Environmental Action Programme (2002-2012) are likely to be met.

The generation of municipal waste is projected to be 290 million tonnes in the EU-27 in 2010 with a further increase to 336 million tonnes in 2020. More than 80% of this waste will be generated in the EU-15. Waste generation per inhabitant has been on the increase for years and the projection shows that this will continue till 2020. In 1995, the 27 countries that are now the EU-27 generated 460 kg municipal waste per person. This amount rose to 520 kg per person by 2004, and it is estimated that by 2020 this will equal 680 kg per person. The quantity of municipal waste is projected using a baseline scenario by DG TREN from 2005, which assumes an average, economic growth of 2% p.a.

The diversion of municipal waste away from landfill is expected to continue and reach a level around 34% in 2020. Recycling of waste is assumed to reach a level of 42% and incineration of waste with energy recovery 23% in 2020. However, the assumed level of landfill may be too high. Eurostat has recently published Structural Indicators for 2006 that shows a landfill rate in the EU-15 of 34% in 2006 and 41% for the EU-27. Still, the projection shows that due to the considerable increase in waste amounts, a slight increase in landfilled waste is seen from 2017. The future distribution of landfill, incineration with energy recovery and recycling is based on an assessment taking into account previous developments in municipal waste management and the implementation of policy measures.

The net greenhouse gas emissions from the management of municipal waste are projected to decline from around 55 million tonnes CO_2-equivalents per year in the late 1980s to 10 million tonnes CO_2-equivalents by 2020. In 2005, the greenhouse gas emissions from waste management (including wastewater treatment) represented 2.6% of the total greenhouse gas emissions in the EU-15.

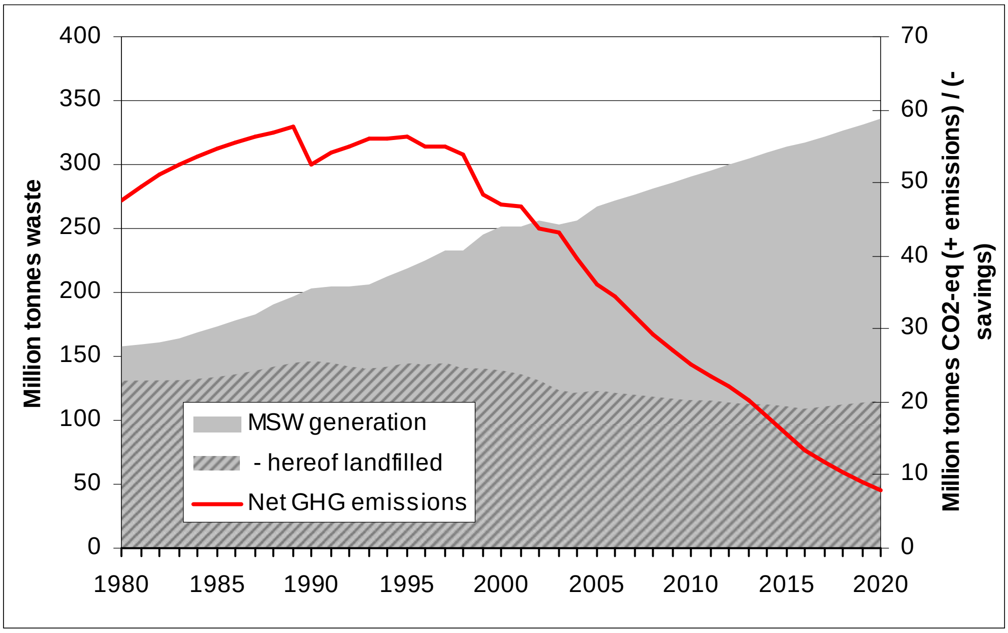
The net greenhouse gas emissions are the sum of the direct emissions (from landfill sites, incineration plants, recycling operations and collection of waste) and indirect emissions. Indirect emissions arise from the energy and secondary materials produced when incinerating and recycling waste replace energy production from fossil fuels and the use of raw materials for plastics, paper, metals etc. The indirect emissions also include a minor contribution from landfills, namely the avoided CO_2-emissions when methane is recovered in landfills and used as an energy source, substituting traditional (mostly fossil-fuel based) energy production.

The IPCC Guidelines describe in detail how to model greenhouse gas emissions from waste management, and are the point of departure for countries' reporting to the UNFCCC. The estimation of greenhouse gas emissions from landfill and incineration are based on recommendations of the IPCC Guidelines. Life-cycle information has been used to estimate emissions from recycling and the indirect emissions.

The development in waste generation and landfill for the period 1980 to 2020 is presented in the figure. The figure also presents the net greenhouse gas emissions from the management of municipal waste.

A key finding is that better management of municipal waste can reduce the emissions of greenhouse gases and, if high rates of recycling and possibly incineration with energy recovery are attained, the net greenhouse gas emissions may even become 'negative'. In other words, this could be interpreted in a way that the municipal waste management is contributing to meeting the targets of the Kyoto Protocol.

Projected generation of municipal waste and greenhouse gas emissions from management of municipal waste in the EU-27



2. Introduction

The Sixth Environmental Action Programme (2002-2012) sets out key environmental objectives to be attained. One of the overall aims is to decouple the use of resources and the generation of waste from the rate of the economic growth (Article 2).

On sustainable use and management of natural resources and wastes, the programme aims at (Article 8):

- a significant, overall reduction in the volumes of waste generated through waste prevention initiatives, better resource efficiency and a shift towards more sustainable production and consumption patterns;
- a significant reduction in the quantity of waste going to disposal and the volumes of hazardous waste produced;
- encouraging re-use, and for wastes that are still generated:
    - the level of their hazardousness should be reduced and they should present as little risk as possible;
    - preference should be given to recovery and especially to recycling;
    - the quantity of waste for disposal should be minimised and should be safely disposed of;
    - waste intended for disposal should be treated as closely as possible to the place of its generation, to the extent that this does not lead to a decrease in the efficiency in waste treatment operations.

The Thematic Strategy on Prevention and Recycling of Waste stated that 'The long-term goal is for the EU to become a recycling society that seeks to avoid waste and uses waste as a resource. With high environmental reference standards in place the internal market will facilitate recycling and recovery activities.' (European Commission, 2005b)

In order to study the likely, future trends in European resource and waste management, the EEA and the European Topic Centre on Resource and Waste Management have developed a model for projection of waste quantities and estimation of greenhouse gas emissions associated with the management of this waste. At present, the model covers municipal waste.

The projections have been made for all 27 EU Member States, but as the focus is the trends in Europe we present aggregated data for the entire EU (EU-27), and for two country groupings: the 15 old Member States (EU-15) and the 12 new Member States (EU-12). The trends in the old and new Member States vary considerably which is the main reason for showing both the EU-15 and EU-12.

Greenhouse gas emissions have been chosen as the environmental pressure indicator because they represent a sizeable environmental effect from the management of municipal waste. This is particularly methane emissions from landfill, the energy consumption from collection and management of waste as well as the avoided energy consumption due to recycling of secondary materials and incineration of waste. Life-cycle information allows calculating these avoided emissions that represent the benefit of recycling for manufacturing materials and for incineration producing energy instead of using fossil fuels and raw materials. The EU-15 agreed under the Kyoto Protocol to a 8% reduction of total greenhouse gas emissions by 2008-2012 from 1990 levels, and EU-12 Member States have individual reduction targets. For reference, in 2005 the direct greenhouse gas emissions from waste management represented 2.6% of the total emissions in the EU-15.

However, from a broad environmental perspective, other pressures such as emissions of particles, nitrogen oxide or dangerous substances cause different environmental effects which should not be neglected.

We have made the projections for the period 2005-2030, but only the projections till 2020 are presented here. The reason is, that the projections beyond 2020 become more uncertain. Also, Member States are in the process of implementing a number of waste directives that aim at increased recycling of various waste streams. This implementation is expected to change the waste management systems in several Member States as it will require more waste streams to be collected and managed, provide access to separate collection systems for a larger part of the population and introduce new treatment options. Finally, the Waste Statistics Regulation will also affect the quality and type of waste data reported by Member States. To date, only data for one year, 2004, have been reported in accordance with the Waste Statistics Regulation.

3. Economic outlook

The baseline scenario used in this context has been developed for the DG TREN, and provides a European 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 (European Commission, 2006a).

The key economic and demographic assumptions for the baseline scenario are presented in Table 3.1.

Table 3.1 Baseline scenario: key assumptions

						Annual % change			
EU-27	**1990**	**2000**	**2010**	**2020**	**2030**	**'90-'00**	**'00-'10**	**'10-'20**	**'20-'30**
Population (Million)	472.7	483.5	492.8	496.4	494.8	0.2	0.2	0.1	0.0
Average household size (persons)	2.7	2.5	2.3	2.1	2.0	-0.8	-0.8	-0.6	-0.5
Gross Domestic product (*)	7358.9	9001.0	11044.1	13825.4	16315.6	2.0	2.1	2.3	1.7
Households expenditure (*)	4298.2	5232.0	6400.6	7938.0	9331.0	2.0	2.0	2.2	1.6
Gross Value Added (*)	6859.9	8382.6	10318.6	12935.7	15242.0	2.0	2.1	2.3	1.7
EU-15									
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-12									
Population (Million)	107.0	105.5	102.2	99.0	96.0	-0.1	-0.3	-0.3	-0.3
Average household size (persons)	3.0	2.7	2.5	2.4	2.3	-1.0	-0.9	-0.4	-0.4
Gross Domestic product (*)	377.0	428.9	652.7	989.7	1366.8	1.3	4.3	4.3	3.3
Households expenditure (*)	223.9	259.5	403.3	608.8	834.4	1.5	4.5	4.2	3.2
Gross Value Added (*)	342.4	380.7	576.1	870.5	1199.9	1.1	4.2	4.2	3.3

Note: * = billion EUR in 2000-prices.
Source: European Commission (2006a)

During the period 2005 to 220 the population in the New EU-12 is expected to decrease by 5 million, and increase by 13 million in the EU-15. During this period, there will also be a decrease in the average household size throughout the EU-27, while the number of households will increase.

The baseline scenario assumes an average, annual GDP growth from 2005 to 2020 of 2.0% for the EU-15, and 4.1% for the New EU-12 (European Commission, 2006a). The average for the EU-27 is 2.2% p.a[1]. 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-12 has been adjusted upwards.

The growth in private final consumption is projected to be slightly lower than the GDP growth in the EU-27.

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[1] The first set of ETC/RWM projections (Skovgaard et al., 2005) was made using the DG TREN baseline scenario from 2003. This scenario assumed an average, annual growth rate of GDP of 2.3 % for the EU-15 and 3.5 % for the New EU-10 (Mantzos and Zeka-Paschou 2002).

4. Projection of municipal waste

4.1. The projection model

The generation of waste relate to a number of economic activities, and different economic activities generate different streams and quantities of waste. Looking at past developments in such streams, economic activities and the size of population, links between amounts of 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 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 of waste stream *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 model 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 model 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 4.1. 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 model (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 4.1. 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 model 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.

4.1.1. Forecast methodology

In analyses of past developments, the activity variables are from Eurostat, and the DG TREN 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. The activity data used are household consumption expenditure by category of goods.

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

4.2. Model parameters for municipal waste

The projections mainly use the population and the final private consumption or the three categories (food, beverages, and clothing) as explanatory variables. The model parameters are shown in Tables 4.2 and 4.3.

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

Table 4.2. 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		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		-1.644	0	1	0.0198	1		0.904	1.823
ES	Eq. 5	9		-1.301	0	1	0.0193	1		0.020	1.220
FI	Eq. 5	10		-0.569	0	1	0.0057	1	0.098	0.863	1.000
FR	Eq. 5	10		-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		-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		-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 4.3 Model parameters for municipal waste, New EU-12 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	0	-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	0	-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	0	0.053	1		0.994	1.183
PL	Eq. 2	10	fcps	1.781	1	0	-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	0	-0.051	1	0.238	0.887	2.777
BG	Eq. 5	8		-0.554	0	1	-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	1	0.020			0.928	1.046

4.3. 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 4.4.

Table 4.4 Generation of municipal waste, method of estimation and source of data

	Method	Comment/source
1950-1994	Estimation of municipal waste generation per capita based on the development in GDP.	1950-1960: GDP 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-12 a constant growth of 1.5% is assumed. 1960-1994: GDP data is based on information from the 'annual macro-economic database' (AMECO) from the European Commission (hosted by DG ECFIN). For the New EU-12 data are only available from 1991, and as a result for the period 1961-1990 is assumed a constant growth of 1.5%. Private final consumption: Eurostat Population: Eurostat/UN
1995-2004	Structural Indicators: Generation of municipal waste generation per capita	Structural Indicators published by Eurostat Private final consumption and population: Eurostat
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

5. Modelling management of municipal waste

The point of departure for the assumptions for municipal waste management in Europe is Eurostat's Structural Indicators on municipal waste generation, landfill and incineration for the period 1995-2004[2]. In this section, we present the assumptions made for the waste management during the entire modelling period, 1950-2030.

The landfill, incineration and recycling rates have all been estimated based on the generated amount of municipal waste.

