Environmental Study

Waste Sector's Contribution to Climate Protection

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Status Report on the Waste Sector's Contribution to Climate Protection and Possible Potentials

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Summary

Following the entry into force of the Waste Management and Product Recycling Act in 1996, the practice of depositing untreated organic waste as landfill was gradually abandoned in the period up to June 2005. Thanks to a marked increase in separate collection and processing, and also to waste avoidance and more efficient waste treatment and disposal methods, it has been possible to replace fossil fuels and raw materials. These improvements are entered as credits in the climate balance, where they lead to significant reductions in climate-relevant emissions and savings in fossil fuels.

Between 1990 and 2003, total emissions of greenhouse gases in Germany were reduced by 18 % (to 1,017.5 million t CO_2 equivalent). In the National Inventory Report (NIR), some 20 million t CO_2 equivalent are attributed to the waste sector as a result of the landfill ban alone. Thus the waste industry has achieved the contribution it was expected to make to the reduction target of the National Climate Protection Programme 2000. A further saving of 8.4 million t CO_2 equivalent by 2012 is forecast as a result of the closing down of landfill sites. For the period from 1990 to 2012 this results in a reduction of 28.4 million t CO_2 equivalent, which under the Federal Government's decision of 13 July 2005 (BMU 2005a) is attributed to the landfill disposal path in the National Climate Protection Programme.

By contrast, the result of the balance in this brief study shows a reduction of approx. 46 million t CO_2 equivalent for the period 1990 to 2005. Owing to different accounting methods, however, the figures are not directly comparable. In particular, the NIR does not give the waste industry credits of any kind for energy generated from thermal treatment of waste. In views of accounting definitions and statistical classifications, the credits arise in other sectors, e.g. the energy industry. There is no intention to change this situation in the future either, but the present brief study wishes to draw attention to the fact that it was the far-reaching restructuring of the municipal waste management sector that laid the foundations for achieving this reduction in the first place. This is made clear for the first time by assigning credits for the achievements of the municipal waste management sector.

In addition to the contribution already made, the study examines further possible improvements on the basis of three different scenarios for the period up to 2020, in order to indicate the potential for climate protection and resource conservation that is offered by systematic further development of the waste management sector. In the future, further savings of the kind achieved up to 2005 cannot be expected on this scale, either in the case of fossil resources or in the case of greenhouse gas emissions. This is shown by the findings of the substance flow analysis undertaken here for the treatment and management of municipal waste for the years 2005 and 2020. Both are based on the forecasts of waste quantities by the Joint Waste Commission of the Federal States (LAGA 2004), which represent the data since July 2005, i.e. since the end of the transitional period for landfill deposition of untreated waste. The waste quantity for 2020 is kept constant at the 2005 level, since the scenarios are intended to show the effect of **changes in the waste management system** (disposal paths, plant efficiency, energy production efficiency etc.). Thus the potential impacts of waste avoidance were not the subject of this study.

The following aspects are varied in the individual studies:

1. **Increased material recovery of ferrous and non-ferrous metals**

2. **Increase in co-incineration**

3. **Capacity expansion and efficiency improvements (including expansion of CHP) at incineration plants for municipal waste**

4. **Changeover from composting to fermentation of biowaste – with use of biogas to power generators**

5. **Phasing out feedstock recycling of plastics in favour of material and energy recovery.**

Table 1: *Greenhouse gas emissions and remaining reduction options in the scenario period up to 2020, figures in million t CO_2 equivalent*

Disposal path	Emissions 1990	Emissions 2005	Emissions 2020-optimised	Reduction potential from 2005 to "2020-optimised"
Waste incineration	-1.00	-2.47	**-5.42**	**-2.95**
Co-incineration	-0.05	-2.16	**-3.55**	**-1.39**
Biowaste	0.10	0.19	-0.06	-0.25
Lightweight packaging	0	-0.54	-0.63	-0.09
Waste paper	-0.31	-1.71	**-1.65**	0.06
Waste glass	-0.39	-0.61	-0.61	0
Bulky waste/waste wood	-0.005	-0.27	-0.3	-0.03
Metals	-0.28	-0.78	**-1.55**	**-0.77**
Collection	0.48	0.36	0.36	0
MBT	0	0.21	0.19	-0.02
Landfill	39.23	0.09	0.02	-0.07

Emissions preceded by a minus sign mean that the CO_2 emissions for this disposal path (debit) are smaller than the credit for the processes replaced

The balance for 1990 was dominated by methane emissions from landfill sites. Since the balance for 2005 is drawn up without landfill, emission reductions and balance sheet results between 2005 and 2020 are no longer possible on the scale seen between 1990 and 2005. But a potential of over 5 million t CO_2 equivalent remains as an important contribution to the German climate protection target.

On the whole, the disposal paths of waste incineration plants and co-incineration display the greatest potential for reducing emissions of greenhouse gases. Waste paper recycling is also of great importance, while all other paths make smaller contributions to climate protection, and even the expenditure involved in the collection of waste is relatively insignificant (cf. Table 1).

In addition to the influence of disposal paths and capacities, the effect of **various credits** was also investigated for waste incineration plants. In the individual scenarios up to 2020 the credits represent the bandwidth depending on the substitution process for the additional power generated compared with 2005:

1. **due to natural gas (gas-and-steam plants) (basic scenarios 2020),**
2. **due to imported coal (2020 optimised).**

Merely as a result of varying the substitute processes, the net credit for waste incineration plants virtually doubles between scenarios, for example by approx. 3 million t for coal power compared with about 1.5 million t CO_2 equivalent for gas-and-steam power. Thus the decision regarding the substitute processes has a major influence on the result of the balance, and in the case of waste incineration plants this has a greater effect than a 10 – 20 % variation in capacity utilisation.

These findings make it clear that political instruments should be selected in a way that brings about as far as possible the replacement of processes that are particularly unfavourable today. Following this philosophy, the present brief study recommends a set of instruments and measures. It is recommended that after detailed environmental and impact analysis these should be integrated to form a practical networked system.

Germany has promised to reduce greenhouse gas emissions by a total of 40 % by 2020 compared with the base year 1990[1]. Thus from 2003 to 2020 the reduction in annual greenhouse gas emissions would have to show a further slight increase on the figure already achieved by 2003. The waste sector can contribute approx. 2 % to 4.6 % to this through a variety of measures[2]. This requires appropriate measures to exploit all potentials to the full. Given optimised use of energy, waste incineration plants contribute about one third of the reduction potential. Under the framework conditions of this balance, all energy-based processes together account for about 90 % of the achievable reduction potential. The study did not investigate any potential that may exist for increasing material recovery.

For the entire period from 1990 to 2020 the share due to the waste sector is considerably higher because of the substantial reduction in methane emissions from landfill sites. Of the total reduction of 500 million t CO_2 equivalent achieved and planned in this period, the municipal waste sector will account for some 50 million t CO_2 equivalent, i.e. a share of approx. 10 %. This is made up of 76 % due to reductions in landfill gas emissions, around 7 % due to energy recovery, 5 % due to materials recovery, and 9 % to waste incineration plants.

Finally, the successes of the German waste sector are compared with the situation in the EU-15 countries. Germany started in 1990 with the highest emissions in the waste sector, and has made relatively good use of the high optimisation potential in the past.

If, like Germany, the European countries turn away from landfill of untreated waste, this will open up great potential for optimisation here too. Instead of producing a debit of 87 million t CO_2 equivalent with their waste sector, they could in future turn this into a credit of 47 million CO_2 equivalent. This offers a reduction potential for the municipal waste sector of the EU-15 countries of 134 million t CO_2 equivalent from 2000 to 2020. The majority share of this, nearly 100 million t CO_2 equivalent, is due to the methane emissions avoided by discontinuing waste deposition as landfill. Separate collection and use of biowaste accounts for a not inconsiderable part of this, as the methane produced is largely due to the biowaste in landfill sites.

Looking at the reduction potential of 134 million t CO_2 equivalent in the municipal waste sector in relation to the planned greenhouse gas reductions of 1,203 million t CO_2 equivalent in the EU-15 countries from 2003 to 2020 reveals a share of 11 %. On average, the savings potential due to power generation from waste incineration is slightly lower in Europe as a whole than in Germany, since the power credits are based on the EU mix, which is generated with smaller fossil fuel quantities than in Germany.

A rough estimate indicates that rigorous compliance with the Landfill Directive can also make a substantial contribution of 74 million t CO_2 equivalent to reducing greenhouse gas emissions by avoiding landfill gas emissions.

Furthermore, materials and energy recovery from waste not sent for landfill could produce additional savings of around 30 million t CO_2 equivalent a year.

1 *A 40 % reduction has been promised provided that Europe as a whole achieves a reduction of 30 % (BMU 2005b).*

2 *As already described, this does not include the reduction due to methane gas emissions still being emitted by shut-down landfill sites, as these are already credited in the 2005 scenario.*

Inhaltsverzeichnis

1 | Introduction

The environmental goal of the waste management sector is to promote closed substance cycles in the interests of conserving natural resources and ensuring environmentally sound waste disposal. Directly linked to this are requirements with regard to the most important protected assets such as water, soil, air and human health. The environmentally harmful effects of waste are to be minimised by means of waste policy measures such as

- **reducing inputs of harmful substances into the treatment cycle;**
- **removing harmful substances from the recovery process;**
- **rendering harmful substances inert;**
- **reducing the consumption of resources.**

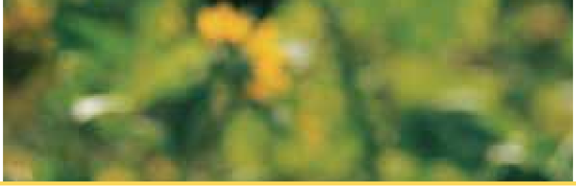
The present study places the focus on climate protection. It describes the contribution made by the waste sector to the German and European climate protection objectives and indicates potential opportunities for optimisation.

Germany has undertaken to make a 21 % reduction in greenhouse gas emissions by 2012 compared with 1990 (Kyoto target). Approximately 18 % of this was achieved by 2003, and the waste sector made a major contribution to this by avoiding methane emissions due to landfill. A further contribution was made by raw material savings due to materials and energy recovery. These successes are based on the great advances in recycling in Germany with regard to safe disposal and the elimination of environmental burdens. With the end of the transitional period for landfill of untreated waste, 2005 represents a further milestone in recycling policy.

Emissions of greenhouse gases in Germany are currently stagnating, following a marked reduction in the 1990s. This is despite the fact that the Kyoto commitments are nowhere near sufficient to combat global climate change. Ambitious climate protection targets are needed in the medium and long term, and the Federal Government plans to reduce greenhouse gas emissions by 40 % by the year 2020. Against this background, systematic use should be made of the remaining savings potential in all sectors.

The year 2020 is an important date, not only as a target for climate protection, but also with regard to the waste management objectives announced by the Federal Ministry for the Environment, Nature Conservation and Nuclear Safety in a key points paper in 1999: with effect from 2020 there is to be no further disposal of waste that is suitable for recycling. This brief study sets out the successes achieved in the field of closed-cycle waste management, from 1990 to 2005. It also identifies potentials capable of exploitation and calculates, in scenarios for 2020, their possible contribution to climate protection on the basis of the criteria *greenhouse gas emissions and fossil fuel savings.* This is intended to serve as a basis for decisions on future sustainable development in the waste sector. Thus the brief study indicates the *maximum* climate protection potential of the municipal waste sector, before going on to discuss possible measures that could help in the implementation of this development.

It also describes the situation of the waste management sector in the EU. To this end it looks at the waste data for the individual EU states, confining this examination to the EU-15 countries, since corresponding data of comparable quality are not yet available for the newly acceded countries. At a European level too there are signs that most of the EU-15 countries are moving away from landfill and towards recovery of waste. Nevertheless, for the EU-15 countries too, the report does not set out the plans of the member states, but rather the maximum greenhouse gas reduction potential in the EU-15 countries given rigorous restructuring of the waste management sector.