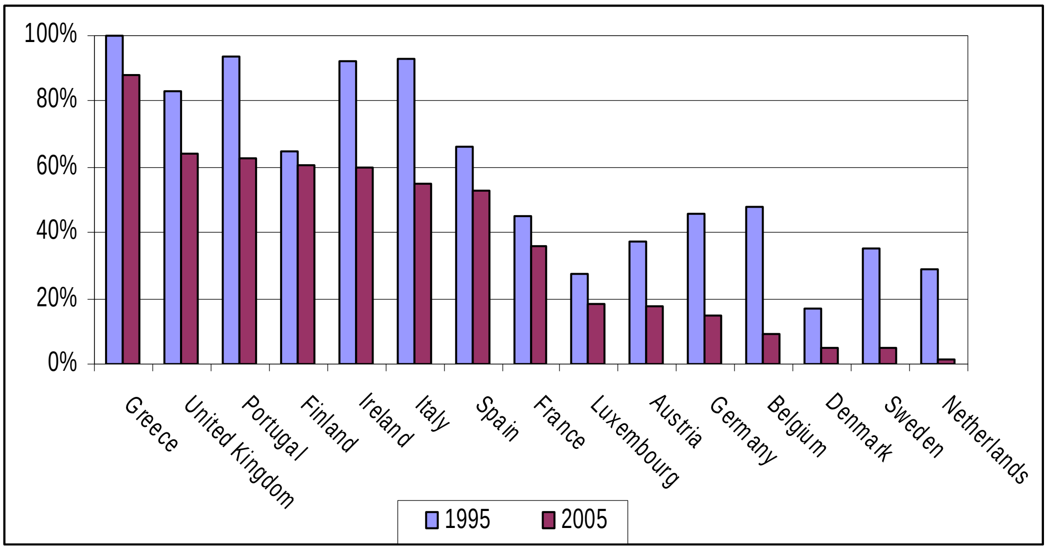
5.1. Landfilling of municipal waste

5.1.1. Observed changes

Landfill of municipal waste has been the predominant option in the EU-27 for several years but this is changing. In 1995 the average landfill rate was 62% but in 2005 this had fallen to 44%. However, waste management practises vary greatly among the member States.

As shown in Figure 5.1 and 5.2, ten EU-15 Member States landfilled less than 60% of the municipal waste in 2005, while the majority of the new Member States landfilled just around 80% or more. The figures also show that in several countries considerable reductions in the landfill of waste have taken place over the 10-year period.

Figure 5.1 Landfill of municipal waste in the EU-15, 1995-2005



Source: Calculated based on Eurostat Structural Indicator data

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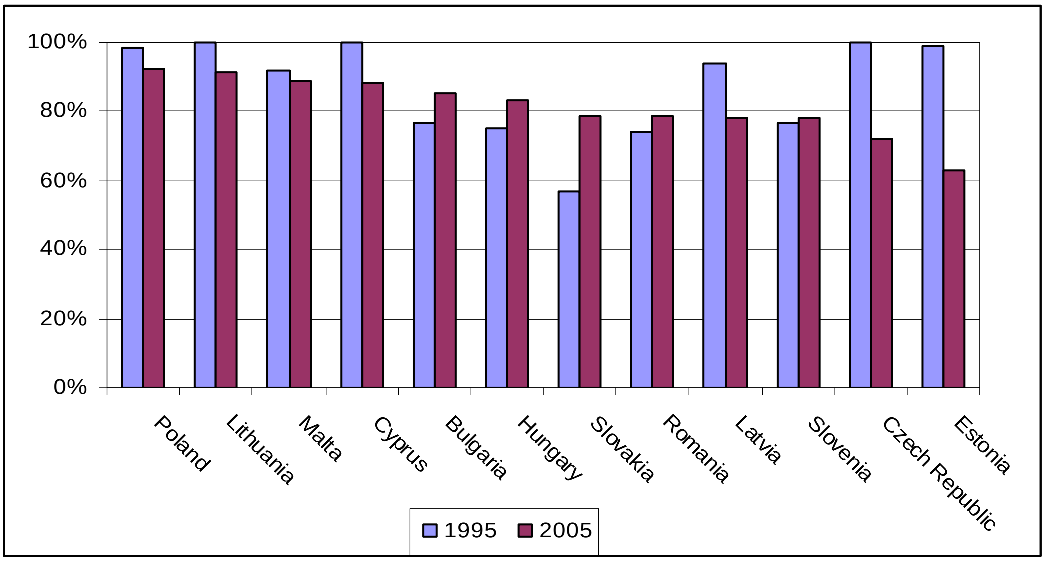
[2] The projection starts in 2005.

Figure 5.2 Landfill of municipal waste in the New EU-12, 1995-2005



Source: Calculated based on Eurostat Structural Indicator data

5.1.2. Assumptions for the estimation

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. The landfill rates are calculated as amount of landfilled waste over the amount of generated waste.

For the period 1950 to 1964 it is assumed that all waste is landfilled.

Between 1965 and 1994, the landfill rate has been interpolated to reach the landfill rate in 1995. This is due to the fact that Eurostat data only cover the period from 1995.

Between 1995 and 2004, Eurostat Structural Indicator data have been used. In a few cases, the landfill shares reported by Member States to UNFCCC[3] are used.

The projected landfilling of waste from 2005 to 2020 is a ´best estimate', taking into account historical trends and the implementation of relevant policy measures to divert waste from landfill.

No further assumptions have been made beyond 2020.

Types of landfills include (IPCC, 2006):

- Managed Solid Waste Disposal Sites,
- Unmanaged Solid Waste Disposal Sites (open dumps, including above-ground piles, holes in the ground and dumping into natural features such as ravines).

Section 6.3 presents further information about the development in landfill types assumed in the model.

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

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[3] The NIR reports. See section 6.2 for further details.

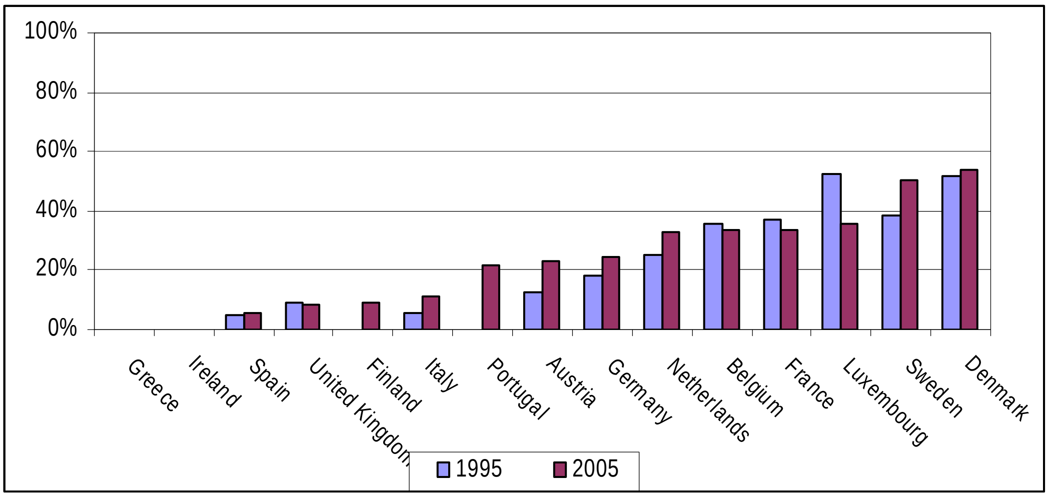
5.2. Incineration of municipal waste

It is assumed that all incineration takes place with energy recovery. However, the production of electricity and heat vary from country to country.

5.2.1. Observed changes

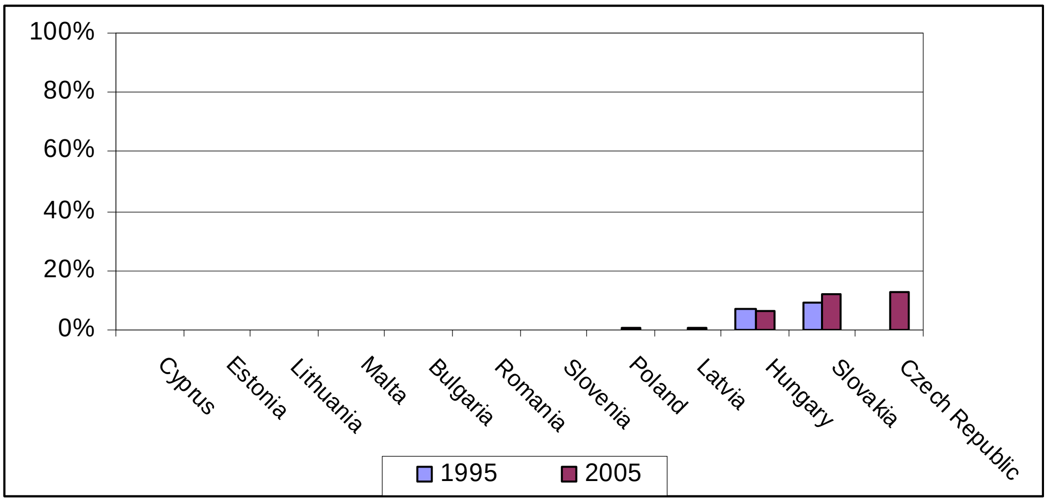
An almost reverse picture can be shown for incineration, where 15 countries had either no incineration or incinerated less than 10% of the generated waste in 2005. Nine countries incinerate more than 20% of municipal waste.

Figure 5.3 Incineration of municipal waste in the EU-15, 1995-2005



Source: Calculated based on Eurostat Structural Indicator data

Figure 5.4 Incineration of municipal waste in the New EU-12, 1995-2005



Source: Calculated based on Eurostat Structural Indicator data

5.2.2. Assumptions for the estimation

The estimates of municipal waste incinerated are calculated as a share of municipal waste generated.

For the period 1950 to 1964 it is assumed that there is no incineration.

Between 1965 and 1994, the incineration rate has been interpolated to reach the calculated incineration rate in 1995. This is due to the fact that Eurostat data only cover the period from 1995.
Between 1995 and 2004, Eurostat Structural Indicator data have been used.

The projected incineration of waste from 2005 to 2020 is a ´best estimate', taking into account historical trends and the implementation of policy measures. The assumptions regarding projections are also based on incineration plants planned or under construction.

No further assumptions have been made beyond 2020.

For further information on emissions from incineration, see section 6.4.

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

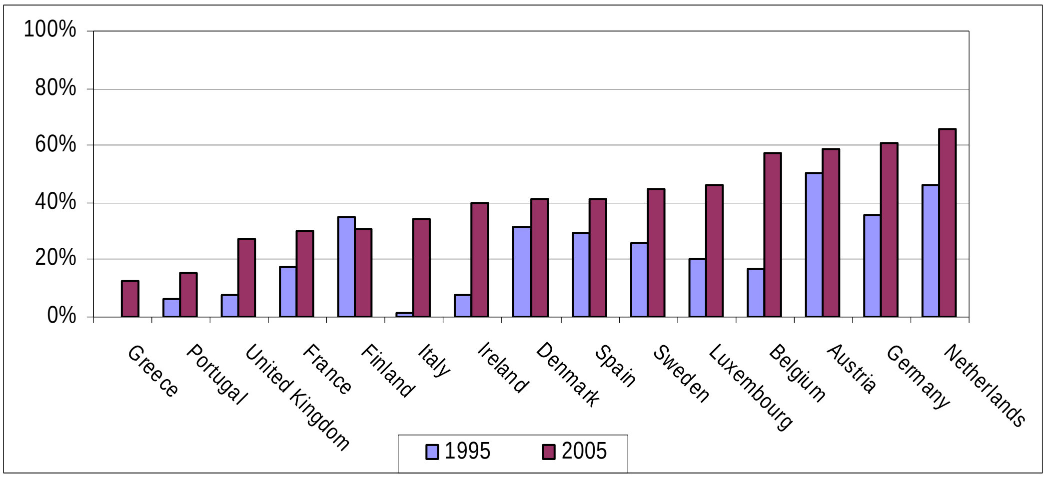
5.3. Recycling of municipal waste

5.3.1. Observed changes

The Structural Indicators published by Eurostat do not include recycling of municipal waste. Thus, we have estimated the recycling rate as the residual of generation once landfill and incineration are subtracted. This is a simplification and the estimated recycling rate may therefore include activities that are not considered as recycling but rather recovery or even unknown (landfill or 'export'). For some countries, the calculated recycling rates are probably a little too high and in these cases the recycling rate has been corrected downwards. For example, in the case of Estonia, in 2003 68% was landfilled or disposed of, 15% was recovered, 3% was exported and 13% went through an undefined handling. Where such cases have been identified, the amount of waste sent to landfill has been assumed to be higher than shown in Figures 5.1 and 5.2.

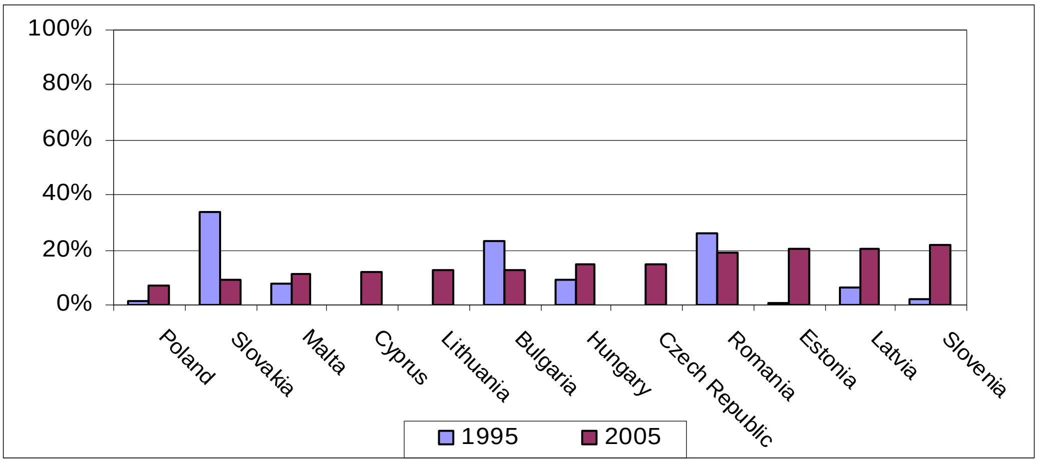
In 1995 the calculated, average recycling rate in the 27 countries was 24% and this rose to 38% in 2005.