2 | Comparative balance for 1990, 2005 and 2020 in Germany

The entry into force of the Closed Substance Cycle and Waste Management Act (KrW-/AbfG)[3] in 1996 broke the link between economic growth and the creation of waste. Thanks to a marked increase in separate collection and processing, and also to waste avoidance and more efficient waste treatment and disposal methods, it has been possible to make great progress in reducing environmental burdens. Successes have also been achieved on the climate protection front, as it has been possible to avoid direct greenhouse gas emissions and reduce consumption of fossil fuels.

This brief study describes the climate protection contribution already made by the German waste management sector in the field of municipal waste. To this end its compares the situation in 1990 and 2005. The study examines further possible improvements on the basis of three different scenarios for the period up to 2020, in order to indicate the potential for climate protection and resource conservation that is offered by systematic further development of the waste management sector.

The work is based on the findings of the ifeu Institute's research report "The Waste Management Sector's Contribution to Sustainable Development in Germany – Section on Municipal Waste"[4], which was jointly commissioned by the German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety and the German Federal Environmental Agency.

The impacts of the waste management sector on greenhouse gas emissions and the conservation of fossil resources in 1990 are compared with the situation in 2005 (following the end of landfill deposition of untreated waste). For this purpose the data for 2005 are forecast on the basis of present knowledge. The scenarios for 2020, on the other hand, are intended to describe not the expected trend, but the potential for greenhouse gas reductions and fossil resource savings that can be achieved as a contribution to climate protection if all ways and means of increasing energy recovery from municipal waste are exploited. Individual scenarios also indicate the impact it has on the balance if biogas treatment largely switches to fermentation, and if feedstock recycling of plastics is replaced by material and energy recovery.

The following scenarios are contrasted with the municipal waste situation in 1990:

- **Scenario municipal waste 2005**
- **Scenario municipal waste 2020, Basis I**
- **Scenario municipal waste 2020, Basis II**
- **Scenario municipal waste 2020, Optimised**

Waste wood and sewage sludge are not included in the balance. However, an estimate of the potential of these two substance flows with regard to climate relevance is made as part of a general overview. For details see Chapter 3.3.

2.1 | Accounting principles

The only environmental assessment instrument that is capable of assessing complex systems is the environmental balance sheet. It was the first tool to be developed internationally on a scientific basis, and its basic principles have been standardised both nationally and internationally since 1993 (DIN EN ISO 14040ff).

If two or more products or services are to be examined at the same time, the environmental balance can be expanded into a substance flow analysis. This moves away from a detailed focus on individual products in favour of an overall view of whole sectors or fields

3 Closed Substance Cycle and Waste Management Act (Kreislaufwirtschafts- und Abfallgesetz) of 27 September 1994

4 See ifeu (2004), published as a special section in UMWELT No. 10/2004

of activity, such as the waste management sector. Accordingly the requirements for the individual execution steps are reduced compared with DIN-ISO 14014.

2.1.1 | Physical accounts and impact assessment

The interim result of the accounts for the individual variants is the "physical balance sheet". This supplies the data on pollutant emissions and resource consumption that are necessary for impact assessment. This brief study confines itself to greenhouse gas emissions and fossil fuel savings, because its focus is the climate-relevant impacts of the German waste management sector. The impact assessment summarises the pollutants covered by the accounts on the basis of their environmental impacts (cf. CML 2001, UBA 1995).

2.1.1.1 | Greenhouse gas emissions

Owing to differences in their absorption spectra and residence times, the individual greenhouse gases each have a different climate impact potential. To make it possible to express the impact potential of all gases in terms of a single value, one calculates the quantity of carbon dioxide that would have the same impact on the climate. Table 2.1 shows these equivalence factors for the gases investigated. When calculating CO_2 equivalents it is necessary to take account of the time frame in question. Depending on the purpose of the study, conversion factors are available for time horizons of 20 or 100 years. The present accounts use the factors for 100 years.

Carbon dioxide emitted during the combustion of renewable fuels does not count as greenhouse gas, since in the course of their growth the plants have taken up and incorporated as carbon compounds the same quantity of CO_2 as is released when they are burned.

Table 2.1: *Greenhouse gas potential of the substances investigated (time horizon 100 years)*

Greenhouse gas	Equivalence factor kg CO_2–equivalente
Methane CH_4 (fossil)	21
Methane CH_4 (renewable)	18
Carbon dioxide CO_2	1
Nitrous oxide N_2O	310

Source: (NIR 2005)

Table 2.2: *Energy resources investigated and their calorific values (H_{net} in MJ/kg)*

Energy resources	MJ/kg
Lignite	8.8
Natural gas.	37.8
Oil	42.6
Coal	29.8

2.1.1.2 | Consumption of fossil energy sources

A good many environmental problems are directly connected with the energy consumption required for a product or service. For this reason energy consumption can in many cases serve as a useful guide – an environmental indicator that can moreover be determined relatively easily in the standardised form of cumulative energy requirements, CER (Öko-Institut 1999). CER represents the sum of all primary energy inputs used for a product or service, including all preceding chains and the energy for manufacturing the materials, and is thus the appropriate indicator of the sum of the energy sources selected to represent resource depletion in the context of these accounts.

The present accounts include only those fossil energy sources that contribute to CER (CER_{fossil}); they are listed in Table 2.2.

This brief study works on the assumption that plants operate normally. It cannot take any account of environmental impacts due to uncontrolled emissions or major accidents.

Table 2.3: *Possible substitute processes, taking waste incineration plants as an example*

Waste incineration plant without energy utilisation	Waste incineration plant plus power	Waste incineration plant plus power and heat
Debit (plus): CO_2 emissions from waste incineration plant due to combustion of fossil components in waste	**Debit (plus):** CO_2 emissions from waste incineration plant due to combustion of fossil components in waste **Credit (minus):** CO_2 emission savings due to avoidance of power generation in power plants	**Debit (plus):** CO_2 emissions from waste incineration plant due to combustion of fossil components in waste **Credit (minus):** CO_2 emission savings due to avoidance of power generation in power plants CO_2 emission savings due to avoidance of heat generation by a typical household heating system

2.1.2 | Comparison of systems

Thanks to recycling and energy recovery from waste, substance flows in the waste management sector today are closely intertwined with those of the energy and raw materials industries. When comparing different waste management systems it is necessary to consider the entire system in order to take account of all benefits and their environmental impacts. One benefit in addition to straightforward waste management is the production of energy or material (by means of energy and material recovery). For example, if municipal waste is disposed of in a waste incineration plant that generates both power and heat for district heating, then both energy benefits belong to the system. If, instead, the same waste is burned in a waste incineration plant that generates power only, the same benefit as in the first case has to be created by an extension of the system, e.g. the same quantity of power and heat has to be produced in separate power plants.

For this purpose the present brief study uses the "credit method"[5] (GEMIS 1994, ETH 1998), which defines, *for each additional benefit above and beyond straight waste management,* a substitute process that produces this additional benefit from primary or other secondary raw materials. The following table lists possible substitute processes, taking waste incineration plants as an example.

The credit method can theoretically give rise to negative environmental burden values as a accounting result. Such negative environmental burden values are to be understood as reductions in environmental burdens compared with the comparative system.

The substance flow analysis was performed with the aid of the software tool Umberto® *(www.umberto.de)*. Umberto® permits the necessary degree of detail for modelling the substance and energy conversion of individual processes in waste management and substance flow management in the necessary degree of detail.

2.1.3 | System limits

When comparing different waste management systems, it is necessary not only to standardise the benefits, but also to define the system inputs in the same way. This brief study investigates waste management systems within the following limits:

5 *Alternatively it is possible to use an allocation that assigns the (environmental) burdens to the individual benefits. According to DIN-ISO 14040, a system extension with credits is to be preferred to an allocation.*

- **Accounting starts at the point where the waste occurs.**

- **Operating supplies and the necessary energy for the collection, treatment or recovery of the waste are accounted for from raw materials extraction to the point of input into the waste management system.**

- **The recovery aspect considers the environmental burdens that arise right through to the production of a marketable product – as a rule these tend to be industrial intermediate products rather than an end product for the consumer. The products of recovery also include energy that is used within the system or output from it.**

- **Recovery products are given a credit that represents the complementary process on the basis of primary raw materials. Accounting for the complementary process also starts with the extraction of the raw materials.**

- **The convention of the 1 % limit is taken as the cut-off criterion: on this basis the accounting includes all processes, operating supplies and use of infra-structure that contribute more than 1 % to the balance sheet result. The sum of all "cut-off" processes and materials should not influence the result by more than 5 %.**

A more detailed description of the system limits for the individual variants is given in Chapter 2.5 "Description of scenarios".

2.2 | Waste volume

The contribution made by the waste management sector to climate protection is primarily determined by both the volume of municipal waste and the waste management paths chosen. The waste volume for the Municipal Waste 1990 scenario is taken from the official statistics on waste disposal for 1990 (StBA 1994). Since there cannot yet be any waste statistics for the current year 2005, the forecasts by the Joint Waste Commission of the Federal States (LAGA 2004) were taken for the Municipal Waste 2005 scenario. These represent the data since July 2005, in other words since the end of the transitional period for landfill of untreated waste.

In the scenarios for 2020, the waste volume figures are kept constant at the 2005 level. For one thing there are no reliable data for forecasting exact waste quantities for 2020, and for another, the waste statistics in recent years indicate that the total volume of municipal waste is stagnating. This balance sheet therefore shows the climate protection contribution made by measures in the field of waste management, and not the possible effects of changes in the volume of waste, for example as a result of waste avoidance. If efficiency improvements within the waste management sector avoid the emission of greenhouse gases, the effect will be most clearly

Table 2.4: *Waste volume as basis for calculation of the individual scenarios (quantities in million t)*

	Waste volume (million t)		
	1990*	**2005****	**2020*****
Total household and bulky waste	**33.9**	**16.2**	**16.2**
Household-type commercial waste	**15.2**	**4.2**	**4.2**
Biowaste and park waste	2.0	8.0	8.0
Waste paper	1.6	7.6	7.6
Waste glass	1.3	3.2	3.2
Lightweight packaging	0	1.9	1.9
Total recoverable material	**4.9**	**20.6**	**20.6**
Total municipal waste	**54.0**	**40.9**	**40.9**

Due to rounding, the totals do not always add up exactly

* *from (StBA 1994)*

** *Data for household and bulky waste and household-type commercial waste from (LAGA 2004)*
Data for recoverable materials from (StBA 2003)

*** *Same basis as 2005 for all 2020 scenarios*

visible at constant volume (action scenarios at status-quo conditions).

Table 2.4 shows the waste quantities on which the scenario calculations are based.

A change in the registration of statistical data between 1990 and the present day complicates the interpretation of the data, since the household-type commercial waste figures for the different years are scarcely comparable. In 1990 the quantities of municipal waste collected were only registered as total figures. In the data for 2005, by contrast, the figures were registered on the basis of a differentiated waste classification. Thus the much smaller quantities for the current year are only partly due to the successes in the field of waste avoidance. Moreover, industrial waste that is collected separately and sent for recovery by private waste management enterprises is not covered by the statistics. Only household-type commercial waste for disposal is registered.

This brief study can nevertheless work on the basis of these statistical data, as in relation to the issue of the climate protection contribution the smaller quantity of household-type commercial waste represents a conservative framework condition and hence an *under*estimate of the achievements: In the past, landfill of untreated waste above all created sources for the formation of methane and carbon dioxide, which as a rule did not offer any additional benefits[6]. Today this waste is rigorously used for energy recovery, thereby replacing fossil fuels and raw materials. These improvements are entered as credits in the balance (cf. Chapter 2.1.2), where they lead to reductions in climate-relevant emissions and savings in fossil fuels. Accordingly, larger quantities of household-type commercial waste would bring an improvement in the results.