Figure 5.5 Recycling of municipal waste in the EU-15, 1995-2005



Note: The recycling rate is estimated as the residual of generation once landfill and incineration are subtracted.
Source: Calculated based on Eurostat Structural Indicator data

Figure 5.6 Recycling of municipal waste in the New EU-12, 1995-2005



Note: The recycling rate is estimated as the residual of generation once landfill and incineration are subtracted.
Source: Calculated based on Eurostat Structural Indicator data

5.3.2. Assumptions for the estimation

Throughout the estimation period, recycling is calculated as waste generation minus landfilled and incinerated waste.

Recycling comprises the recycling of the following fractions: food and garden waste, paper, glass, metals, plastics, textiles and wood. Comparable data for recycling of these fractions are scarce which is why we have chosen a relatively simple approach.

Recycling of food and garden waste is assumed to equal composting[4] and on the basis of composting data from Eurostat for the period 1995-2003, we have calculated a composting rate. If data series are not complete, they have been interpolated. The recycling of materials other than food and garden waste is calculated as a percentage of the (total recycling rate – compost rate) fraction recycled. This distribution of waste fraction recycling is constant throughout the projection period.

Table 5.1 Recycling of waste fractions in % of total recycling rate

Composting	Paper & cardboard	Plastic	Glass	Metals	Wood	Textiles & other
Eurostat data 1995 – 2003	50%	10%	15%	10%	15%	2%

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[4] Composting is assumed to include 20% anaerobic digesting, cf. Table 6.3.

6. Modelling greenhouse gas emissions

The following sections describe the methodology used to model the greenhouse gas (GHG) emissions from the treatment of municipal waste. The baseline scenario includes assumptions regarding the composition of municipal waste; direct emissions from landfill sites, incineration and recycling plants; and the benefits from recovery of methane gas, incineration and recycling of waste.

The Intergovernmental Panel on Climate Change, IPCC, provides a guideline (IPCC, 2006) on how to model greenhouse gas emissions from waste management (landfilling and incineration). On the basis of this guideline, the EU Member States report the composition of waste and emissions from landfilling and incineration to the UN Secretariat for Climate Change on a yearly basis.

We have modelled the emissions from landfilling, incineration and recycling using the following principles:

1. Landfilling: Follows the IPCC guideline. Emissions are calculated on the basis of a carbon mass balance. Recovery rates are estimated on the basis of the Member States' reports to the UN Secretariat for Climate Change and the recommendations in the IPCC guideline.
2. Incineration: Emissions are calculated on the basis of a carbon mass balance, 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. Recycling: Calculation of emissions is based on life cycle data collected in a previous ETC/RWM study on environmental impacts from treatment of specific waste streams (ETC/RWM, 2006) combined with data from Danish and European life cycle assessment databases.
4. Indirect effects: Savings per kg material are calculated on the basis of life cycle data from the same sources as for the recycling.

6.1. Greenhouse gas emissions as environmental indicator

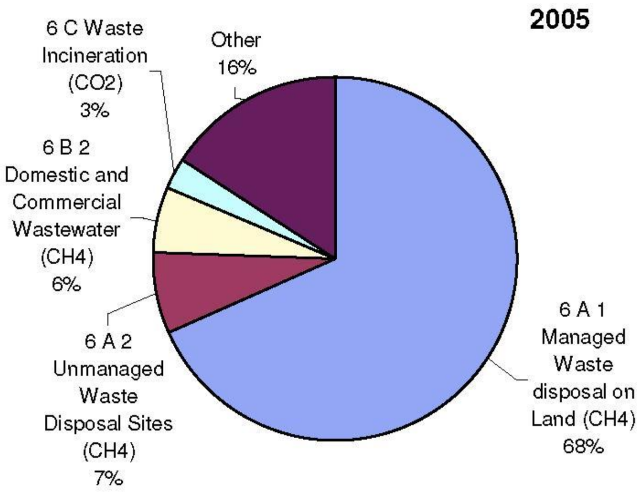
We have chosen to focus on GHG emissions in this study for political as well as methodological reasons. Climate change is very high on the international political agenda as the scientific proof of the human impact on climate change becomes stronger (see for example IPCC, 2007) and as the politicians are becoming aware of the potential consequences of climate change. Therefore, the GHG emissions resulting from waste management is of high interest.

The methodological considerations regarding the choice of environmental indicators are related to data availability and reliability. The method for calculating GHG emissions is rather simple (in this study mainly simple mass balances) and GHG emissions are always included in life cycle data. Moreover, there is scientific agreement on the cause-effect relations of GHG and climate change.

According to Gugele et al. (2007), the emissions from waste management in the EU-15 contributed by 2.6% of the total greenhouse gas emissions in 2005. The total emissions from waste management have decreased by 38% from 176 million tonnes[5] CO_2-equivalents in 1990 to 109 million tonnes CO_2-equivalents in 2005 despite an increase in waste generation in the same period, mostly as consequence of the implementation of national and EU policies oriented towards emission reduction from the waste sector.

The greenhouse gases covered in the IPCC reporting are carbon dioxide (CO_2), nitrous oxide (N_2O), methane (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 common in the waste sector. The key sources of greenhouse gas in waste management are illustrated in Figure 6.1 below.

Figure 6.1 Greenhouse gas emissions from the waste management sector in the EU-15, 2005



Source: Gugele et al. (2007)

Figure 6.1 shows that CH_4 emissions from landfills account for 75% of the 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 inventories, because the carbon is of biogenic origin and it is therefore assumed that they stem from uptake of atmospheric CO_2.

In contrast to common GHG inventories, our model includes all carbon inputs and outputs, be these biogenic or anthropogenic. In order to ensure this, the model is based on a carbon mass balance. 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

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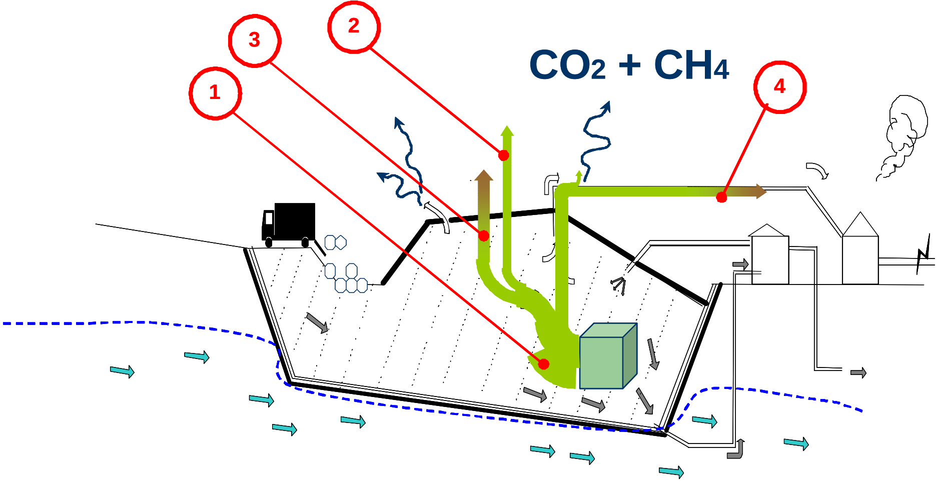
[5] In the context of Greenhouse Gas Inventory publications, e.g. IPCC Guidelines, the International System is used, and therefore 1 tonne will be 1Mg (M, Mega=10^6), 1000 tonnes will be 1Gg (G, Giga= 10^9), and 1 million tonnes will be 1Tg (T, Tera, 10^{12}).

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 6.2. No methodology is provided for N_2O emissions from landfills due to their small significance.

Figure 6.2 Sources of carbon emissions in a landfill



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. mass balances, which would assume immediate emissions after deposition in a landfill.

The GHG model has been completed with CO_2, N_2O and CH_4 emissions from all sources (landfill, incineration, and recycling - including composting), and 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 6.1. We have chosen the 100 years time horizon.

Table 6.1 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
Carbon dioxide	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: Climate Change 1995, The Science of Climate Change: Summary for Policymakers and Technical Summary of the Working Group I Report, page 22.

6.2. IPCC guideline and country reports to UNFCCC

The emission of greenhouse gasses from the waste sector in Europe has 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 guideline is from 2006 (IPCC, 2006).

The IPCC Guideline describes in detail how to model greenhouse gas emissions from waste management (composting, incineration and 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 better match national waste generation and management characteristics.

Using either the IPCC proposed method or national methods, all EU Member States report yearly their estimates of greenhouse gas emissions from waste management 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 is one of the main sources for the estimation of emissions from landfilling. 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.

The studies by Gugele et al. (2005, 2006, 2007) include figures and tables giving an overview of the methodologies, and data completeness of the NIR and CRF from EU-15.

The main data source is the NIR and CRF of the EU-27 Member States, and the data on municipal waste generation, landfilling and incineration reported by Eurostat.

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

1) Activity data: are data on amounts of landfilled biodegradable waste. 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.

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.

The time-dependent methodology developed by IPCC has been used to model emissions in all EU-27 countries, using the background activity information provided, and regardless of the method used in these countries for NIR and CRF reporting.

To model the emissions from landfill, the IPCC Guideline model uses a series of coefficients, which are technical parameters that help modelling the generation of GHG from landfill sites and incineration plants. The IPCC coefficients are used as default values, but national data have been used instead if reported by Member States in the NIR. When the coefficients are not available, they are estimated based on IPCC default values.

6.2.1. Waste composition

Unless otherwise specified, data on the composition of waste is acquired from the NIR and CRF reports 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 1950-2004, and that it will not change in the period 2005-2020. This means that in the model, the composition of municipal waste in each country remains constant throughout the period 1950-2020[6]. The composition varies from country to country and for those countries that explicitly report the composition variation in the years 1990-2005, we have included that.

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 may be 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 (2001)
- Recovery rates, Source collection rates (paper, glass, biodegradable waste): OECD (2001), European Commission’s reporting on the Landfill Directive (1999/31/EC)

In addition, the waste materials reported in the NIR/CRF diverges slightly from the model used in this project. 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, we have chosen to keep 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 according to 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, we have calculated the amount of organic waste as food waste. Food waste and garden waste contain the same amount of degradable organic carbon, but have different half-life values. This implies that in the calculations, the speed at which the waste degrades is somewhat overrated. The total amount of methane generated is, however, the same.

6.3. Modelling GHG emissions from landfills

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

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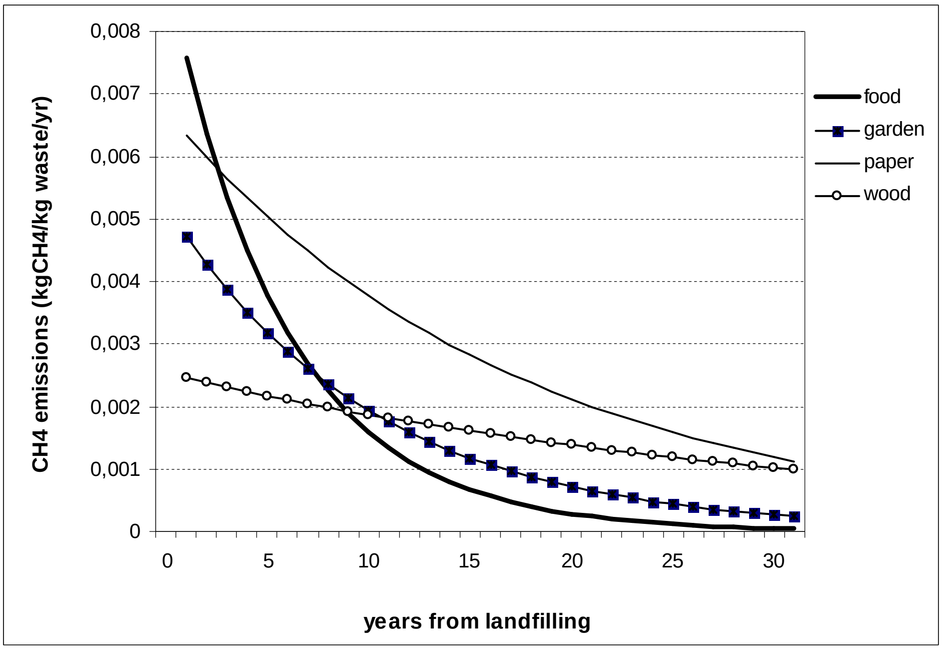
[6] For some countries the waste composition changes over the period (e.g. Ireland, Netherlands and Denmark).

year. According to the IPCC Guideline, 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; Jensen and Pippatti, 1996; IPCC, 2006).

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 6.3 for 1kg of different waste materials with different degradation rates.

Figure 6.3 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).

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 Guideline.

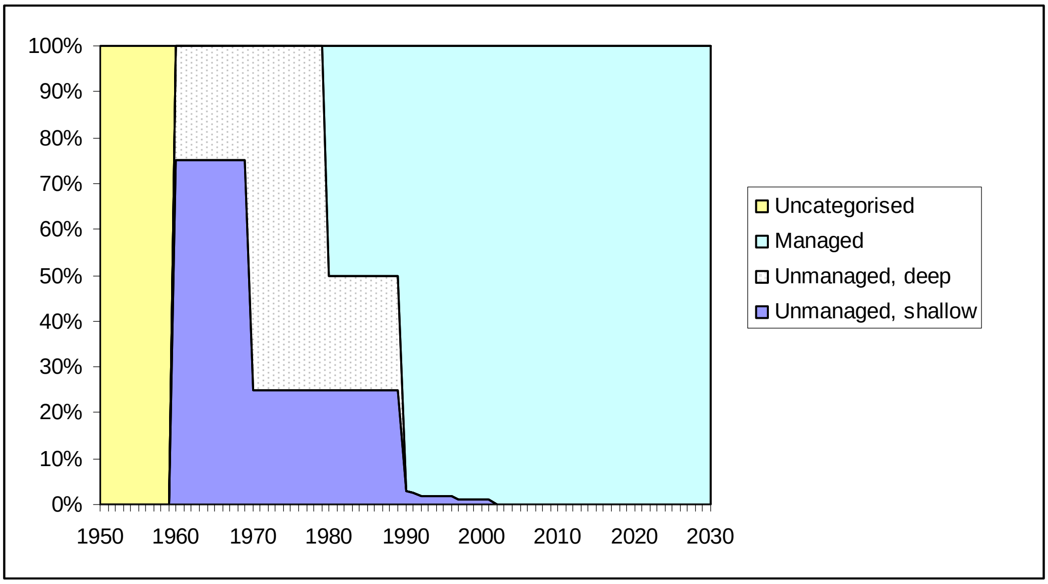
All EU-15 Member States apart from Greece and Luxembourg apply in the inventories for 2005 the Tier 2 methods in order to estimate CH_4 emissions from landfills, in line with the IPCC good practice guidance. While the method used in Luxembourg is not indicated, Greece applied a simplified, time-independent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

The modelling of landfill emissions has been undertaken using a two-string approach:

1) use of the NIR and CRF data exclusively
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 solid waste disposal sites.

In the model, the methane correction factor (MCF) is used to take into account the fact 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 1990-2005 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, we had to estimate MCF values in the time span 1950-1990. In general, we have assumed that prior to the use of managed landfills, landfilling was performed at a mix of shallow and deep unmanaged landfills. Furthermore, we have assumed that when going back in time the share of shallow, unmanaged landfills will increase. This trend is incorporated in the assumed composition of landfill types in the period from 1950-1990. In the model, we assume that the MCF factors/landfill types change gradually every 10 years. Figure 6.4 illustrates the assumed evolution of landfill types (and MCF values) in Finland as an example.

Figure 6.4 Assumed evolution of landfill types (and MCF values) in Finland



We assume the maximum feasible recovery rate for methane gas is 20%. This percentage is considered a maximum technically achievable recovery rate, and it has been used as the maximum, regardless of the values reported in the NIR and CRF. According to the experience of Oonk (2006) and Willumsen (2005), the maximum recovery values in European landfills lie rather between 20% for landfills in operation and 37% for closed, controlled landfills. The IPCC Guideline estimate a default value of 20% (IPCC, 2006). According to the Guideline, country-specific values may be used, but then significant research is necessary to obtain information on the following parameters: cover type, percentage of solid waste disposal sites covered by recovery project, presence of a liner, open or closed status, and other factors.

Most of the EU-15 Member States reach a level above 20% in their reported recovery rates (EEA, 2007). From the point where 20% is reached, a constant maximum rate of 20% has been assumed until 2020. If a country has reported recovery rates below 20%, data is extrapolated until the 20% maximum is reached.

In general, the recovery rates in the New EU-12 Member States are much lower. In countries where a rate of 0% has been reported until 2005, we have assumed that the recovery of methane starts in 2013 by 2%. This is an anticipated result of the Landfill Directive (1999/31/EC). Furthermore, we have assumed that these countries reach a recovery rate of 20% in 2020. In the remaining EU-12 Member States, we have extrapolated data to 20% as in the case of the EU-15 Member States.

6.4. Modelling GHG emissions from incineration

The estimations of emissions from incineration are based on the composition of the waste and the mass balance of carbon. The calculation is as follows:

$$\textit{kg CO2/year} = \textit{kg MSW for incineration} \cdot \textit{oxidation factor of carbon in incinerator (0,98)} \cdot \textit{conversion factor of C to } CO_2 \textit{ (3.67)} \cdot \sum(\textit{waste fraction}_i \textit{ (in \%)} \cdot \textit{dry matter content}_i \cdot \textit{carbon content}_i \textit{ (g/g dry weight)})$$

The emission factors used are presented in Table 6.2.

Table 6.2 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

6.5. Modelling GHG emissions from recycling

Recycling of municipal waste is a complex mix of several treatment processes. In some cases, not all parts of the separated fractions can be recycled and are instead incinerated or landfilled. In 2006, the Topic Centre carried out a study (ETC/RWM, 2006) that included collection of data and modelling of the environmental impacts from the recycling processes of organic waste, paper, plastic, glass, metals and wood. Together with data on textile extracted from the Gabi EDIP database[7], we have modelled the total emissions from recycling of municipal waste.

Table 6.3 shows how the recycling processes are modelled and the data sources used. With regard to the incineration of waste, a 50/50 distribution on medium and high standard incineration plants is used to calculate the output of electricity and thermal energy.

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[7] EDIP is the official Danish LCA database maintained by LCA Center Denmark, www.lca-center.dk

Table 6.3 Recycling processes

	Recycling	Incineration[8]	Landfill	Data sources
Organic waste	40% composting closed reactor, 40% composting open, 20% digestion	Incineration plant, 50% medium standard, 50% high standard	Methane for recovery	ETC/RWM, 2006
Paper and cardboard	Material recycling, 50% pulping + deinking (newspaper & copypaper), 50% pulper (cardboard)	Incineration plant, 50% medium standard, 50% high standard	Methane for recovery	ETC/RWM, 2006
Plastic	Material recycling, gasification, incineration of residuals	Incineration plant, 50% medium standard, 50% high standard	No degradation	ETC/RWM, 2006
Glass	Production of glass cullets	No incineration	No degradation	ETC/RWM, 2006
Metals	Material recycling, 33% aluminium, 67% tinplate	No incineration	No degradation	ETC/RWM, 2006
Wood	Production of wood chips	Biomass heating power plant high standard	Methane for recovery	ETC/RWM, 2006
Textile	Material recycling, 40% cotton, 60% polyester	Incineration plant	Methane for recovery	Gabi UMIP database

The resulting emission factors are shown in Table 6.4. These are based on 2006 data and we have assumed that this will not change during time. Of course, the processes have been less efficient in previous times and are expected to become more efficient in future times. However, we have not had access to information to justify such type of projections.

Table 6.4 Emission factors used for recycling processes

	Organic waste	Paper & cardboard	Plastic	Glass	Metals	Wood	Textile
gCO_2/g material	9.4E-03	1.1E-01	1.3E+00	2.1E-02	8.6E-01	2.4E-02	2.2E-01
gCH_4/g material	1.25E-05	2.17E-04	6.02E-04	1.00E-05	1.09E-03	4.10E-05	4.29E-04
gN_2O/g material	1.38E-04	3.06E-06	7.04E-07	1.92E-08	1.01E-05	1.10E-05	5.56E-06

Most of the processes represent German facilities, since no European averages exist in the LCA databases. In order to account for the variations in the mix of energy sources in Europe, the German energy mix has been substituted by an EU-25 energy mix. The emissions from this energy mix is calculated using LCA data sets on electricity and heat production from the European Reference Life Cycle Data System (ELCD) and information on the consumption of electricity and heat in the European countries from the International Energy Agency. Ireland, Cyprus and Malta have not been included due to lack of data.

The estimated emissions per MJ energy produced are shown in Table 6.5. These were converted into CO_2-equivalents using the conversion factors presented in Table 6.1.

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[8] High and medium standards refer to the efficiency of flue gas cleaning. Efficiency: net electricity = 10%; net thermal energy = 30%. For wood, high standard means that the plant meets the requirements of the German directive on combustion (17. BImSchV) and therefore wood containing hazardous substances is allowed to be treated in this plant. Efficiency: net electricity = 19%; net thermal energy = 46%.

Table 6.5 Estimated emissions from the production of electricity and thermal energy, EU-25, kg/MJ

	Electricity	**Thermal energy**
CO_2	0.16	0.067
N_2O	3.9E-06	1.9E-06
CH_4	0.0003	0.0002

Sources: Electricity: European LCA platform ELCD data on electricity production in the EU countries (2002) + IEA energy consumption statistics (2004); Thermal energy: European LCA platform ELCD data on thermal energy production in EU-25 (2002)

6.6. Estimation of indirect effects

The model also takes into account 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).

This part of the model is based on life cycle data collected from ETC/RWM (2006) and the Gabi EDIP database. As it is the case with the direct effects from recycling, the German energy mix has been replaced by an EU-25 energy mix. Table 6.6 presents the processes that we have used to model the emissions avoided by landfilling, incineration and recycling. For landfilling, only the biodegradable waste fractions contribute to the energy recovery. In the incineration plant, there are no benefits from glass and metals. By recycling, the use of virgin materials is avoided, and thus the emissions from production of these materials are saved.

Table 6.6 Production processes avoided by recycling, incineration and landfilling

	Saved energy production from methane recovery	**Saved energy production from incineration**	**Saved material production by recycling**
Organic waste	Electricity	Electricity and thermal energy	Organic substance, mineral fertilizer
Paper and cardboard	Electricity	Electricity and thermal energy	Newspaper, copy paper, cardboard
Plastic	No benefits	Electricity and thermal energy	Polyolefins, polyethylen, polystyrene, wood and concrete palisades, methanol
Glass	No benefits	No benefits	Glass bottles (with 71% cullets)
Metals	No benefits	No benefits	Aluminium and tinplate
Wood	Electricity	Electricity and thermal energy	Industrial wood (harvesting and processing for use as chipboards)
Textile	Electricity	Electricity and thermal energy	Cotton fibres and polyester

6.6.1. Landfills

The indirect effects from landfilling have been calculated by converting the amount of methane available for recovery (see Table 6.7) into the potential amount of energy produced from this recovery. A maximum of 20% recovery of landfill gas is used for all of the waste fractions. We used a higher heating value (HHV) of methane of 55 MJ/kg CH_4.

Table 6.7 Estimated amount of methane available for recovery from each waste fraction (kg CH4/kg wet material)

Food	Garden	Paper	Wood	Textile	Plastics	Metals	Inert
0.011	0.012	0.029	0.032	0.018	0	0	0

Furthermore, we have estimated the emissions from the production of electricity and thermal energy, i.e. the saved energy production, see Table 6.5 above. For methane recovery, we assume that only electricity is produced and that this is done with an efficiency of 33% (CIWM, 2003).

On this basis, we have calculated the indirect emissions from landfills as:

$$CO_2 \text{ savings} = \text{methane for recovery (kg)} \cdot \text{HHV (MJ/kg)} \cdot \text{efficiency (33\%)} \cdot CO_2 \text{ emissions/MJ for electricity}$$

6.6.2. Incineration

To estimate the indirect effects from incineration, we have calculated how much energy is produced in the incineration plants. The potential for energy production was calculated as follows:

$$\text{Energy content} = \text{kg waste} \cdot \sum(\text{waste fraction}_i \text{ (\%)} \cdot \text{calorific value}_i \text{ (J/kg)})$$

The calorific values of the different waste fractions are shown in Table 6.8.

Table 6.8 Calorific value of waste fractions

	Food	Garden	Paper	Wood	Textile	Plastics	Inert
Calorific value of the materials (GJ/Mg)	2	5	15	15	16	30	0

The distribution of energy on electricity and heat in the incineration plants is estimated on the basis of CIWM (2003) and CEWEP[9] national reports. The indirect effects from incineration have been calculated as follows:

$$CO_2 \text{ savings} = \text{energy content (MJ)} \cdot (\text{electricity\%} \cdot \text{efficiency (33\%)} \cdot CO_2 \text{ emissions/MJ for electricity} + \text{heat\%} \cdot \text{efficiency (56\%)} \cdot CO_2 \text{ emissions/MJ for thermal energy})$$

6.6.3. Recycling

The calculation of the indirect effects from recycling was based on life cycle information in the same way as the direct effects were modelled.

6.6.4. Total indirect emissions

The total sum of CO_2-equivalents for each of the treatment methods is shown in Table 6.9. There are some uncertainties linked to these figures as they are mainly based on German data and EU-25 energy averages.

Table 6.9 Emission factors used for estimation of indirect effects

gCO_2-equivalents/ g material	Organic waste	Paper & cardboard	Plastic	Glass	Metals	Wood	Textile
Landfilling	-0.06	-0.15	0	0	0	-0.16	-0.09
Incineration	-0.09	-0.69	-1.28	0	0	-0.95	-2.29

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[9] Confederation of European Waste-to-Energy plants

Recycling	-0.13	-0.68	-1.71	-0.18	-4.09	-0.09	-1.95

In this project we were not concerned with the relative differences between the treatment options, but only the absolute values of the direct and the indirect effects. To gain more information on comparisons of waste treatment we refer to two of the Topic Centre's previous studies that compare environmental impacts from the treatment of paper (EEA, 2006) and other waste fractions (WRAP, 2006) on the basis of several life cycle assessments.

6.7. Inclusion of biogenic and anthropogenic CO_2 emissions

GHG emissions have been split into two categories: anthropogenic and biogenic, following the IPCC definitions (IPCC, 2006). The results presented in this report include only the anthropogenic CO_2 emissions. We have assumed that the CO_2 release from incineration of plastics and the fraction of synthetic textiles (60%) is anthropogenic. In landfilling, we have considered plastics (incl. 40% of the textiles), glass and metals as inert materials, and the CO_2 emissions from the remaining fractions are all biogenic. However, considerable CH_4 emissions are released from landfills, and these are accounted for as anthropogenic. We assume that all N_2O emissions are anthropogenic.