2.3 | Disposal paths and quantities

The disposal paths for the scenarios Municipal Waste 1990 and 2005 are taken from the BMU/UBA research project "The Waste Management Sector's Contribution to Sustainable Development in Germany" (ifeu 2005), with the exception that the capacity of mechanical-biological treatment plants is brought into line with the latest forecast by the Joint Waste Commission of the Federal States (LAGA 2004). The following assumptions are made for the 2020 scenarios:

- **The quantities for material recovery of waste glass, waste paper, light packaging and biowaste are kept constant at 2005 levels.**

- **The data on input for mechanical-biological treatment plants and co-incineration are taken from the LAGA forecast (LAGA 2004).**

For the years 2005 and 2020 the waste quantities entering waste incineration plants are calculated by modelling in Umberto®. Fixed elements here were the volume of waste and the capacities determined for the following waste management paths: recovery, mechanical-biological treatment plants and co-incineration. These fixed inputs give rise to differences compared with the capacities forecast for waste incineration plants by LAGA. The effects of fixing these parameters for the purpose of the model are examined in a separate chapter when the results are discussed.

The sum of all waste for disposal cannot be reconciled with the data on the volume of waste, as multiple entries are inevitable. The problem can be illustrated by two examples:

6 *While the capture and use of landfill gases can result in utilisation, the relevant credits with regard to greenhouse gas emissions are relatively small and cannot cancel out the burdens due to the residual methane emissions.*

1. **Non-combustible components of waste (inert substances) are also included in the statistics as input into waste incineration plants. The ash from the incineration plant is then recovered or disposed of as backfill, which means the same mass of inert substances is counted as input into another process and thus registered twice.**

2. **The lightweight fraction of the input into mechanical-biological treatment plants is separated there and becomes part of the quantities sent for co-incineration.**

Differences between the waste volume and disposal paths also result from the classification of residual quantities from sorting. In the case of biowaste, for example, the volume occurring is 8 million t, but only 7.6 million t is shown for the biowaste treatment path. Most of the remaining 0.4 million t goes to incineration plants, while a small proportion – inert residues from fermentation – goes for landfill (cf. Appendix 1, Table A1.1).

Table 2.5: *Waste management paths (waste quantities in '000 t)*

Disposal path	1990	2005	2020 Basis I	2020 Basis II	2020 Optimised
Recovery of dry residual waste*	3,339	16,373	16,373	16,373	16,373
Recovery of biowaste	1,006	7,604	7,604	7,604	7,604
Mechanical-biological treatment		6,221	7,122	7,122	7,122
Co-incineration	72	2,093	3,529	3,532	3,532
Waste incineration plants**	7,914	13,420	16,237	16,296	16,296
Bottom ash from incineration***	1,302	2,300	2,806	2,807	2,807
Fe metals from incineration and mechanical-biological treatment	109,390	309,916	354,532	447,852	447,852
NF metals from incineration and MBT		12,833	15,041	52,534	52,534
Total primary waste to landfill	41,911	0	0	0	0
Total sorting residues to landfill	104	63	63	63	275
Incineration residues to landfill	261	467	605	599	599
MBT residues to landfill	0	3,261	0	0	0
Grand total input to landfill	42,277	3,791	669	663	874

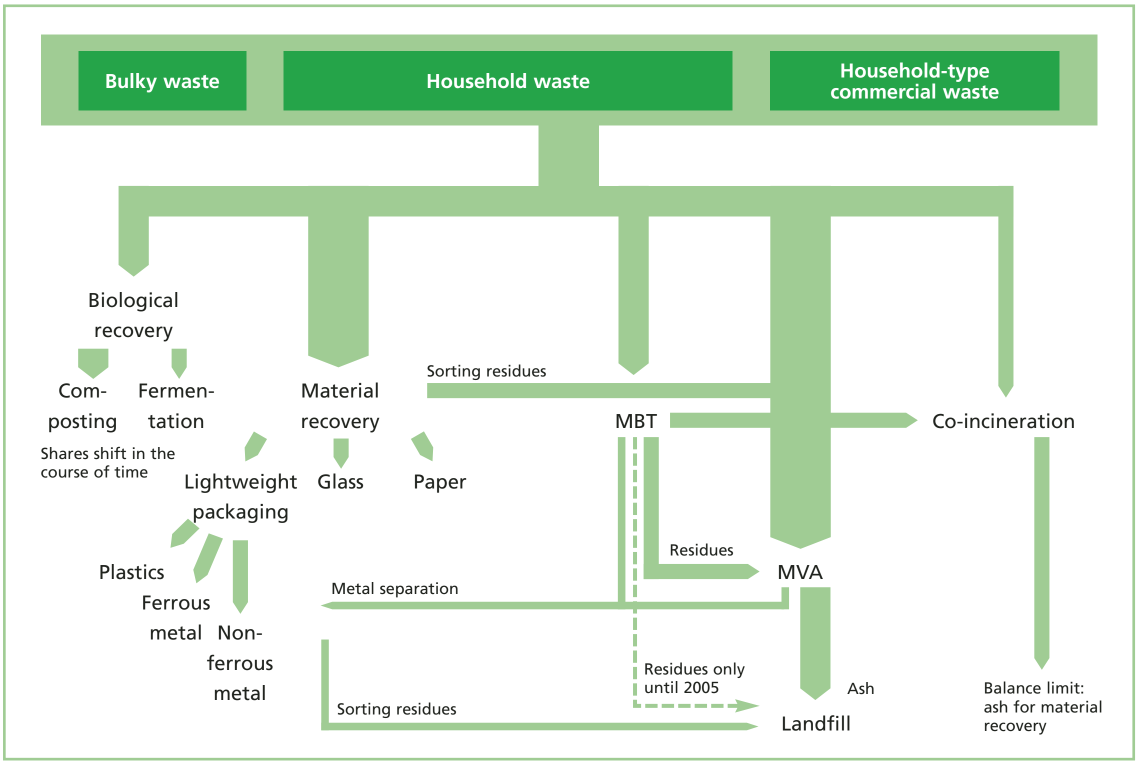
Due to rounding, the totals do not always add up exactly

* *From separate collection, bulky waste and household-type commercial waste*

** *The capacities for waste incineration plants result from the accounts calculated after entering the capacities for mechanical-biological treatment, co-incineration and recovery as fixed parameters. In fact LAGA states waste incineration capacities of 16.3 million t for 2005 and 17.7 million t after 2005.*

*** *After separation of metals, the bottom ash from waste incineration plants leaves the system without any account being taken of inputs for further processing of the ash or credits for construction materials replaced, since the construction materials replaced do not possess any relevant CO_2 reduction potential.*

Fig. 2.1: *Substance flow diagram of disposal paths*



Compared with 1990, the redirection of waste flows from landfill to material and energy recovery in the scenarios 2005 and 2020 results in marked increases in the disposal paths:

- **Recovery of dry residual waste (factor 5),**
- **Recovery of biowaste (factor 7.6),**
- **Co-incineration (2005: factor 29, 2020: factor 49)**
- **Metals from incineration and mechanical-biological treatment (2005: factor 3, 2020 Basis I: factor: 3.4)**

For metals the assumption of optimised separation from incineration and mechanical-biological treatment plants in the scenarios 2020 Basis II and Optimised means a further increase of 36 % compared with the scenario 2020 Basis I.

In 2005 the quantities for landfill are reduced to the quantities due to fermentation residues and a certain amount of incineration ash, resulting in a reduction of a good 90 %. In 2020 the residues from mechanical-biological treatment also go for incineration, which means a further reduction of approx. 80 %.

Fig. 2.1 is a simplified representation of the disposal paths taken by the various types of waste. A detailed breakdown of the disposal paths can be found in Table A1.1 in Appendix 1.

2.4 | Composition of waste

The composition and quality of the waste has a substantial influence on the accounts. For example, the metal content of the input and the efficiency of metal separation determine the quantity of metals that can be sent for recycling. The amounts of power and heat that can be produced in a waste incineration plant depend among other things on the calorific value of the waste incinerated in the plant. The greenhouse gas emissions attributed to waste incineration plants as debits depend in particular on the ratio of renewable to fossil carbon, because CO_2 from renewable carbon is not classified as climate relevant and is therefore disregarded in the accounts (cf. Chapter 2.1.1.1).

For the scenarios up to 2020 it is assumed that there is no change in waste composition compared with 2005. Table 2.6 shows the composition of the main waste fractions for the accounts. The data are based on various sources that describe the situation at the turn of the century (Öko-Institut 2002, Wollny 2002, BIfA 1998, Bay LFU 2003, Wallmann 1999, ifeu 2005).

2.5 | Description of scenarios

The following section describes the various process stages, from collection through various treatment stages to the substitute processes by means of credits.

2.5.1 | Collection and transport

As a rule, waste is collected using refuse collection vehicles. Separate truck transport is only used for separately collected bulky waste and for local authority garden, park and cemetery waste. The vehicle fleet represents the national average for Germany (VKS 2002), for which the emissions are calculated by the TREMOD[7] model developed by ifeu (ifeu 2005).

In this study it is assumed that even in 2020 the input for collection and transport will not differ substantially from the figures for 2005, since the volume of waste remains constant throughout this period. Although the discussion about changes in the collection systems is already in full swing, this aspect will not be investigated here, since it is hardly possibly at present to foresee which system will prevail. Regardless of this aspect, collection systems only have a minor influence on the results.

2.5.2 | Mechanical-biological treatment

Mechanical-biological treatment encompasses processes such as size reduction, sorting and fermentation or rotting (cf. also Dehoust et al. 1998, Öko/ifeu 2001, Öko/igw 2003). Since there were no mechanical-biological treatment plants operating in 1990, no waste flows are shown for this waste

Table 2.6: *Composition and quality of major waste flows considered in the accounts*

	Unit	Household waste	Household-type commercial waste	Secondary fuels	Residual waste from MBT
Moisture content	%	33 %	23 %	25 %	33 %
Calorific value	MJ/kg dry matter	9	18	18	
C total	% dry matter	22.4 %	25 %	35 %	17 %
C renewable	% Ctot	65 %	40 %	35 %	55 %
C fossil	% Ctot	35 %	60 %	65 %	45 %
C renewable	g/kg dry matter	146	100	123	94
C fossil	g/kg dry matter	78	150	228	78
NF metals	% dry matter	0.4 %	0.4 %		0
Iron and steel	% dry matter	2.5 %	4 %		0

management path in the 1990 scenario. Mechanical-biological treatment systems are however integrated in the scenarios for the other years.

During mechanical treatment 20 % of the input is separated as lightweight fractions. All plants also perform separation of ferrous metals and non-ferrous metals (aluminium). Separation in the individual plants ranges from 0 % to 70 %. It is assumed that 20 % of the plants use fermentation as the biological treatment process and burn the resulting gas in a gas engine to generate power. The fermentation residues undergo follow-up treatment in an aerobic pit and, like the residual waste from aerobic systems, are deposited on the MBT plant's landfill site. The accounting data can be seen from Table 2.5. Additional items compared with the BMU report which served as the basis for the accounts (ifeu 2005) are fermentation and the separation of non-ferrous metals.

Unlike the earlier years, the **MBT plants in 2020** no longer send any substance flows for disposal as landfill. There are three possible alternatives for the remaining residual waste:

1. **Conventional MBT plant with transfer of pit residues to a waste incineration plant**

2. **MBT plant with fermentation of wet fraction, followed by drying of fermentation residues in a follow-up pit and transfer to a waste incineration plant**

3. **Mechanical-biological stabilisation plant (MBSP) with drying of all input in a short-term pit, mechanical separation of dried waste into one or two secondary fuel fractions, metals and – where appropriate – inert substances.**

There are no great differences between the three process variants with regard to the criteria included in these accounts. It can be assumed that MBS will prevail – provided residues are no longer deposited as landfill – since MBS in conjunction with subsequent incineration is the cheapest process. The shorter rotting time saves energy and time. Compared with fermentation, which is in any case more complicated, it also eliminates the drying of the wet fermentation residues. Fermentation plants for residual waste that are already operating today could switch to the treatment of biowaste. Accordingly, the two MBT variants will approximate to MBS. For this reason the figures used in the accounts are for a plant that could be either an MBS or an MBT plant adapted to the new situation.

In the Basis II scenario and in the optimised variant for 2020 it is assumed that 30 % of the input is separated as a high-calorific fraction and used for co-incineration. Incentive factors here are the high utilisation figures for waste incineration plants and the support for co-incineration that is provided by emissions trading[8]. The remainder is treated in a short-term pit that uses about 50 % less power than the MBT plant.

7 *The credits assigned, which are determined on the basis of GEMIS 4.3 (see www.gemis.de), also include the fuel inputs for transport.*

8 *Power plants and production facilities do not need any CO_2 emission rights for the CO_2 emissions from the renewable component in the waste (cf. also Chapter 5)*

In the scenario 2020 Basis I the mechanical treatment stage remains unchanged compared with 2005. In the scenarios "2020 Basis II" and "2020 Optimised" the separation of non-ferrous metals is increased to take account of improved separation systems (see Table 2.7).

2.5.3 | Waste incineration

in the accounts for this field, the direct CO_2 emissions from waste incineration plants and the use of operating supplies feature as debits. These two parameters are kept constant in all five scenarios. By contrast, credits are made for the *utilised* energy from incineration[9] and for separated material for recovery. These two parameters are varied in the scenarios.

In the scenarios for the years 1990 und 2005, 10 % of the energy surplus is output as electricity and 30 % as heat. As far as material recovery is concerned, 50 % of the ferrous and 10 % of the non-ferrous metals are separated from the ash (see Table 2.8).

In the scenarios for 2020 all waste incineration plants are optimised compared with the present situation, with improved energy generation efficiency and increased separation of metals. This presupposes the creation of incentives leading to marked increases in the profitability of power and especially heat marketing compared with today (cf. Chapters 5 and 6).

The recovery rate for separated metals in the scenario 2020 Basis I is unchanged from the 2005 scenario. In the scenarios Basis II and Optimised, the separation efficiency for ferrous metals is increased to 70 % and for non-ferrous metals to 50 %.

No account is taken of credits for the use of ash from waste incineration plants, since their use as a

Table 2.7: *Accounting data MBT scenarios 2020*

	2005	Basis I	Basis II/ Optimised	
Mechanical treatment				
Separated lightweight substances	20 %	20 %	30 %	of input
Separated interfering substances	3 %	3 %	3 %	of input
Metal separation efficiency				
Iron (Fe)	80 %	80 %	80 %	of metal fraction
Non-ferrous metals (NF)	30 %	30 %	70 %	of metal fraction
Biological treatment				
Aerobic	80 %	100 %	100 %	of plant throughput
Anaerobic	20 %	0 %	0 %	of plant throughput
Rotting losses	30 %	10 %	10 %	of rotting input
Gas yield, fermentation	54.8			m^3/t input
Methane content	55			vol %

Table 2.8: *Summary of accounting data for waste incineration plants for the scenarios examined*

	1990 and 2005	2020 Basis I	2020 Basis II and Optimised
Net energy production			
_el	10 %	15 %	15 %
_th	30 %	36.8 %	36.8 %
Recovery			
Ferrous metals	50 %	50 %	70 %
NF metals (as aluminium)	10 %	10 %	50 %

substitute for gravel does not make any relevant contribution to climate protection and does not bring significant savings in fossil fuels.

Substitute processes for energy from waste incineration plants

If a waste incineration plant produces power, this energy no longer has to be produced by other power plants and the resulting emission savings are credited to the waste incineration plant. Thus the choice of power plants to be replaced by waste incineration power has a crucial influence on the size of this CO_2 credit and hence on the final result.

In the interests of simplicity, the CO_2 emissions of the German electricity mix for the year in question are used for the past, but for the future a change in this mix is assumed (see Table 2.9).

However, the scenarios for 2020 only set off the power from today's plants against the electricity mix. In future, however, more waste incineration power will be generated due to improved efficiency and the construction of new incineration plants. Different credits are taken into account for this power in the different scenarios:

1. **The first possibility considered is that generation of additional power could prevent the construction of new modern gas-and-steam power plants. In the scenarios "2020 Basis I" and "2020 Basis II" the credit is made on the basis of this type of power plant.**

2. **On the other hand there are signs that emissions trading and other climate protection instruments could make power from coal more expensive, which would lead to increasing replacement of coal-fired power plants, whereas the construction of new modern power plants would continue unrestricted. This case is depicted by the scenario "2020 Optimised", where the credits are made on the basis of power generation using imported coal.**

The electricity mix of the reference scenario from GEMIS 4.3 is used for 2020. This in turn is based on the EU Commission data[10], as this ensures comparability of the figures with most relevant European environmental accounts. It does not take account of the Federal Government's plans to increase power generation from renewables to 20 %, and only partly reflects the phasing out of nuclear

Table 2.9: *Summary of power mix for the individual scenarios*

	1990	2005	2020*
Coal	23.5 %	22 %	32.1 %
Lignite	26.2 %	24.4 %	30.6 %
Gas	12.0 %	14.25 %	10.4 %
Oil (heavy)	0.7 %	0.6 %	0.2 %
Waste		2.3 %	2.5 %
Uranium	29.7 %	28.25 %	13.9 %
Water	4.4 %	4.5 %	4.4 %
Wind	1.9 %	2.7 %	4.7 %
Solar			0.2 %
Wood		1 %	1 %
Miscellaneous	1.7 %		

** Does not apply to additional construction*

Sources: 1990: (ifeu 2005), 2005/2020: (GEMIS 2005)

9 *The utilised energy always represents the calorific value of the waste input after deduction of the losses and internal requirements of the plant (surplus).*

10 *DG-TREN – PRIMES-REF scenarios*

power under the nuclear energy consensus. With regard to the climate protection aspects investigated here, however, this aspect only has a minor effect of the accounts, as on balance some 10 % more power will be generated from renewables compared with roughly the same percentage less from nuclear energy, leaving the share of the mix accounted for by fossil fuels more or less the same.

A more serious effect is that the PRIMES scenario from GEMIS assumes an increasing share of power from coal and lignite and a decreasing share of power from gas. Since this would not be compatible with Germany's climate protection objectives, present indications are that a scenario is more likely which, instead of 63 % coal and 10 % gas, assumes only 46 % coal but 25 % gas for the electricity mix 2020 (EWI/PROGNOS 2005, BMU 2004). Thus the amount of CO_2 actually emitted by power stations would be smaller than calculated on the basis of GEMIS, and the credits for power CO_2 would be correspondingly lower. Since the electricity mix in the scenarios is only used for inventory purposes, and since electricity offtake only accounts for a total of 30 % of energy utilisation, the impact on the result is not serious.

Table 2.10: *Summary of heat credits for the individual scenarios*

	1990/2005	2020
Process heat*	**17.4 %**	**17.4 %**
of which light oil	7.5 %	7.5 %
of which heavy oil	9.2 %	9.2 %
of which gas	57.8 %	57.8 %
of which coal	21.3 %	21.3 %
of which lignite	4.2 %	4.2 %
District heating	**82.6 %**	**82.6 %**
of which oil-fired heating	85 %	30 %
of which gas-fired heating	10 %	70 %
of which electric heating	5 %	0 %

* *Sources: Mix for process heat (ITAD 2002), Assumptions for credits 1990/2005 (ifeu, 2005) and own assumptions for 2020.*

The heat credits for the 1990 and 2005 scenarios use the assumptions from (ifeu 2005) (see Table 2.3). On this basis 82.6 % of the heat is used for district heating, where it replaces individual household heating systems. The remaining heat is used as process steam for industry, where it replaces the mix for generation of superheated steam.

For 2020 the figures for industrial use of heat remain the same. On the domestic heating front, by contrast, gas-fired heating systems are largely replacing the oil-fired systems that are still widespread (see Table 2.10), so that to a large extent the district heating input can only be credited with the lower emissions of gas heating systems (cf. Table A2.2 in Appendix 2).

2.5.4 | Co-incineration

Co-incineration is the term applied to the burning of waste in conventional power plants and production facilities, which as a rule are coal-fired power plants and cement works. The fuels used are secondary fuels produced specifically for the purpose from high-calorific waste and high-calorific fractions of mixed waste.

Co-incineration only plays a minor role in the 1990 scenario: only paper sludge from the processing of paper and board is relevant here, with a volume of 72,000 t.

The situation has already changed by 2005: because of the requirement to treat waste prior to landfill, paper sludge from paper and board processing is joined by other secondary fuels. These are divided equally between coal-fired power stations and cement works. The cement works also take the sorting and processing residues from the recovery of lightweight packaging.

The co-incineration quantities for 2020 are set on the basis of the LAGA data (LAGA 2004). These figures indicate that coal-fired power plants, cement works and special-purpose furnaces will in future each burn one third of the secondary fuels available.

The present accounts group coal-fired power stations and special-purpose furnaces together, since the latter can have widely differing environmental impacts depending on the individual type of plant and it is therefore impossible to predict any average figures for these accounts. Coal-fired power plants, by contrast, reflect the possible debits and credits relatively well compared with cement works.

the situation after the ban on landfill of untreated waste. In the scenarios for 2005 and 2020 only inert substances that do not give rise to any greenhouse gas emissions are sent for landfill. In view of the accounting method chosen, landfill waste from previous years is no longer relevant, since the emissions are assigned to the year in which they were caused.

2.5.5 | Landfill

When it comes to landfill, methane emissions in particular have a climate-relevant impact. Methane is produced over a period of *many years* by anaerobic degradation of the organic components in municipal waste. Landfill gas emissions can be accounted for in two different ways:

the first is to assign to the first accounting year the entire potential of methane and CO_2 emissions that will be released over a period of 50 years or more. This method is regularly used in waste accounting to assign all emissions arising from waste to the year in which they were produced, and the environmental accounting model Umberto® used by ifeu also calculates in this way.

The second method uses a dynamic model to determine the emissions and spreads them over several accounting years. This method is a better reflection of how a landfill site behaves, but it is not suitable for describing municipal waste management performance in relation to the year under review[11].

In the 1990 scenario, landfill gases are still of considerable importance. All other scenarios depict

The exact distribution of landfill gas emissions over time would not have any significant influence in these scenarios, as the time-span of 15 years between the scenarios is so long that even using the Tier 2 model the greater part of the methane would have been released.

In addition to the formation of landfill gas, the necessary operating supplies for landfill are taken into account for all years. Thus the associated emissions of climate-relevant gases and the fuel requirements are registered.

Landfill gas can be captured and used in the same way as natural gas. But not all landfill sites in Germany have captured the gas: in 1990 the proportion in the eastern states (former GDR) was a bare 3 %, and in the western states it was around 62 %. In the same year one third of the landfill gas captured was used as fuel for generators (ifeu 2005). The power generated served as a substitute for power from the German electricity mix. The rest was at least flared off, since methane has a stronger greenhouse impact than CO_2.

The data for the 1990 scenario are taken from Federal Environmental Agency's environmental data

11 The international reporting requirements for greenhouse gases also make a distinction between these two methods. Since for monitoring purposes the emissions have to be assigned as precisely as possible to the individual years, IPCC recommends modelling using the First-Order Decay method (Tier 2) (IPCC 1996).

for 1990/91 and 1992/93. The figures make a distinction between the technology used in the eastern and western states.