6.8. Waste collection – transport

We have used the data on collection of waste that was also modelled in ETC/RWM (2006). Table 6.10 shows the distances and the emissions in CO_2-equivalents.

Table 6.10 Transport distances and emissions

Waste fraction		Vehicle and distances	g CO2-eqivalents/ kg material
MSW for incineration and landfilling		Refuse collection vehicle; collection tour: 11.46 km; distance to sorting plant: 14.52 km (medium data for Germany)	7.59
Recycling	Organic waste	Refuse collection vehicle; collection tour: 14,425 km; distance to sorting plant: 16,85 km (medium data for Germany)	9.83
	Paper & cardboard	Refuse collection vehicle; collection tour: 14,25 km; distance to sorting plant: 13,93 km (medium data for Germany)	10.07
	Plastic Wood Textile	Refuse collection vehicle; collection tour: 11,32 km; distance to sorting plant: 15,44 km (medium data for Germany)	17.36
	Glass	Refuse collection vehicle; collection tour: 15 km; distance to sorting plant: 75 km (medium data for Germany)	15.11
	Wood	Refuse collection vehicle; collection tour: 10,9 km; distance to sorting plant: 14,8 km (medium data for Germany)	11.94

Source : ETC/RWM (2006)

7. Baseline scenario for municipal waste

In this section we present a likely, future development in generation of waste, management of waste and emission of greenhouse gases based on the model and assumptions described in sections 3 to 6. This is provided that no new and innovative policy measures are introduced to further prevent the generation of waste or to divert waste from landfill.

The baseline scenario has been designed to assume what is likely to happen – not necessary to meet the objectives of the Sixth Environment Action Programme or targets of specific directives, such as the Landfill Directive.

7.1. Municipal waste generation

The projected growth in the municipal waste generation in the EU Member States, Norway and Switzerland[10] are presented in Tables 7.1 and 7.2.

In the EU-15, the generation of municipal waste is projected to increase by approx. 9% from 2005 to 2010, by 22% in 2020[11]. Except for a few countries (Austria, the Netherlands, Luxembourg and Portugal), the projected increase in waste generation is between 22% and 43%.

Waste generation in the New EU-12 is projected to grow faster than in the EU-15, i.e. increase by 11% from 2005 to 2010, by 50% in 2020[12]. However, the variations between countries are significant. The estimations show that Slovenia and Latvia will have a considerably lower growth than the Czech Republic, Hungary, Malta and the Slovak Republic who all have a projected growth of more than 60% from 2005 to 2020. The waste generation in Bulgaria is projected to decrease by 15% from 2005 to 2020. Norway and Switzerland are projected to have a higher long-term growth in waste generation than the EU-15.

Table 7.1 Projected growth in municipal waste generation in the EU-15, 2005-2030

Percent	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	22.3

Table 7.2 Projected growth in municipal waste generation in the New EU-12 and EEA2, 2005-2030

Percent	BG	CY	CZ	EE	HU	LT	LV	MT	PL	RO	SI	SK	New EU-12	NO	CH
2005-10	-5.9	13.0	13.7	14.1	15.9	7.4	6.8	22.0	7.9	19.4	-1.4	4.4	10.7	8.5	10.3
2005-20	-15.4	45.7	63.5	43.7	62.1	31.8	18.7	63.7	66.0	56.4	4.5	54.3	49.9	28.6	35.4

The generation of municipal waste in the EU-15 from 2005 to 2020 is presented in Figure 7.1. 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 the waste is generated in Germany, the United Kingdom, France, Italy and Spain.

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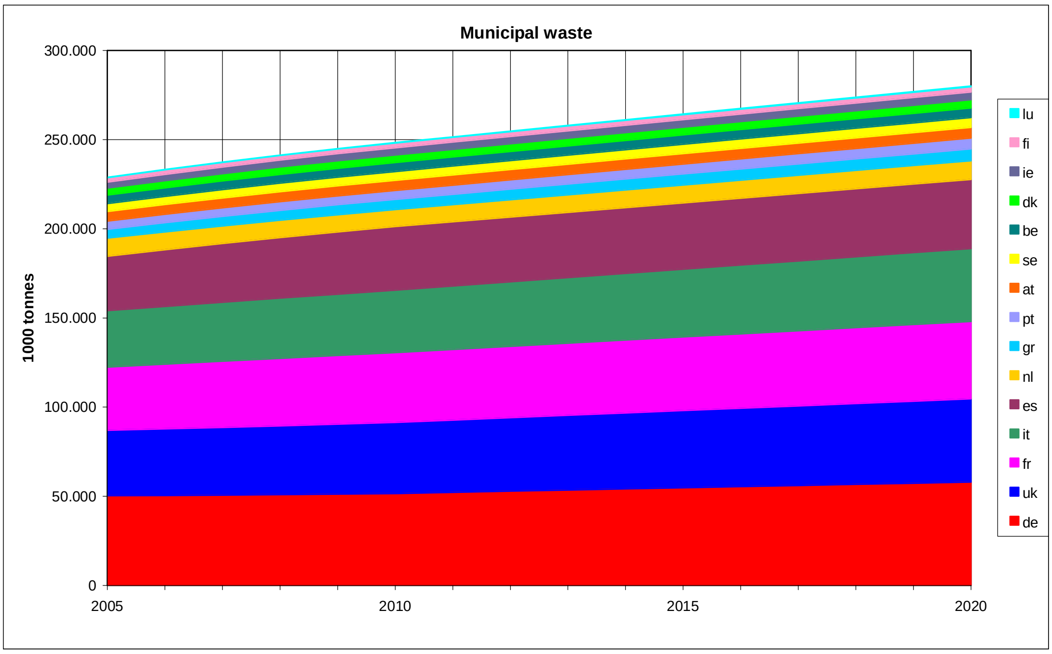
[10] Data from Norway and Switzerland are included as these countries were also included in the initial phases of this project.

[11] The annual growth rates are 1.6% p.a. till 2010; 1.4% till 2020.

[12] The annual growth rates are 2.1% p.a. till 2010; 2.7% till 2020.

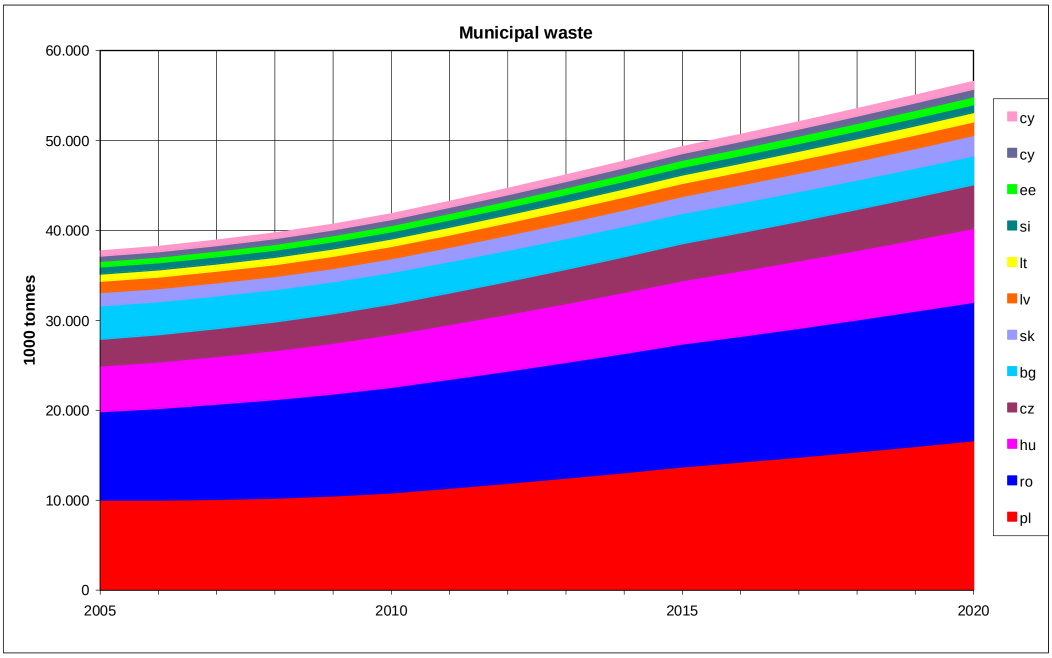
Figure 7.1 Generation of municipal waste in the EU-15, 2005-2020



Note: Country codes, see Annex I.

A similar situation applies for the New EU-12 where Poland, Romania and Hungary produce around 70% of the total waste generated. As the three countries have a projected growth above the EU-12 average, the result is a rapidly growing curve as shown in Figure 7.2.

Figure 7.2 Generation of municipal waste in the New EU-12, 2005-2020



Note: Country codes, see Annex I.

In 2010 the generation of municipal waste in the EU-27 is projected to be around 290 million tonnes with a further increase to some 335 million tonnes in 2020. The projected amounts for each country are shown in Table 7.3 and 7.4.

Table 7.3 Projected generation of municipal waste in the EU-15, 2010 and 2020, million tonnes

	AT	BE	DE	DK	ES	FI	FR	GR	IE	IT	LU	NL	PT	SE	UK	EU-15
2010	5.7	5.1	51.5	4.2	35.7	2.6	39.2	5.8	4.0	35.0	0.3	9.5	5.0	4.9	39.9	248.4
2020	6.0	5.5	57.9	4.5	38.7	2.9	43.4	6.6	4.4	40.9	0.5	10.5	6.1	5.5	46.7	280.1

Table 7.4 Projected generation of municipal waste in the New EU-12, Norway and Switzerland, 2010 and 2020, million tonnes

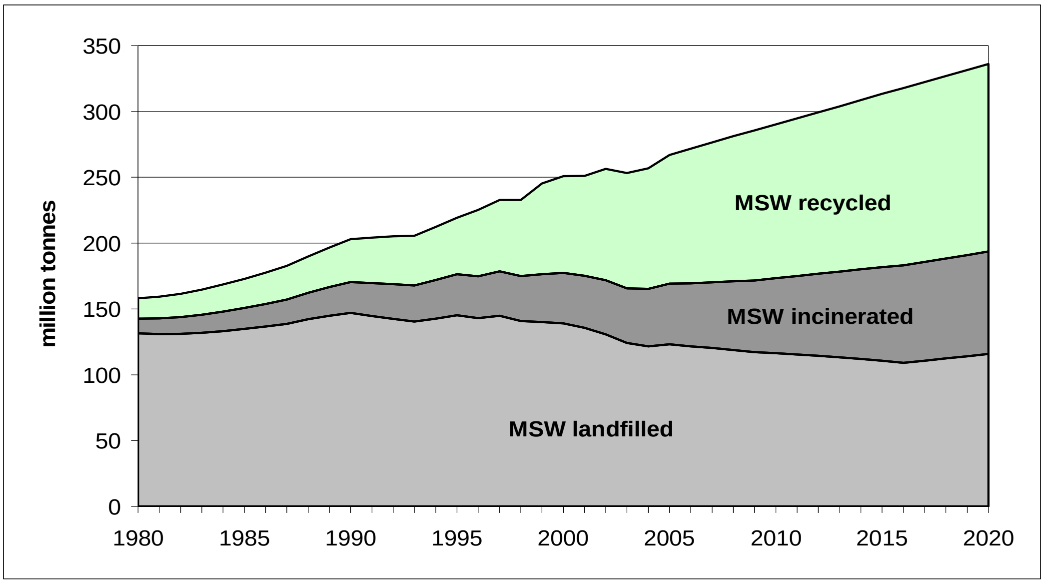
	BG	CY	CZ	EE	HU	LT	LV	MT	PL	RO	SI	SK	New EU-12	NO	CH
2010	3.5	0.7	3.4	0.7	5.9	0.8	1.4	0.3	10.8	11.8	0.8	1.5	41.5	3.3	5.7
2020	3.1	0.8	4.9	0.9	8.2	1.0	1.5	0.4	16.6	15.4	0.8	2.3	56.0	4.0	7.0

7.2. Municipal waste management

The management of waste is illustrated in Figure 7.3. Before 1990, around 90% of the municipal waste was disposed of in landfills. However, in the late 1980s and beginning of the 1990s, several countries began introducing policies to reduce the use of landfills as outlet for municipal waste. In 1994 and 1999, two directives aiming to increase the recycling and recovery of packaging waste (Packaging and Packaging Waste Directive) and to divert biodegradable municipal waste away from landfill (Landfill Directive) were introduced. Both directives have reinforced the diversion of waste from landfill.

It is expected that the diversion will continue, but a slight increase in landfilled waste is seen from 2017. The model uses relative shares of landfill, incineration and recycling, and due to the considerable increase in waste generation, the landfill share will have to be very low if the landfill of waste is to remain at a constant level or even decrease. In 2020, 34% of the generated waste is assumed to be landfilled. This share may be too high, especially in the light of the latest Structural Indicators published by Eurostat that shows a landfill rate in the EU-15 of 34% in 2006 and 41% for the EU-27 (Eurostat). Incineration of waste with energy recovery is assumed to reach 23% in 2020.