The accounts assume degradation of 50 % of the renewable carbon (IPCC 1996b). In 1990 landfill gas capture was practised by only 3 % of sites in the eastern states, whereas the figure for the western states was 62 %. The proportion of diffuse emissions is put at 50 %, resulting in a calculated quantity of 31 % for the western states and 1.5 % for the eastern states. The methane content of landfill gas is taken to be 55 % (IPCC 1996b). A methane oxidation rate of 10 % is assumed for diffuse releases of methane in the western states. In accordance with the IPCC recommendations, no account is taken of methane oxidation in the eastern states.

2.5.6 | Waste paper and waste glass

After sorting, waste paper is processed and recovered in paper mills. This gives rise to reject material and paper sludge as waste. The reject material is burned in incineration plants, the paper sludge in coal-fired power plants (cf. Chapter 2.5.4). Waste paper recovery, however, is entered directly in the accounts: the energy saved is credited as a replacement for new fibres from industrial timber.

Waste glass is sent for processing of broken material to obtain glass for containers. The waste glass collected is first size-reduced, sorted and processed to ensure final separation of foreign material from the glass fragments. The sorted glass fragments go to a glass works, where they are substituted for the raw materials used in primary glass manufacture and the relevant quantities of energy.

It is assumed that there will be no change in quantities and credits for waste paper and waste glass recovery for the period up to 2020.

2.5.7 | Recovery of lightweight packaging

Lightweight packaging is sales packaging made of various materials such as plastic, composite materials, aluminium or tinplate. Sorting systems are used to separate lightweight packaging into the individual fractions. These are then processed and sent for recycling.

Plastics are separated into various fractions. Mixed plastics account for the largest share, and are recovered in the form of both energy and materials. Materials recovery includes in particular the production of methanol in the gasification plants of the Schwarze Pumpe lignite power plant, and use of material as a reducing agent in metal foundries. Material recycling is the term applied to the production of regranulates used in the manufacture of plastic materials. Mixed plastics are also used to a small extent as secondary fuel in waste incineration plants and in co-incineration.

Other plastics such as sheet and film, cups, PO, PET and PS fractions are recovered largely in the form of material. And they are also used for manufacturing moulded parts made of secondary feedstock, which replace products made from other materials such as wood or concrete palisades.

Lightweight packaging was not recorded separately in 1990, which is why it does appear in the relevant scenario.

Aluminium and tinplate undergo further treatment (e.g. pyrolysis of aluminium) before being sent to foundries, and the secondary aluminium or secondary tinplate produced replaces the equivalent primary raw materials.

Tetrapacks, as examples of composite packaging, are separated into their paper fibre and aluminium foil components and recovered.

In the scenarios for 2020 the lightweight packaging quantities and the credits for the individual products and raw materials output remain unchanged compared with 2005. It is however assumed that in

2020 there will no longer be any raw material recovery of plastics and no landfill of residual substances. In 2020 the plastics that still undergo raw material recovery in 2005 are assigned half each to material recovery and energy recovery. This results in part of the credits being shifted to co-incineration. For metals collected and recovered with the lightweight packaging fraction, the credits (ifeu 2001a) are shown under lightweight packaging. Metals from mechanical-biological treatment plants and waste incineration plants are accounted for separately. As already described, the proportion of metals recovered from waste incineration plants and mechanical-biological treatment plants increases in the scenarios "2020 Basis II" and "2020 Optimised".

2.5.8 | Biowaste recovery

In the 1990 scenario, recovery of biowaste was exclusively by means of simple open composting, in which greenhouse gases such as methane and mitrous oxide (laughing gas) were emitted in non-negligible quantities and had a climate-relevant impact. The energy input, especially for aerating the compost clamps, made the figures even worse.

In the 2005 scenario, 88 % of biowaste is composted (ifeu 2005), half of it in closed systems. The remaining 12 % of the biowaste undergoes wet fermentation (StBA 2004, Kern et al. 1998). Residual substances from fermentation are fermentation residues or composted fermentation residues (assumed ratio 50:50). Of the fresh fermentation residues, 90 % are used in the agricultural sector and 10 % in fruit growing and horticulture. Half of the composted fermentation residues are used in agriculture and fruit growing, and 30 % in horticulture and landscape gardening. The remaining 20 % are used in other areas. The processes are modelled on the basis of (ifeu 2001b).

In the basic scenarios for 2020 the distribution remains the same, but all units work as closed systems. This substantially reduces emissions of the particularly critical greenhouse gases methane and nitrous oxide.

In the scenario "2020 Optimised" it is assumed that 80 % of biowaste goes to fermentation units and only 20 % to aerobic rotting units. Here the focus is on climate protection aspects. This study does not examine the extent to which this makes ecological sense from the point of view of waste management and soil improvement aspects.

Compost is largely used as a replacement for primary production of mineral fertilisers (e.g. NP, NPK), (StBA 1997, Patyk and Reinhardt 1997) and primary production of peat and bark humus. In the case of peat the content of inorganic substances is taken as the equivalent figure. It is assumed, after (De Groot 1999), that 1 kg dry peat produces 2 kg CO_2 when used. Since bark occurs as a waste product in the forestry sector, the production of bark humus is only entered in the figures from the point where it occurs. A rotting time of 6 months and rotting losses of 50 % are assumed (Eurich-Menden 1996).

The methane gas from fermentation is used to generate electricity in gas-powered generators and replaces the relevant electricity mix (cf. Table 2.2).

3 | Results

3.1 | General discussion of balance results

By abandoning landfill the waste management sector made a substantial contribution to climate protection during the period 1990 to 2005. One cannot expect further savings on this scale in the future, either for fossil resources or for greenhouse gas emissions. Further potential for improving the efficiency of energy and material recovery nevertheless exists for the period up to 2020 and beyond. Compared with other sectors of the economy the potential and the resulting savings are considerable. Thus the waste management sector will continue to play an important part in compliance with the CO_2 reduction commitments under the Kyoto Protocol.

The balance results are shown in the following diagram.

3.2 | Contributions of the individual disposal paths

In all scenarios, fossil fuels are saved by the recovery and disposal of municipal waste (cf. Fig. 3.2). This is ensured in particular by the generation of power and heat in waste incineration plants and through co-incineration – and the trend is increasing, since plant efficiency will continue to improve up to 2020 and

Fig. 3.1: *Summary of balance results for fossil resources and greenhouse effect*

Fig. 3.2: *Representation of debits and credits for the individual disposal paths as a contribution to conservation of fossil fuels*

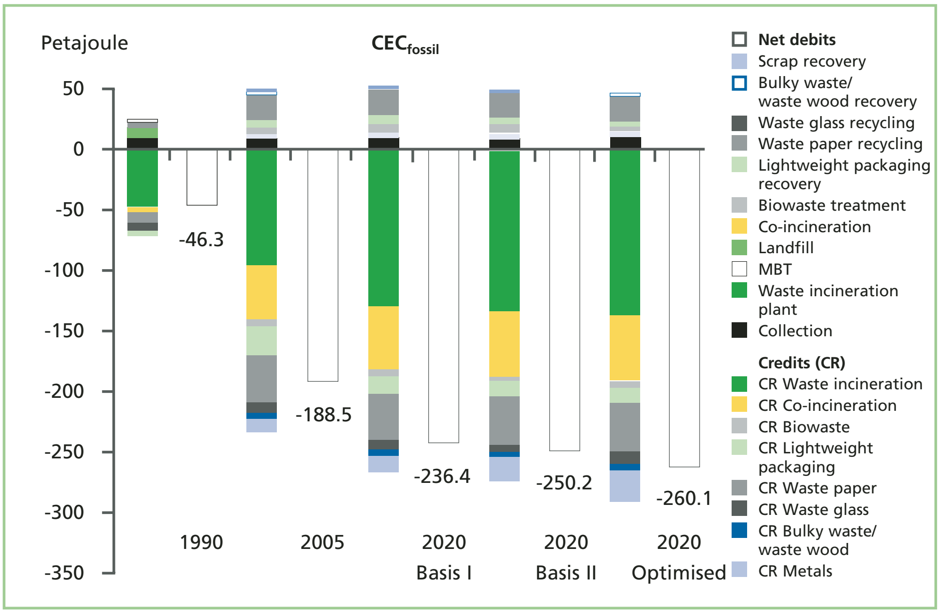
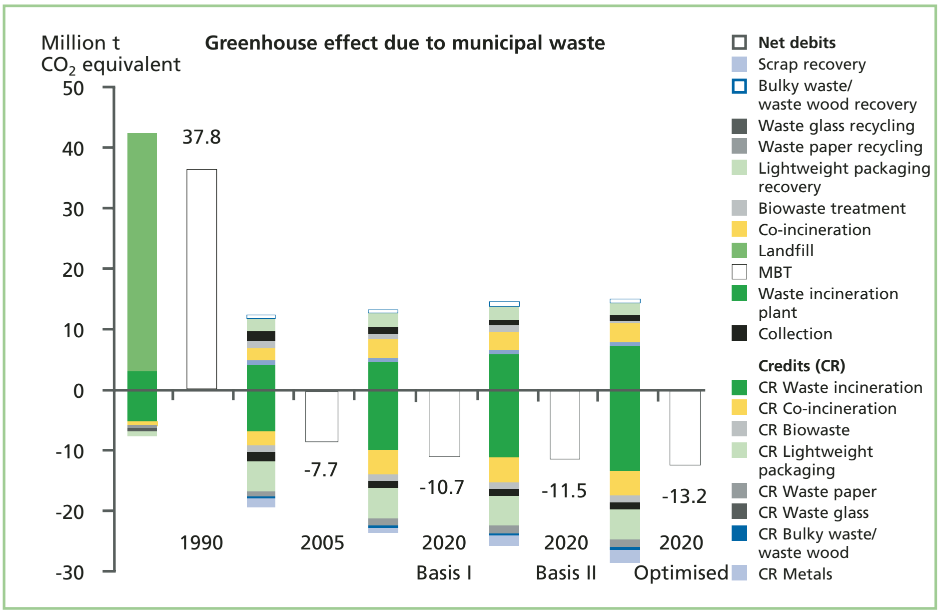


Fig. 3.3: *Representation of debits and credits for the individual disposal paths as a contribution to greenhouse gas emissions*



additional plants will be built. Waste paper recycling also saves resources on balance, although it has the highest fossil fuel consumption of all waste management paths considered. Better separation and recovery of metals in mechanical-biological treatment plants and waste incineration plants in the scenarios 2020 Basis II and 2020 Optimised can roughly double the credits for this fraction compared with 2005 and 2020 Basis I.

Fig. 3.3 shows the credits and debits for the individual waste management paths for greenhouse gas emissions. The balance for 1990 was dominated by methane emissions from landfill sites. Since the balance for 2005 is drawn up without landfill, emission reductions and accounting results between 2005 and 2020 are no longer possible on the scale seen between 1990 and 2005. The bottom line is that the reduction potential for the period from 2005 onward is indeed very relevant at over 5 million t CO_2 equivalent and can make an appreciable contribution to meeting the reduction targets for climate protection in Germany.

The contributions of the collection and transport of waste are virtually negligible (cf. Fig. 3.3 and Table A4.1 in Appendix 4). This shows that in many cases too much importance is attached to the input necessary for collection when discussing the various waste collection systems.

The credits for energy recovery from mixed plastics in the lightweight plastic fraction are shown under co-incineration. The contribution due to recycling of lightweight packaging nevertheless shows an increase as a result of the increase in material recycling.

For the period up to 2020 there is still a reduction potential of 5.5 million t CO_2 equivalent compared with 2005. Waste incineration plants and co-incineration continue to offer the greatest potential in all scenarios.

In the scenario "2020 Optimised", the increase in the fermentation figure from 10 % to 80 % of biowaste treatment brings additional savings. However, the change from crediting power from waste incineration plants on the basis of imported coal instead of natural gas (gas and steam) has a greater effect (cf. Chapter 3.2.1).

The contribution of a waste fraction and its waste management path depends on its volume and its specific credit, i.e. on the credit per tonne of waste. The size of the credit provides a valuable indication of potential for future improvement. The specific credits are listed in Appendix 4.

3.2.1 | Contribution of waste incineration plants

The substance flow model used first exhausts the capacity of all other waste management paths before sending waste to incineration plants as residual municipal waste. This method is due to the modelling requirements (cf. Chapter 2), but does not entirely do justice to the important position of waste incineration plants in the waste management system, since it underestimates the contribution made by waste incineration plants[12]. This chapter therefore sets out to show in detail what influence a variation in the substitute processes (and hence credits) and waste volumes has on the accounting figures for waste incineration plants.

Thanks to efficiency improvements and capacity expansion, waste incineration plants output more electricity in the scenarios for 2020 than in 2005 (cf. also Johnke, Treder 2004). Different credits are invoked for these additional plants, as described in Chapter 2.5.3, namely electricity from gas-and-steam plants or electricity from imported coal. Simply as a result of this difference, the net credit for waste incineration plants doubles between the scenarios, from approx. 1.5 million t for gas-and-steam electricity to 3 million t CO_2 equivalent for coal electricity. Thus the decision on the substitute processes has a major influence on the accounting results.

At present waste incineration plants also burn a certain amount of waste types that are not covered by the categories in these accounts, such as industrial waste and sewage sludge. For this reason it is not possible to determine exactly the capacity used for residual municipal waste. However, on the basis of the present market situation it may be assumed that residual municipal waste will fully utilise the capacity of the waste incineration plants. This would cause a further increase in the climate protection contribution of waste incineration plants.

Table 3.1 sets out both the influence of **credits** and the influence of **capacity** on the net bonus.

Table 3.1: *Electricity credits (net bonus) for waste incineration plants*

Credit for waste incineration plants	Specific net bonus	Balance volume	Net bonus balance	Saving over 2005	Max. waste incineration capacity*	Net bonus max.	Saving over 2005
	kg/t	mill. t waste	mill. t CO_2	mill. t CO_2	mill. t waste	mill. t CO_2	mill. t CO_2
Scenario 1990	-126	7.9	-1.0				
Scenario 2005	-184	13.4	-2.5		16.2	-3.0	
Scenario 2020, Basis II	-251	16.3	-4.1	1.6	17.8	-4.5	1.5
Scenario 2020, Optimised	-333	16.3	-5.4	2.9	17.8	-5.9	2.9
Electricity mix 2020	-285	16.3	-4.6	2.1	17.8	-5.1	2.1
Gas-and-steam 2020	-160	16.3	-2.6	0.1	17.8	-2.8	-0.2
Imported coal 2020	-363	16.3	-5.9	3.4	17.8	-6.5	3.5
Rhineland lignite 2020	-415	16.3	-6.8	4.3	17.8	-7.4	4.4

* *after (LAGA 2004)*

The bonus takes in both power and heat, but the variation in the table relates solely to power, which accounts for only about 30 % of the energy. The heat credits remain virtually unchanged.

The variation for the credits takes place within the various rows: the grey cells show data according to the original logic of the scenario (i.e. for additional plants only). The blue cells, by contrast, assign credits for the entire electricity quantity for 2020 (i.e. no distinction is made between existing and additional plants). The orange cells show an increase in waste incineration capacity compared with the accounting data. The green cells show the figures for a combination of the two variations.

It will be seen that the influence of the choice of credit is greater than the precise determination of capacity utilisation: replacing electricity from Rhineland lignite would bring a saving of 6.8 million t (or 7.4 million t at maximum utilisation), compared with 2.6 million t (or 2.8 million t) for electricity from gas-and-steam power plants. Improvements in the efficient exploitation of energy potentials of waste incineration plants on the basis of best available technology, given full utilisation and credits in line with the scenario requirements, result in a CO_2 savings potential of 4.5 million to around 6 million t CO_2 equivalent.

3.2.2 | Contribution of biowaste recovery

The focus of this brief study is on the climate protection contribution and potential of the entire waste management sector. For this reason the methane emissions saved in the landfill segment are not assigned as a credit to any other process. However, separate collection and recovery of biowaste in modern closed systems plays an outstanding role, because it is one of the waste management paths that made the departure from landfill possible in the first place.

Through material and energy recovery from biogenic residual waste, this path makes a contribution to reducing climate-relevant gases by avoiding methane emissions. It is also possible to replace fossil fuels if the waste is fermented, thereby producing biogas. For this purpose fermentation systems would have to replace the aerobic composting that is standard practice today. The biogas can be used to power efficient gas generators in CHP plants. Fermentation plants as a closed system also have the advantage

12 *For accounting reasons the figure used for waste incineration is not the full 17.8 million t/a available in future according to LAGA 2004, but – as described – approximately 16.2 million t/a.*

that they minimise emissions of nitrous oxide (laughing gas), which is particularly climate relevant. The economic foundation for changing over to fermentation has been laid in the Renewable Energies Act (Fritsche et al. 2004).

3.2.3 | Contribution of dry materials recovery

The dry materials – lightweight packaging, waste glass, waste paper and metals – make a major contribution of 47 % to the good greenhouse gas balance for 2005 in the waste management sector.

For the forecasts in the scenario 2020 Basis I, the thermal processes are all optimised and the recovery of dry materials is left unchanged, leading to a relative drop in the share of the result to 35 %. As a result, recovery accounts for only about 5 % of the further reduction in greenhouse gases compared with 2005.

Owing to the assumption of more effective separation of metals in mechanical-biological treatment plants and waste incineration plants, the share of the reduction accounted for by dry materials recovery in the scenario 2020 Basis II increases to about 21 % compared with 2005.

3.2.4 | Contribution of landfill

The modelling technique used means that no methane emissions are produced and entered in the accounts in years when there is no longer any landfill deposition of biodegradable waste components. In the 2005 scenario only residues from mechanical-biological treatment plants are responsible for slight methane emissions, whereas in the 2020 scenarios there are no longer any methane emissions from landfill sites.

However, the accounting results must not be allowed to obscure the fact that methane emissions from municipal waste landfill sites in Germany will continue to be significant even after 2005. According to forecasts by the Federal Environmental Agency, methane emissions will fall from approx. 400,000 t to some 100,000 t a year from 2005 to 2012 (Butz 2005). The resulting contributions are 8.4 million and 2.1 million t CO_2 equivalent (Johnke, Butz 2005).

Accordingly, active capture of and energy recovery from landfill gas will continue to make a relevant contribution to greenhouse gas reduction for many years to come. Since methane emissions from open landfill sites cannot be effectively prevented, gas-tight capping must be put in place without delay as part of the process of closing down landfill sites.

3.3 | Savings potential of sewage sludge and waste wood

These accounts do not include sewage sludge or waste wood. This section therefore shows, on the basis of a rough estimate, the contribution that energy recovery from municipal sewage sludge and

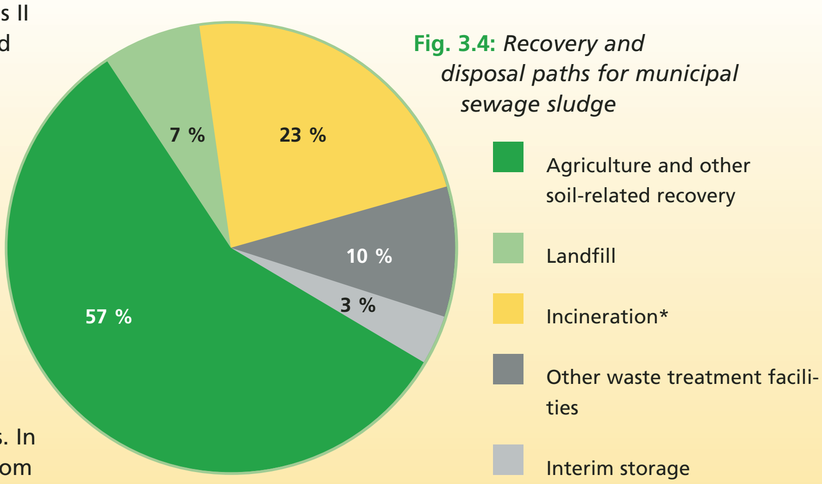


Fig. 3.4: *Recovery and disposal paths for municipal sewage sludge*

* *Incineration in waste incineration plants, coal-fired power plants, sewage sludge incineration plants in 2001*

waste wood can make to climate protection. Only the years 2005 and 2020 are considered.

3.3.1 | Sewage sludge

In 2001 a total of 2.4 million t of municipal sewage sludge was produced (UBA 2004). Agriculture, landscape engineering uses and landfill, and also incineration, were important recovery and disposal paths (see Fig. 3.4). No account is taken here of the 1.3 million t of industrial sewage sludge.

As from 1 June 2005, untreated sewage sludge may no longer be sent for landfill, and incineration in purpose-built sewage sludge incineration plants will probably stagnate. On the other hand there will be a considerable rise in the share due to co-incineration in coal-fired power plants and increasingly in cement works.

The calorific value of dried sewage sludge is in the region of 9 – 12 MJ/kg dry matter (UBA 2004). A figure of 10.5 MJ/kg dry matter was assumed for the calculations.

The following assumptions are made for the estimate:

- **In 2005 some 0.6 million t of municipal sewage sludge is sent for incineration. The greater part of this goes to purpose-built sewage sludge incineration plants. The sewage sludge is dewatered, but not dried, which does not bring any significant energy benefits. Accordingly, no credit is assigned to this waste management path.**

- **The other half is co-incinerated in coal-fired power plants and other installations of comparable efficiency. Here the sewage sludge is fed into the coal pulveriser, where it is dried by means of recovered heat. Energy is generated in the form of electricity only. There is no external use of heat.**

- **In 2020 the entire volume of municipal sewage sludge is co-incinerated in coal-fired power plants. The figures for incineration of sewage sludge in waste incineration plants will continue to decrease, and special-purpose sewage sludge incineration will largely be confined to sewage sludge with higher pollution levels.**

- **A figure of 40 % is assumed for the energy efficiency of coal-fired power plants. Co-incineration of sewage sludge reduces the use of imported coal[13].**

The credits for electricity from imported coal are listed in Appendix 2, Table A2.1, and the results of the calculations can be seen in Table 3.2 (cf. also footnote 11). At 2.5 million tonnes, the CO_2 savings potential for the year 2020 is at least 8 times more than is achieved by present-day thermal processes for sewage sludge recovery.

Table 3.2: *Results of rough calculation of CO_2 credits for sewage sludge*

	(million t CO_2 equiv.)
2005	0.3
2020	2.5
Difference	2.2

3.3.2 | Waste wood and residual wood

The potential of industrial residual wood for 2005 is put at 55 petajoule (PJ) (Fritsche et al. 2004). A large part of this potential is already being used. The future trend in volume therefore depends to a large extent on demand for wood processing and especially on the situation in the building industry. However, since these factors are very difficult to forecast (Fritsche et al. 2004), a constant residual wood potential is assumed for this study.

The potential for residual wood from forestry in 2005 is assumed to be 149 PJ, and this will increase to 156 PJ by 2020 (Fritsche et al. 2004). Unlike residual wood from industry, this potential is not yet fully utilised (cf. Table 3.3).

13 *The specific emission factors for the two years are rather different. In 2005 the factor is 928.3, while in 2020 it is 870.9 g CO_2 equivalent per kilowatt-hour of electricity.*

Table 3.3: *Shares of thermal utilisation in biomass CHP plants due to individual wood categories, in relation to total input of wood biomass (cf. Fritsche et al. 2004)*

	PJ	mill. t	Share
Total wood biomass	48	3.9	100 %
of which: A I/II	24	2.0	50 %
of which: A III/IV	14	1.2	30 %
of which: residual wood from forestry	10	0.8	20 %

Unlike the figures in Table 3.3, the estimate is based on the following assumptions:

- **In 2005 some 3.1 million t of waste wood (excluding residual wood from forestry) will be burned (see Table 3.3). Energy is generated exclusively in the form of electricity, with an efficiency of 30 %.**
- **The calculations do not take account of residual wood from forestry, since this material flow is not counted as belonging to the waste management sector, but represents classic renewable raw materials.**
- **For 2020 there is no increase in the quantities of waste wood burned. The electricity generation efficiency also remains unchanged from 2005. In addition, however, heat utilisation from combined heat and power generation is taken into account at a rate of 30 % of the input.**
- **The credits assigned for electricity are 624 g CO_2 equiv./kWh for 2005 and 694 g CO_2 equiv./kWh for 2020. The credit for heat utilisation is 109 g CO_2 equiv./kWh.**

The increase in energy recovery from waste wood, and especially the additional co-generation, saves 1.4 million t CO_2 equivalent by 2020.