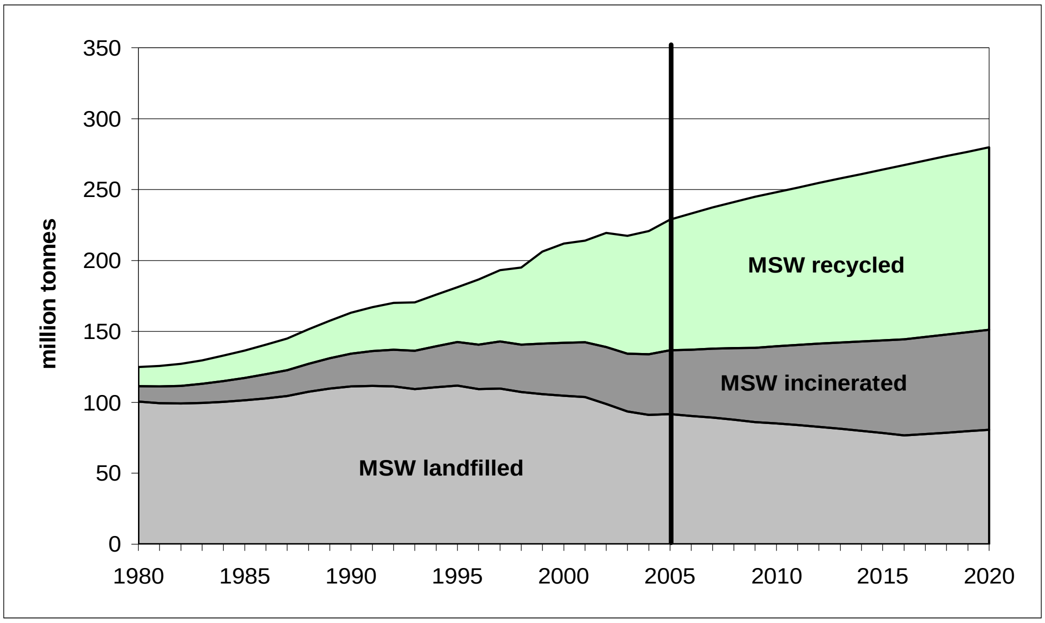
Figure 7.3 Municipal waste management in the EU-27



Figures 7.4 and 7.5 show the management of municipal waste in the EU-15 and the New EU-12 respectively.

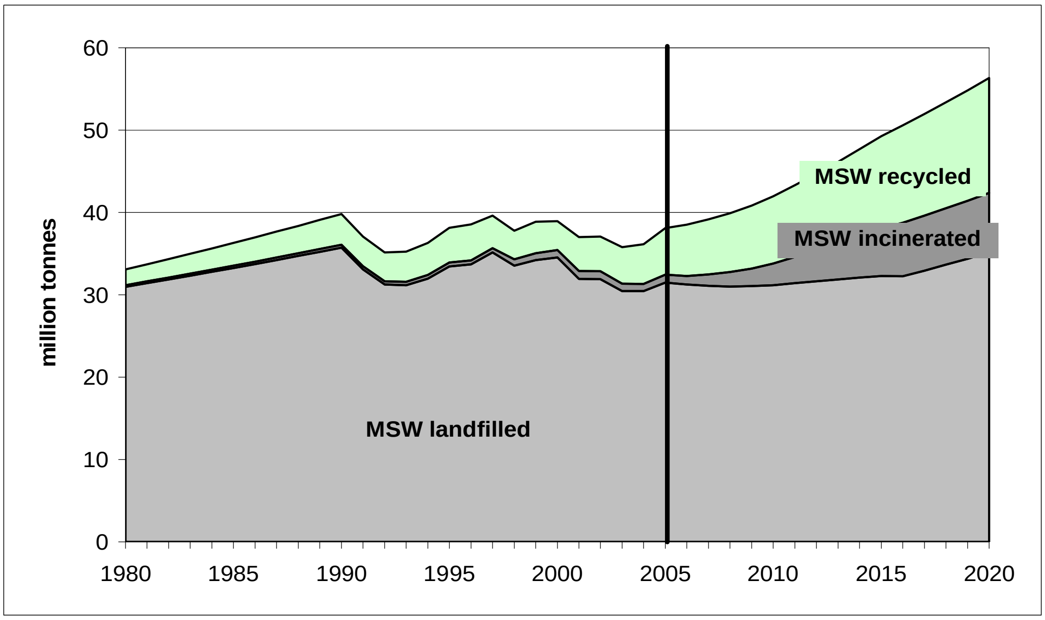
Most municipal waste was also landfilled in the EU-15 until 1990. From the mid-1990s Member States started to expand their recycling activities noticeably, most likely as a result of the German Packaging Ordinance in 1991 (which led to the 'Green dot' system which later spread across Europe) and later the Packaging and Packaging Waste Directive in 1994. This trend is expected to continue, albeit at a slower rate. Incineration with energy recovery is also expected to increase to some extent.

Figure 7.4 Municipal waste management in the EU-15



Note: the line in 2005 shows when the projection begins.

Figure 7.5 Municipal waste management in the New EU-12



Note: the line in 2005 shows when the projection begins.

In the New EU-12 almost all waste was landfilled up to 1990. This situation continues after 1990, but some countries such as Slovakia, Slovenia and Hungary started to divert waste from landfills (they landfilled between 49% and 77% in 1995). However, since then all three countries experienced an increase in the landfill rates. In Slovenia and Hungary the increase took place between 1995 and 1998-2001 while in Slovakia the landfill rate continued to increase until 2003. The Czech Republic and Estonia both have decreasing landfill rates from 2001. In Poland the landfill rate remained constant at 97-98% between 1995 and 2003, but in 2006 it seems to have fallen to 91% (Eurostat).

The estimation shows that the landfill of municipal waste will decrease to around 60% in 2020. Very little waste was incinerated with energy recovery till 2005, but we have assumed that this will increase to around 13% in 2020.

7.3. Greenhouse gas emissions

In order to obtain an overall view of waste management, the net balance of greenhouse gas emissions is calculated. Figure 7.6 presents the direct emissions from landfill sites, incineration plants, recycling operations and collection of waste on the positive side of the y-axis.

Direct emissions represent, however, only a part of the picture of GHG emissions from waste. The energy and secondary materials produced when incinerating and recycling waste replace energy production from fossil fuels and the use of raw materials for plastics, paper, metals etc. Using life-cycle information, these ‘savings’ or indirect effects can be translated into CO_2-equivalents, as presented on the negative side of the y-axis. The mentioned savings also include a minor contribution from landfills, namely the avoided CO_2 emissions when methane is recovered in landfills and used as an energy source, substituting traditional (mostly fossil-fuel based) energy production.

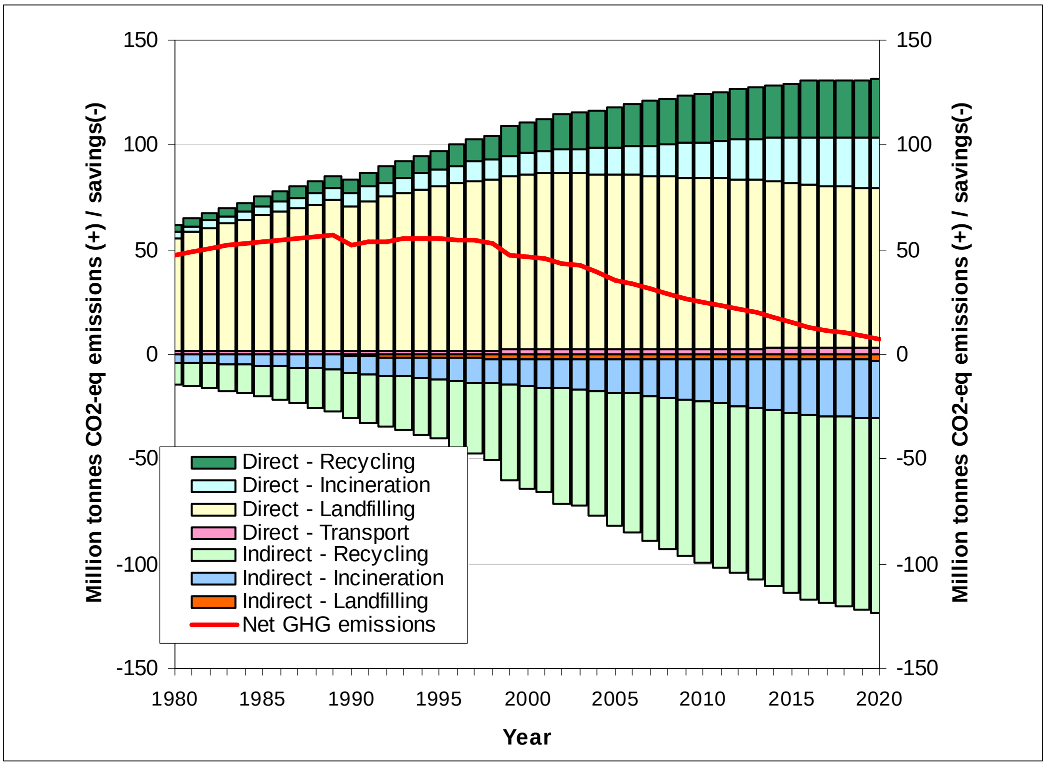
Moreover, if a country has a very low landfill rate as a consequence of high recycling and possibly energy recovery (combined with a low growth in waste volumes), the net emissions of greenhouse gases from the waste sector may even become negative. This means that an effective management of waste with high recycling and possibly incineration can partly offset the emissions that occurred when the raw materials and products were extracted and manufactured. If the greenhouse gas emissions become ‘negative’ it would imply that the waste management sector contributes to or eases the meeting of the Kyoto targets.

The estimated emissions of greenhouse gases in the EU-27 for the period 1980 to 2020 are shown in Figure 7.6. The net emissions of greenhouse gases from the management of municipal waste are projected to decline from around 55 million tonnes CO_2-equivalents per year in the late 1980s to 10 million tonnes CO_2-equivalents by 2020. In 2005, the greenhouse gas emissions from waste management (including wastewater treatment) represented 2.6% of the total emissions in the EU-15 (Gugele et al., 2007).

The direct emissions from landfills continue being a major source of greenhouse gases till 2020 despite the fact that only 34% waste is landfilled. This is due to the delay of methane emissions from landfill. Because of the rate of decay of waste with biodegradable contents, methane emissions will occur for several years after the waste was landfilled (the first order decay model presented in section 6.3). The direct and indirect emissions are shown in Table 7.5.

But, as a counterweight, the increase in recycling leads to a rapid increase in the indirect emissions, or avoided emissions, from recycling of waste.

Figure 7.6 Greenhouse gas emissions from municipal waste in EU-27, million tonnes CO_2-equivalents



As for the estimation of emissions from recycling, we have taken a global approach. This implies that both direct and indirect emissions from recycling are ascribed to the country that generates and collects waste for recycling. Thus, even though the recycling or the manufacturing of materials may not physically take place in the country, or even within the EU for that matter, the emissions are still considered as arising in (or allocated to) the country. In practise however, when a country exports waste for recycling, the emissions from the recycling process are not included in the export country's GHG emission and neither are emissions from manufacturing of materials or products that are imported and will become waste at a later stage. Hence, the model reflects the GHG emissions and savings *caused* by the EU-27, regardless of where these emissions arise. The model does not take into account that the emission factors from treatment of waste exported to countries outside the EU-27 may be different.

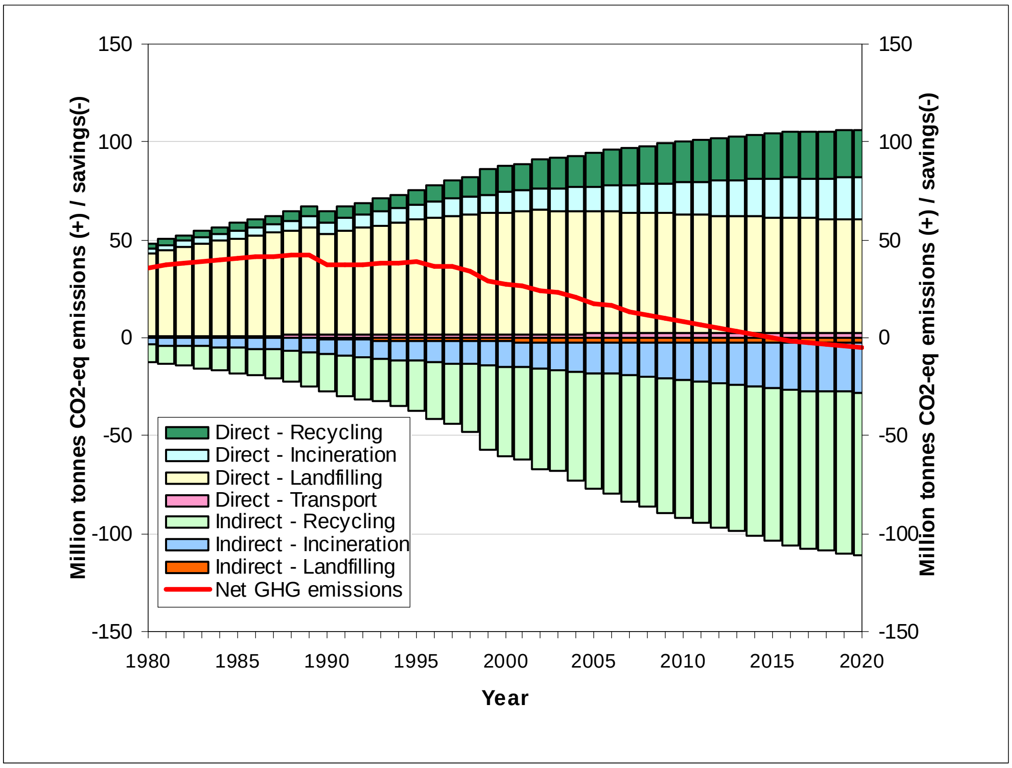
Another interesting finding is that the collection and transport of waste accounts for less than 5% of estimated GHG emissions, and is therefore not an important contributor to the climate change effect of the waste sector. However, GHG emission is only one indicator among several to illustrate environmental pressures. In a broader environmental context, pressures such as particles, noise or accidents may make transport a more significant contributor of impacts in the waste sector.