3.4 | Assessment of balance in the light of the climate protection objectives

Over the period 1990 to 2003, CO_2 emissions from combustion processes in Germany fell by 150 million t CO_2 equivalent, corresponding to nearly 15 % of the 1990 figure for emissions from combustion processes. All sectors except transport reduced their emissions during this period (cf. Fig. 3.5). By contrast, CO_2 emissions due to transport increased by 8 million t CO_2 equivalent.

The largest share of emissions was contributed by industry with 65 million t CO_2 equivalent, followed by the energy sector with 57 million t CO_2 equivalent, and the trade and light industry sector with 30 million t CO_2 equivalent (see Fig. 3.5).

If one adds other greenhouse gases, especially methane and nitrous oxide emissions from the waste and agricultural sectors, the greenhouse gas emissions are as shown in Table 3.5.

The reduction requirements for CO_2, CH_4 and N_2O are based on the year 1990, and for the remaining parameters 1995 is taken as the base year. This results in a starting figure of 1,248.3 million t CO_2 equivalent that has to be taken as a basis for the reduction targets. By 2003 the starting figure had been reduced by 230.8 million t CO_2 equivalent to 1,017.5 million t CO_2 equivalent (cf. Table 4.1).

The waste sector is credited with 20 million t CO_2 equivalent for this period thanks to avoidance of methane emissions from landfill. Thus the waste industry has achieved the contribution it was

Table 3.4: *Results of rough calculation of CO_2 credits for waste wood*

	(million t CO_2 equiv.)
2005	2.0
2020	3.4
Difference	1.4

Fig. 3.5: *Sectoral development of CO_2 emissions from combustion processes in Germany (figures in million t CO_2), (from BMU 2005a)*

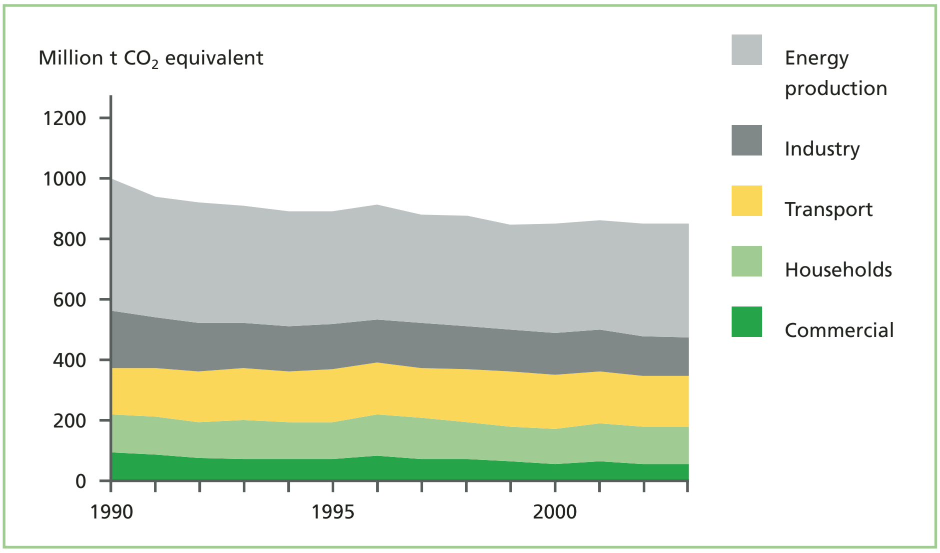


Table 3.5: *Development of greenhouse gas emissions in Germany (figures in million t CO_2 equivalent) (BMU 2005a)*

Greenhouse gases	1990	1995	2000	2003
CO_2	1015	902	860	865
CH_4	132	105	83	75
N_2O	86	81	62	64
H-CFC	4	6	7	8
CFC	3	2	2	1
SF_6	4	6	3	4
Total (excl. LULUCF)*	1244	1102	1017	1017
Total (incl. LULUCF)*	1251	1108	1031	1031

* *LULUCF = Sources and sinks due to land use, land use changes and the agricultural and forestry sector*

grey cells = base year for relevant greenhouse gas

expected to make to the reduction target of the national climate protection programme.

A further saving of 8.4 million t CO_2 equivalent by 2012 is forecast as a result of the closing down of landfill sites. For the period from 1990 to 2012 this results in a reduction of 28.4 million t CO_2 equivalent, which under the Federal Government's decision of 13 July 2005 (BMU 2005a) is attributed to the landfill disposal path in the National Climate Protection Programme.

By contrast, the balance result in this brief study shows a reduction of 46 million t CO_2 equivalent for the period 1990 to 2005. Owing to different accounting methods, however, the figures are not directly comparable. In particular, the National Inventory Reports (NIR) do not assign any credits for energy produced as a result of energy recovery from waste.

For waste incineration the national climate protection programme sets out reduction potentials of 1.5 million to 2 million t CO_2 equivalent for the period 2005 to 2012. This potential is in line with the results of this brief study, according to which waste incineration plants can make a contribution of 1.5 million t to 3 million t CO_2 between 2005 and 2020. This would represent 0.6 to 2 % of the German reduction target of 150 to 250 million t for CO_2 from combustion processes, simply as a result of more efficient use of energy and increases in waste incineration capacity. Given the right framework it would be possible to achieve these ambitious targets by as early as 2012.

For metal recycling the national climate protection programme states a reduction potential of 0.7 million t CO_2 equivalent. This is also confirmed by the results of present balance (reduction by 0.77 million t CO_2 equivalent), provided a higher recovery rate for metals, especially non-ferrous metals, can be achieved.

The figures of 2.2 to 3.7 million t CO_2 equivalent for co-incineration are also in the range determined in this report for the reduction potential in this sector (3.5 million t CO_2 equivalent for the period from 1990 to 2020).

Germany has promised to reduce greenhouse gas emissions by a total of 40 % by 2020 compared with the base year 1990[14]. If the 1,248.3 million t CO_2 equivalent in 1990 (cf. Table 4.1) are taken as the starting point, the reduction of 230.8 million t CO_2 equivalent in 2003 means that the cuts achieved come to around 18 %. From 2003 to 2020 the reduction in annual greenhouse gas emissions would have to amount to a further 270 million t CO_2 equivalent, if the target of a 40 % reduction is to be achieved.

By means of various measures, the waste management sector can contribute a total of around 2 % to this[15]. This requires appropriate measures to exploit all potentials, which – assuming full utilisation of waste incineration plants – could be in the region of as much as 4.5 million t to 6 million t CO_2 equivalent. If one adds the reduction components estimated in Chapter 3.3 resulting from energy recovery from waste wood and sewage sludge, with a further combined potential of approx. 3.6 million t CO_2 equivalent, this takes the waste management sector's contribution to about 3.5 %.

For the entire period from 1990 to 2020 the share due to the waste sector is considerably higher because of the substantial reduction in methane emissions from landfill sites. Of the total reduction of 500 million t CO_2 equivalent achieved and planned in this period, the municipal waste sector will account for some 50 million t CO_2 equivalent, i.e. a share of approx. 10 %.

However, the official accounts in the NIR generally attribute only the avoided methane emissions from landfill to the waste sector. The credits for energy produced as a result of energy and material recovery are assigned to the industrial and energy sectors.

Table 3.6: *Reduction contributions of the individual sectors up to 2012, as set out in the climate protection programme of 18 October 2000 (from BMU 2005a)*

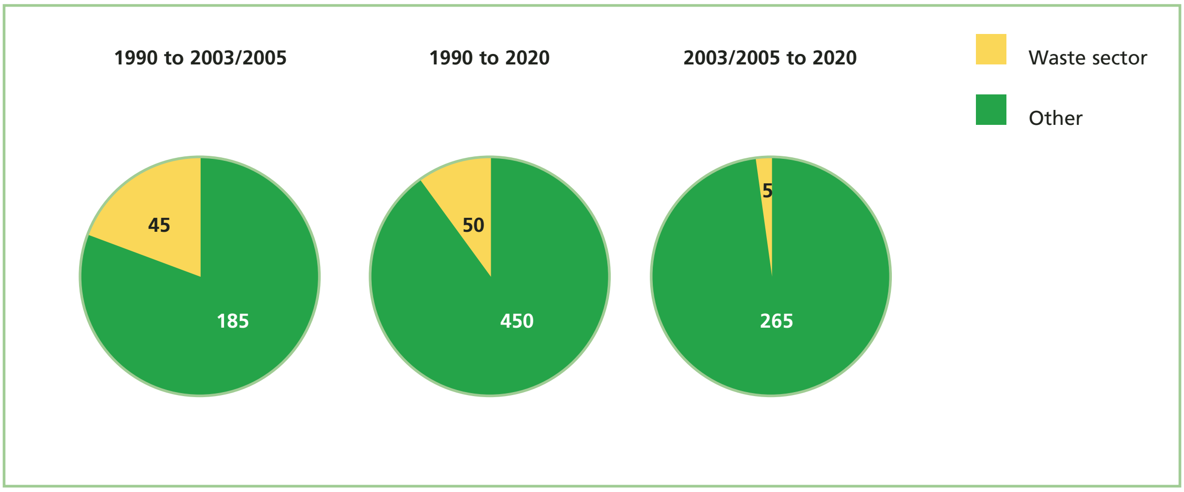
Measures and instruments	Reduction potential (in mill. t CO_2 equivalent)
Ecological tax reform	20
Renewable energy sources	20
Measures in household and building sector	18 to 25 (by 2005)
Measures in industry	15 to 20 (by 2005)
Measures in transport sector	15 to 20 (by 2005)
Measures in energy sector	20 (by 2005)
Contribution by waste sector	**20**
Measures in the agricultural and forestry sector	not quantified

* *Source: National Climate Protection Programme of 18 October 2000*

14 *A 40 % reduction has been promised provided that Europe as a whole achieves a reduction of 30 % (BMU 2005b).*

15 *As already described, this does not include the reduction due to methane gas emissions still being emitted by shut-down landfill sites, as these are already credited in the 2005 scenario.*

Fig. 3.6: *Contribution of German municipal waste sector to the planned overall reduction of 40 % in greenhouse gases in Germany during the period 1990 to 2020.*



4 | Ways and means of reducing greenhouse gas emissions in the waste sector in Europe (EU-15)

4.1 | Situation in Europe as reported by the Member States

Efforts to reduce greenhouse gas emissions in the individual European countries (EU-15) have met with very mixed success to date.

Table 4.1 shows that apart from Germany only the United Kingdom and Luxembourg have succeeded in reducing greenhouse gas emissions to any appreciable extent. It must however be remembered that Germany started with the highest emission levels and hence with the greatest theoretical reduction potential.

In the 13 years from 1990 to 2003 a reduction of approximately 73 million t CO_2 equivalent (1.7 %) was achieved in the EU-15 countries. If the discussed target of a 30 % reduction on 1990 levels is to be achieved by 2020, some 1,200 million t CO_2 equivalent will have to be saved in the remaining 17 years from 2003 onwards. It is obvious that rigorous exploitation of every potential will be needed to achieve this.

According to their reported progress, the EU-15 countries reduced CO_2 emissions in the waste sector (landfill, incineration, wastewater treatment) by 44 million t CO_2 equivalent between 1990 and 2003 (cf. Fig. 4.1).