The GHG emissions from the management of municipal waste in the EU-15 and the New EU-12 are shown in Figures 7.7 and 7.8.

We have estimated that the net GHG emissions in the EU-15 will decrease even further than in the EU-27, thereby making the waste management sector neutral or a sink for GHG emissions. As is the case in the EU-27, the direct emissions from landfill remain high as a result of the delayed methane emissions. However, as recycling is assumed to increase to around 46% in 2020, the indirect emissions will offset the direct emissions from landfill and recycling. The net emissions from incineration are close to nil.

The net greenhouse gas emissions in the EU-12 are also estimated to decrease although not quite as fast as in the EU-15. Again, the main source is the direct emissions from landfill even though we assume that landfill will decrease from 83% in 2005 to 62% in 2020. Recycling increases to 25% and incineration to 13%.

Figure 7.7 Greenhouse gas emissions from municipal waste in EU-15, million tonnes CO_2-equivalents



Note: The decrease in direct emissions from landfill around 1990 is due to the assumption that methane recovery starts from that year.

Figure 7.8 Greenhouse gas emissions from municipal waste in EU-12, million tonnes CO_2-equivalents

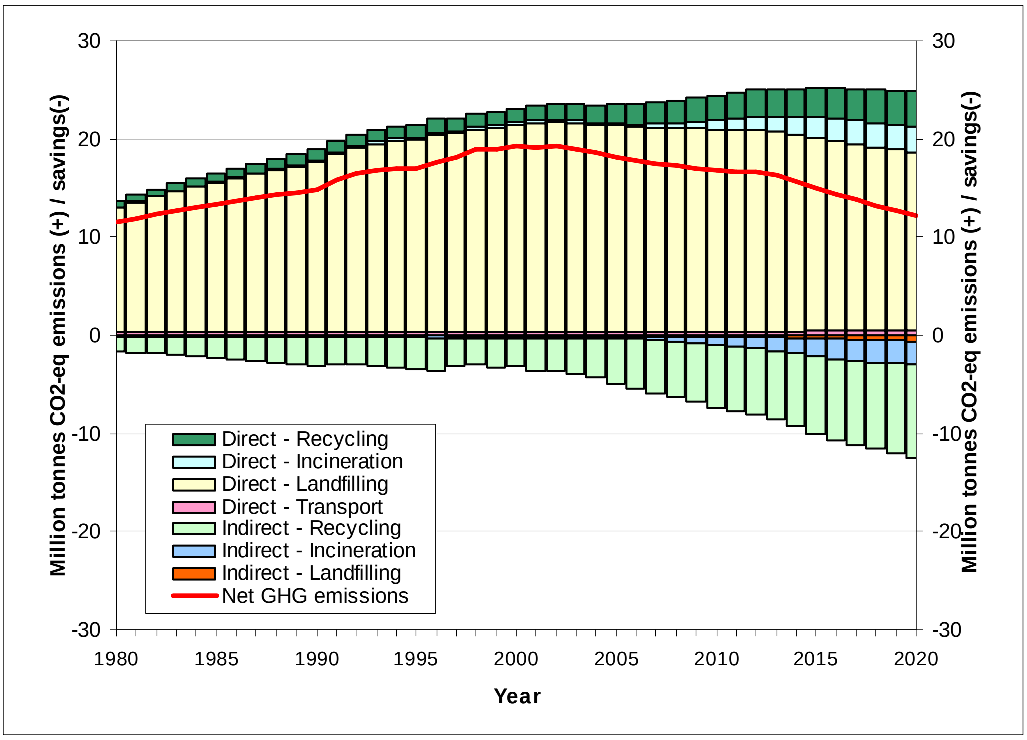


Table 7.5 Net emission of greenhouse gases for the waste management options and transport, million tonnes CO_2-equivalents

		1980	1990	2000	2010	2020
Landfill	Direct	54	69	83	82	76
	Indirect	0	-1	-2	-2	-3
Incineration	Direct	3	6	10	17	24
	Indirect	-4	-8	-13	-20	-28
Recycling	Direct	3	7	15	23	28
	Indirect	-10	-22	-49	-77	-93
Transport	Direct	1	2	2	3	3
Total	Net GHG	47	53	47	25	8

Note: The figures have been rounded off, and may not add up

The net emissions of greenhouse gases in each Member State is shown in Table 7.6 and 7.7 for the years 2010 and 2020. In several Member States the waste management sector will become a sink of GHG emissions, provided that the estimations are reasonable. These results should be interpreted carefully as one of the main assumptions in the modelling of the benefits from waste management is that emissions are the same throughout the EU-27.

Table 7.6 Net emission of greenhouse gases in the EU-15, 2010 and 2020, million tonnes CO_2-equivalents

	AT	BE	DE	DK	ES	FI	FR	GR	IE	IT	LU	NL	PT	SE	UK	EU-15
2005	158	-803	-8 741	-637	3 471	898	1 454	1 382	322	8 647	-26	-1 767	983	-462	12 716	17 595
2010	-43	-1 075	-11 222	-846	2 970	775	656	1 366	185	7 698	-33	-1 980	971	-840	9 631	8 211
2020	-187	-1 323	-15 562	-1 029	3 543	547	-201	2 025	345	5 988	-67	-2 615	829	-1182	4 330	-4 560

Note: Data in the table have been imported from an Excel sheet, and should be interpreted with care. The aim is to show a trend, not to predict an exact amount.

Table 7.7 Net emission of greenhouse gases in the New EU-12, 2010 and 2020, million tonnes CO_2-equivalents

	BG	CY	CZ	EE	HU	LT	LV	MT	PL	RO	SI	SK	New EU-12
2005	2 171	N/A	2 162	450	1 685	695	281	61	7 182	2 469	783	666	18 603
2010	2 133	N/A	1 616	398	1 583	480	306	57	6 499	2 887	542	579	17 081
2020	1 523	N/A	1 602	289	1 194	257	358	56	4 402	1 964	252	459	12 357

Note: Data in the table have been imported from an Excel sheet, and should be interpreted with care. The aim is to show a trend, not to predict an exact amount.

8. Sensitivity analysis and uncertainty

The aim of the projection is to show the likely, future trends not to predict exact amounts of waste generated or emissions of GHG. The model includes a wide range of parameters for waste quantities, waste composition, waste management, methane recovery, emission factors, etc. Some of these parameters are more uncertain than others. The results presented in this paper should therefore be interpreted carefully as the result may change if another set of parameters are applied.

The model includes 27 countries which all have different waste management conditions, and for some countries it may have been easier to collect detailed information than for others. However, it should be kept in mind that the objective is to show the consequences for Europe, which is why many of the assumptions on emission factors, methane recovery etc. are European rather than national data. This should also be seen as a strength of the model: the GHG emissions have been estimated using a similar approach for all 27 countries which should make the estimations more suitable for comparisons.

In this section, we present a limited number of sensitivity analyses. The first one is the level of methane recovery rate as it has turned out to have a substantial influence on the net GHG emissions. The second analysis is based on a different economic baseline scenario, namely the one for the OECD Environmental Outlook.

8.1. Methane recovery rate

A 20% limit in recovery of methane from landfills is assumed in accordance with the IPPC Guideline. However, this limit is considered a technical limit in 2006. An alternative scenario was set up using a maximum recovery rate of 30% by 2020. Data was extrapolated from 20% in 2006 to 30% in 2020 for all EU-15 countries and the EU-12 countries with high recovery rates. In the remaining cases, a 20% maximum is assumed in 2020 and 30% in 2030. Table 8.1 provides an overview of the assumptions in the baseline scenario and in this sensitivity analysis scenario.

Table 8.1 Methane recovery rates assumed for the New EU-12 in the baseline scenario and sensitivity analysis

Countries	Baseline scenario Maximum CH_4 recovery of 20%	Sensitivity analysis scenario Maximum CH_4 recovery of 30%
BG, LT,PL, SK, RO	Methane recovery starts in 2013 at 2%. 20% reached in 2020	Extrapolation from 20% in 2020 to 30% in 2030
CZ, EE, LV	Extrapolated to 20%	If 20% is reached, extrapolation to 30% in 2030
HU	Extrapolated to 20% in 2020	Extrapolation from 20% in 2020 to 30% in 2030
CZ, SI	20% reached in 2006	Extrapolation to 30% in 2030

Furthermore, the emissions have been modelled using the recovery rates reported by the countries to UNFCCC. As shown in the Annex of EEA (2007), nine Member States have methane recovery rates between 38% and 72%[13].

The results of these two scenarios are shown in Figure 8.2 in comparison with the baseline scenario (max 20% recovery). In the 20% scenario, the net emissions decreases more

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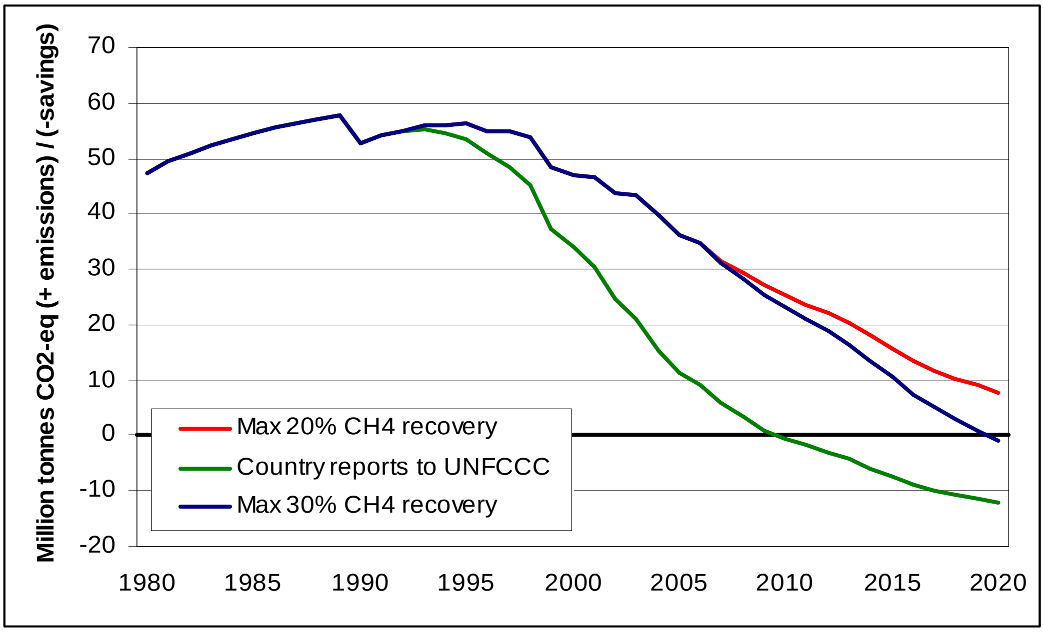
[13] Read from Figure 81 in the Annex.

steeply from 2007 and end as a negative value of nearly 900 000 million tonnes of CO_2-equivalents in 2020. In the scenario that follows the country reports, we see a steeper decrease in net emissions from 1993. In 2010 the net emissions become zero and reach a negative value of nearly 12 million tonnes in 2020.

Figure 8.2 Net emissions of greenhouse gases at different levels of methane recovery, EU-27



8.2. OECD Baseline scenario

As part of the preparation for the next OECD Environmental Outlook, the OECD has projected the global economic development for the period 2005-2030 (OECD, 2006).

The OECD baseline scenario includes a projection for 'Europe' only. Table 8.2 shows the growth rates for the OECD baseline scenario and the DG TREN baseline scenario presented in section 3. The projection of waste generation and GHG emissions presented in this paper is based on the DG TREN baseline scenario.

The OECD baseline scenario assumes a continuation of recent rapid growth rates for the first five years. After 2010 the economic growth is assumed to decelerate. In comparison the DG TREN baseline has lower short-term growth rates for the EU-27 and slightly higher after 2010. There are, however, considerable differences between the EU-15 and the 12 new Member States.

Table 8.2 GDP annual growth rates

Coverage	Source	2005-10	2010-20
EU-27	DG TREN	2.0%	2.3%
EU-15	DG TREN	1.8%	2.1%
EU-12	DG TREN	3.8%	4.3%
Europe	OECD	2.5%	2.1%

We have estimated the generation of municipal waste using the OECD baseline and keeping other model parameters constant. The growth rates for the private final consumption is assumed to be 0.1% lower than the GDP growth rates. In this analysis not all countries' waste generation will be affected, only the ones where the waste generation is explained via the economic activity variables (see Table 4.2 and 4.3). The result is shown in Table 8.3.

For the EU-27 the generation in the ETC/RWM baseline is projected to be 0.7% lower than the OECD baseline in 2010 and 1.6% higher in 2020. This result covers the fact that more waste will be produced in the ETC/RWM baseline due to higher growth rates in the new Member States.

Table 8.3 Comparison of municipal waste generation in the ETC/RWM and the OECD Baseline scenario

		2010	**2020**
EU-27	ETC/RWM projection, million tonnes	290	336
	OECD baseline, million tonnes	292	331
	Difference, %	-0.7%	1.6%
EU-15	ETC/RWM projection, million tonnes	248	280
	OECD baseline, million tonnes	253	286
	Difference, %	-2.0%	-2.1%
EU-12	ETC/RWM projection, million tonnes	42	56
	OECD baseline, million tonnes	39	45
	Difference, %	7.1%	19.8%

9. Improvements of the model

9.1. Alternative energy mix

The future energy mix is assumed to change towards including more renewable and nuclear energy while the share of fossil fuels can be assumed to decline. Thus, it would be interesting to analyse how a change in the energy scenario would affect the net GHG emissions as well as the relative effects of landfill, incineration and recycling.

9.2. Inclusion of more environmental pressures

Projecting the greenhouse gas emissions is of high political relevance at the moment in the EU and globally. Therefore, the initial focus of the model is on the emissions of CH_4, CO_2 and N_2O (the main greenhouse gases from the waste sector). Inclusion of other parameters such as acidification or toxicity can help drawing a more nuanced picture of the environmental impacts from waste management. So far, the focus has been on reducing uncertainties and improving the reliability of the results on greenhouse gases, but future work may include collection of data on other parameters through other report mechanisms and life cycle data.

9.3. 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[14] 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 9.1.

Table 9.1 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 will postpone attainment of the targets by four years (European Commission 2005a; DoEHLG 2006). The same applies to the New EU-

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

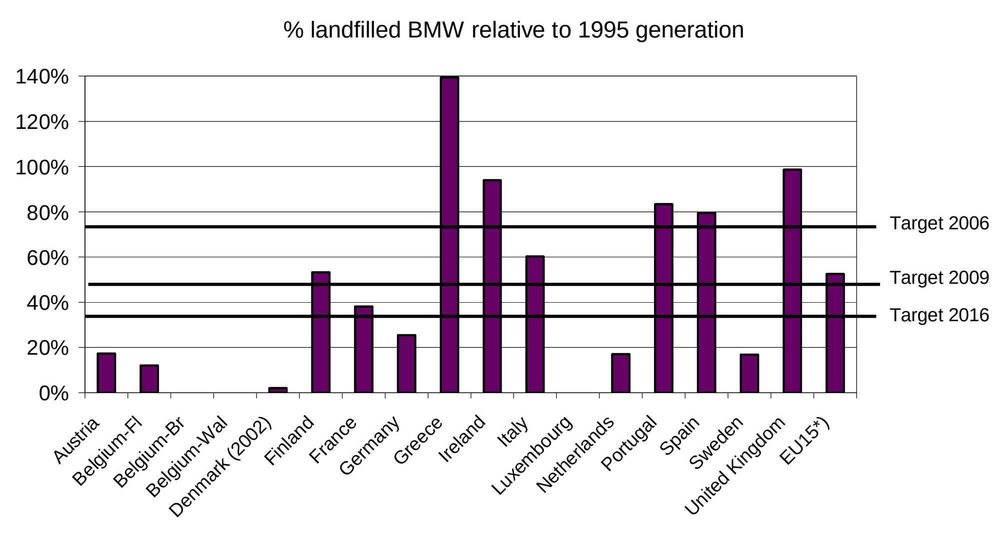
12, where it is assumed that most of the new Member States will use the four-year derogation.

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 9.1.

The status in the EU-15 for meeting the targets is presented in Figure 9.1. 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 is not already the case. It looks like additional efforts will be necessary to achieve the targets’ (European Commission, 2005a).

Figure 9.1 BMW distance to target, 2003



Note *): Excluding Luxembourg and the regions Wallonia and Brussels.
Source: European Commission (2006b).

In the model at the moment, the composition of waste is assumed to be more or less constant throughout the period, 1980-2020. Moreover, the biodegradable municipal waste is assumed to be managed the same way as municipal waste, i.e. the share of BMW sent to landfill, incineration or recycling is the same as for the rest of the municipal waste. This approach leads to the result that several Member States will not meet the targets of the Landfill Directive. One of the reasons for this is the increase in the generation of municipal waste (and thus BMW) which makes it difficult to meet the targets based on the absolute amount generated in 1995.

An improvement of the model would be to study the change in composition of waste as it is doubtful whether the increase in municipal waste is due to more organic waste being generated. It is more likely that the increase is due to more bulky waste (such as furniture, electric and electronic waste) and the collection of new waste streams.

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I. Annex: Abbreviations and country codes

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
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
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)
New EU-12	12 new EU Member States
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

Country codes for EU-15 and EU-12

	EU-15		*EU-12*
AT	Austria	BG	Bulgaria
BE	Belgium	CY	Cyprus
DE	Germany	CZ	Czech Republic
DK	Denmark	EE	Estonia
EL	Greece	HU	Hungary
ES	Spain	LT	Lithuania
FI	Finland	LV	Latvia
FR	France	MT	Malta
IE	Ireland	PL	Poland
IT	Italy	RO	Romania
LU	Luxembourg	SI	Slovenia
NL	The Netherlands	SK	Slovakia
PT	Portugal		
SE	Sweden		
UK	United Kingdom		

II. Annex: Modelling 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.

II.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).

II.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

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

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

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

Where:

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

III. Annex: Assumptions for estimation of GHG emissions 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	

Country	Data in NIR / CRF excel datasheets	Assumptions and estimations to cover non-reported data
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.
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.

Country	Data in NIR / CRF excel datasheets	Assumptions and estimations to cover non-reported data
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.
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)

Country	Data in NIR / CRF excel datasheets	Assumptions and estimations to cover non-reported data
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 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.

Country	Data in NIR / CRF excel datasheets	Assumptions and estimations to cover non-reported data
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

IV. Annex: Landfill and incineration rates

Table III.1 Municipal waste landfilled, 1995-2004

	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2006 (10)	2009 (13)	2016 (20)
EU-27	65%	62%	60%	59%	57%	56%	54%	51%	50%	47%			
EU-25	64%	61%	60%	58%	56%	54%	53%	50%	48%	45%			
EU-15	60%	57%	56%	54%	51%	50%	49%	46%	44%	41%			
Belgium	48%	47%	31%	24%	22%	17%	13%	13%	11%	10%	9%	9%	9%
Bulgaria	76%	77%	75%	77%	77%	77%	80%	81%	82%	84%	85%	80%	75%
Czech Republic	100%	100%	100%	93%	85%	84%	78%	73%	72%	72%	65%	60%	50%
Denmark	17%	13%	11%	11%	11%	10%	7%	6%	5%	4%	5%	5%	5%
Germany	46%	41%	39%	36%	30%	27%	27%	21%	19%	18%	15%	14%	10%
Estonia	99%	100%	100%	100%	100%	100%	96%	93%	83%	80%	75%	70%	50%
Ireland	77%	80%	80%	86%	89%	92%	77%	72%	65%	60%	55%	50%	45%
Greece	100%	100%	98%	95%	95%	95%	93%	93%	93%	93%	85%	80%	70%
Spain	66%	61%	62%	60%	57%	57%	61%	61%	59%	56%	52%	47%	40%
France	45%	46%	46%	45%	44%	43%	41%	40%	38%	37%	35%	33%	30%
Italy	93%	83%	80%	77%	77%	76%	67%	63%	60%	57%	55%	46%	37%
Cyprus	100%	92%	92%	91%	90%	90%	90%	90%	90%	89%	84%	80%	70%
Latvia	94%	94%	94%	93%	93%	93%	94%	83%	83%	83%	75%	70%	55%
Lithuania	100%	100%	100%	100%	100%	95%	89%	89%	89%	91%	87%	80%	65%
Luxembourg	27%	28%	24%	23%	22%	21%	20%	20%	19%	18%	18%	17%	16%
Hungary	75%	78%	80%	82%	84%	84%	83%	84%	84%	80%	78%	75%	60%
Malta	92%	92%	93%	90%	92%	90%	91%	95%	93%	91%	85%	80%	65%
Netherlands	29%	20%	12%	9%	7%	9%	8%	8%	3%	2%	2%	2%	2%
Austria	47%	36%	36%	35%	35%	34%	33%	31%	30%	20%	16%	13%	13%
Poland	98%	98%	97%	98%	98%	98%	96%	96%	97%	94%	90%	85%	70%
Portugal	94%	94%	94%	95%	81%	72%	75%	73%	66%	67%	60%	57%	45%
Romania	74%	71%	47%	81%	81%	83%	79%	80%	79%	81%	80%	75%	65%
Slovenia	77%	79%	83%	88%	83%	78%	75%	88%	83%	75%	75%	68%	50%
Slovakia	57%	63%	64%	70%	71%	77%	77%	78%	78%	81%	75%	68%	60%
Finland	65%	67%	63%	63%	58%	61%	61%	64%	61%	60%	60%	50%	40%
Sweden	35%	33%	31%	28%	25%	23%	22%	20%	14%	9%	5%	5%	5%
United Kingdom	83%	86%	86%	84%	82%	81%	80%	78%	74%	69%	62%	55%	40%

Source: 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.

Note: The projected landfill rates in the years 2006, 2009 and 2016 refer to the target years of the Landfill Directive. The years in parentheses refer to derogations.

Table III.2 Municipal waste incinerated, 1995-2004

	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2006 (10)	2009 (13)	2016 (20)
EU-27													
EU-25	15%	15%	15%	16%	16%	16%	17%	17%	17%	17%			
EU-15	17%	17%	17%	17%	17%	18%	18%	18%	19%	19%			
Belgium	36%	34%	39%	36%	33%	33%	35%	34%	34%	33%	35%	35%	35%
Bulgaria	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	5%	10%
Czech Republic	0%	0%	0%	6%	9%	9%	13%	14%	14%	14%	15%	15%	25%
Denmark	52%	50%	54%	53%	50%	53%	57%	56%	54%	54%	54%	54%	54%
Germany	18%	20%	20%	21%	21%	22%	22%	22%	23%	25%	25%	26%	29%
Estonia	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	5%	5%	15%
Ireland	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	5%	5%	10%
Greece	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	10%
Spain	5%	5%	6%	7%	6%	6%	6%	6%	6%	5%	6%	10%	20%
France	37%	35%	34%	33%	33%	33%	33%	34%	34%	34%	35%	35%	35%
Italy	5%	6%	7%	7%	7%	8%	9%	9%	10%	11%	10%	15%	20%
Cyprus	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Latvia	0%	0%	0%	0%	0%	0%	4%	7%	3%	4%	5%	5%	17%
Lithuania	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	10%
Luxembourg	53%	52%	49%	46%	48%	43%	42%	42%	39%	37%	45%	45%	45%
Hungary	7%	7%	7%	7%	7%	8%	8%	6%	5%	3%	5%	7%	15%
Malta	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Netherlands	25%	30%	37%	33%	34%	31%	32%	31%	32%	32%	33%	33%	33%
Austria	12%	10%	11%	10%	10%	11%	11%	11%	12%	22%	25%	25%	25%
Poland	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	10%
Portugal	0%	0%	0%	0%	14%	20%	22%	21%	21%	22%	25%	25%	30%
Romania	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	5%	10%
Slovenia	0%	0%	0%	0%	0%	0%	0%	0%	1%	2%	0%	5%	10%
Slovakia	9%	10%	11%	13%	12%	15%	10%	10%	10%	12%	12%	15%	18%
Finland	0%	0%	5%	6%	8%	10%	9%	8%	9%	10%	10%	15%	20%
Sweden	39%	38%	36%	38%	38%	38%	38%	40%	45%	47%	50%	50%	50%
United Kingdom	9%	7%	6%	7%	7%	7%	7%	8%	8%	8%	10%	10%	15%

Source: 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.

Note: The projected landfill rates in the years 2006, 2009 and 2016 refer to the target years of the Landfill Directive. The years in parentheses refer to derogations.

V. Annex: Composition of waste

Table IV.1 Composition of municipal waste in 2003

	Food	Garden	Paper	Wood	Textile	Plastics	Inert
Austria	31.2%		18.0%	2.6%	8.2%	19.0%	21.0%
Belgium	44.0%		19.0%			5.0%	32.0%
Bulgaria	29.7%		15.6%		3.0%	17.4%	34.3%
Czech Republic	49.5%		8.0%			4.0%	38.5%
Denmark	13.8%	1.0%	37.5%	12.7%	12.7%	5.1%	17.3%
Estonia	30.1%		21.8%	7.5%	6.2%	6.2%	28.2%
Finland	36.8%	7.2%	26.7%	6.5%	1.2%	5.6%	16.0%
France	29.0%		25.0%			11.0%	35.0%
Germany	54.5%		18.0%			5.0%	22.5%
Greece	56.5%		17.0%			10.3%	16.1%
Hungary	29.7%		15.6%		3.0%	17.4%	34.3%
Ireland	29.0%		37.0%		3.0%	10.0%	21.0%
Italy	38.7%		30.1%		5.1%	15.0%	11.0%
Latvia	47.9%		15.9%		2.6%	14.5%	19.1%
Lithuania	47.9%		15.9%		2.6%	14.5%	19.1%
Luxembourg	44.0%		19.0%			5.0%	32.0%
Malta	38.7%		30.1%		5.1%	15.0%	11.0%
Netherlands	37.6%		16.2%	9.8%	2.1%	14.6%	19.2%
Poland	47.9%		15.9%		2.6%	14.5%	19.1%
Portugal	48.1%		23.7%		3.4%	11.1%	13.7%
Romania	29.7%		15.6%		3.0%	17.4%	34.3%
Slovakia	37.3%		14.7%		3.8%	7.5%	36.7%
Slovenia	30.0%		12.0%	5.0%			53.0%
Spain	46.0%		21.2%		4.8%	10.6%	17.4%
Sweden	52.5%		29.5%	1.2%	4.5%	9.9%	2.4%
United Kingdom	31.0%		32.0%		2.0%	11.0%	24.0%
EU-27 average	***38.9%***	***0.3%***	***21.2%***	***1.7%***	***3.0%***	***10.6%***	***24.2%***

Source: NIR and CRF

Note: The EU-27 average is calculated.