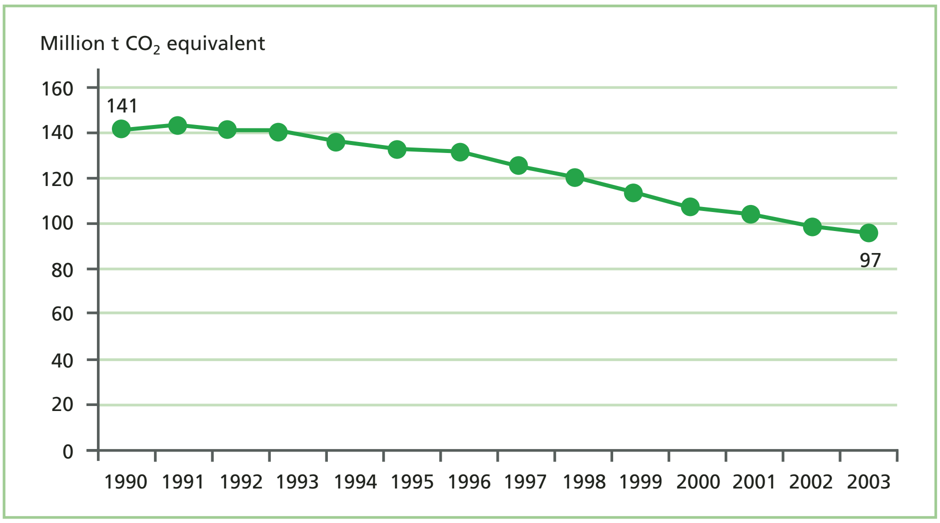
Table 4.1: *Development of greenhouse gas emissions in EU-15 (from BMU 2005a)*

	Base year*	1990	1995	2003	2000	Absolute change 2003/base year	Change 2003/base year	Emission target under Kyoto Protocol (EU burden sharing) by 2008/2012
	in mill. t CO_2 equivalent						in %	
Belgium	147	146	152	148	148	1	+0.6	-7.5
Denmark	70	69	77	68	74	4	+6.3	-21.0
Germany	1248	1244	1103	1017	1018	-230.8	-18.5	-21.0
Finland	70	70	71	70	86	15	+21.5	0
France	568	568	563	560	557	-10.8	-1.9	0
Greece	112	109	114	132	138	26	+23.2	+25.0
U.K.	751	748	691	652	651	-100.3	-13.3	-12.5
Ireland	54	54	58	69	68	14	+25.2	+13.0
Italy	510	511	528	551	570	60	+11.6	-6.5
Luxembourg	13	13	10	10	11	-1.4	-11.5	-28.0
Netherlands	213	212	224	214	215	2	+0.8	-6.0
Austria	79	79	80	81	92	13	+16.6	-13.0
Portugal	59	59	70	80	81	22	+36.7	+27.0
Sweden	72	72	73	67	71	-1.7	-2.4	+4.0
Spain	286	284	315	380	402	116	+40.6	+15.0
EU-15	**4,253**	**4,238**	**4,129**	**4,100**	**4,180**	**-72.9**	**-1.7**	**-8.0**

* *The base year data forCO_2, CH_4 und N_2O are based on emissions in 1990, and for all other gases on emissions in 1995*

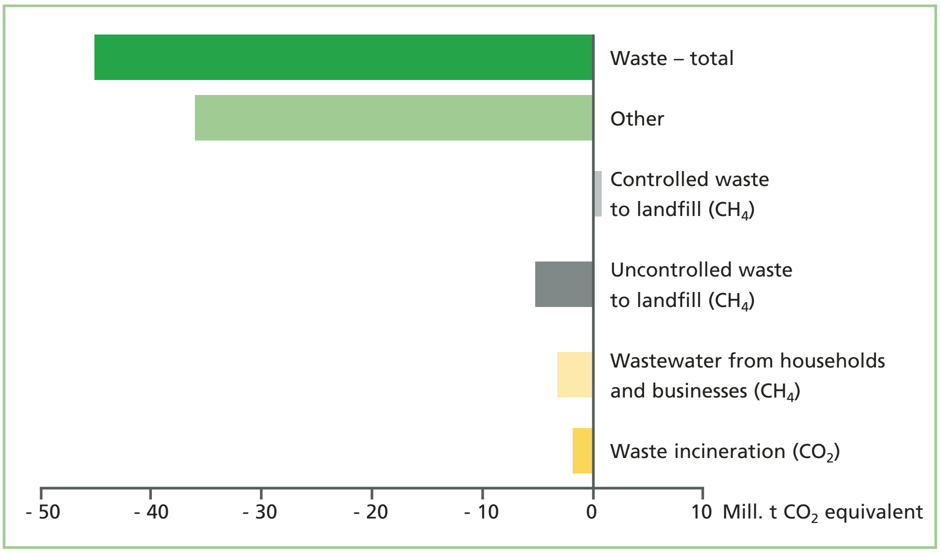
Source: Annual European Community greenhouse gas inventory 1990-2003 and inventory report 2005 (EEA, May 2005)

Fig. 4.1: *Trend in EU-15 greenhouse gas emissions in the waste sector from 1990 to 2003 in million t CO_2 equivalent*



Source (Deuber, Herold 2005)

Fig. 4.2: *Reduction in greenhouse gas emissions by individual waste sectors in the EU-15 countries from 1990 to 2003 in million t CO_2 equivalent*



Source (Deuber, Herold 2005)

A good 90 % of the reductions achieved in the waste sector are due to reduced emissions of methane from controlled and uncontrolled landfill sites (cf. Fig. 4.2). Overall, more than half of all CO_2 equivalent reductions achieved were due to the waste sector.

Despite this, methane from landfill sites still dominates the remaining greenhouse gas emissions in 2003, with a share of 73 %.

If all European countries were to prohibit landfill of untreated waste in the near future, the grand total for 2003 would remain as the reduction potential for the period to 2020, in other words 70 million t CO_2 equivalent. Over the entire period from 1990 to 2020 the reduction potential due to methane emissions avoided amounts to 110 million t CO_2 equivalent.

Measured in terms of the planned reduction of 1,266 million t CO_2 equivalent, and assuming a reduction target of 30 % of the initial figure in 1990[16], this is still a remarkable share of nearly 9 %.

The European data for CO_2 emissions from waste incineration plants are much more difficult to compare with the figures for Germany in this study, as the underlying data were registered for different system limits. For this reason the reported

16 *The EU has since decided on a reduction target of 30 % and a commitment corridor of 15 to 30 %.*

emission data cannot be used as a basis for estimating further reduction potentials under the premises of this brief report (cf. Table A5.1 in Appendix 5).

4.2 | Own estimates based on European waste statistics

4.2.1 | Utilisation of total reduction potential

To make it possible to compare the reduction potential in Germany with the reduction potential in the EU-15 countries, this study takes the waste data for the European Community (EU-15) for the year 2000 from a comprehensive survey of European data on the waste sector published by the European Commission (European Commission 2003) (cf. Table 4.3). The data are then used to arrive at the reduction potential in the EU-15 countries on the basis of the modelling approaches used in this report. The survey in question is an estimate of potential from a waste management point of view, which is not directly comparable with the emissions reported by the Member States (details of the differences in the systems are described inter alia in Chapter 3.4).

A comparison of the waste statistics for 1990 and 2000 shows that the older data evidently suffer from very great uncertainties and gaps. For one thing not all Member States recorded data on waste, for another a large proportion of the waste was not registered in accordance with the appropriate system in some of the EU-15 countries in 1990. The problems can be seen among other things from the fact that data for 1990 were not available in all Member States and it was therefore necessary in some cases to make do with data from 1991 to 1995 (cf. Table A6.1 in Appendix 6). It is not possible to determine meaningful CO_2 emissions from these data.

The grand totals shown in Table 4.3 for the EU-15 countries form the basis for the actual scenario (for the year 2000). The scenario for the future shows the climate protection potential that could be achieved by implementing a committed concept for optimising the waste management sector in Europe (if possible by 2020).

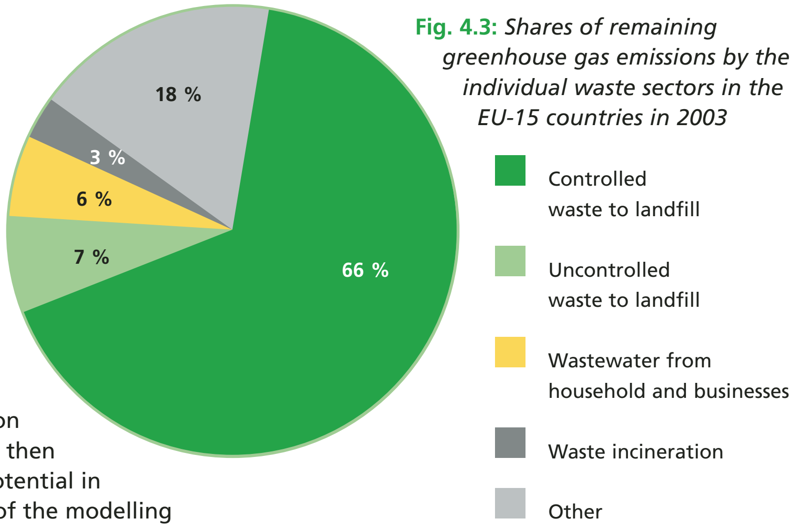


Fig. 4.3: *Shares of remaining greenhouse gas emissions by the individual waste sectors in the EU-15 countries in 2003*

Source (Deuber, Herold 2005)

To this end it is necessary for

- **landfill to be permitted solely for inert waste,**
- **recovery of dry materials and the bio fraction to be a mandatory requirement, and**
- **the components of municipal waste capable of being used for energy recovery to be consigned to a path that ensures efficient utilisation of energy.**

In order to assess the climate protection potential of the EU-15 countries, the sum of the waste in 2000 is allocated to the waste management paths of recycling, biowaste recovery and energy recovery on a percentage basis in the same way (see Table 4.5) as

Table 4.2: *Member States' reported contributions to methane emissions from landfill sites in the EU-15 countries in '000 t CO_2 equivalent*

Member States	1990			2003			Reduction Total
	controlled	uncontr.	Total	controlled	uncontr.	Total	
Austria	4.1	0	4.1	2.8	0	2.8	1.3
Belgium	2.6	0	2.6	0.9	0	0.9	1.2
Denmark	1.3	0	1.3	1.2	0	1.2	0.2
Finland	2.2	0	2.2	1.5	0	1.5	0.7
France	6.3	4.9	11.2	8.0	2.4	10.3	0.9
Germany	**31.5**	**0**	**31.5**	**11.7**	**0**	**11.7**	**19.8**
Greece	1.1	1.6	2.7	2.1	1.8	3.9	-1.2
Ireland	0.9	0.3	1.2	1.5	0.5	1.9	-0.7
Italy	7.8	2.6	10.4	9.3	0.4	9.7	0.7
Luxembourg	0.1	0	0	0	0	0	0
Netherlands	12.0	0	12.0	6.8	0	6.8	5.2
Portugal	0.5	1.3	1.8	1.7	1.3	3.0	-1.1
Spain	2.7	0.8	3.4	6.4	1.0	7.4	-4.0
Sweden	2.6	0	2.6	1.7	0	1.7	0.8
United Kingdom	23.8	0	23.8	8.0	0	8.0	15.7
EU-15	**99.5**	**11.4**	**110.8**	**63.7**	**7.2**	**70.9**	**40**

* *Totals do not always add up exactly owing to rounding*

Source: (Deuber, Herold 2005)

Fig. 4.4: *Contribution due to methane emissions avoided or still to be avoided in Europe as a percentage of the total planned reduction of 30 % in greenhouse gas emissions during the period 1990 to 2020*

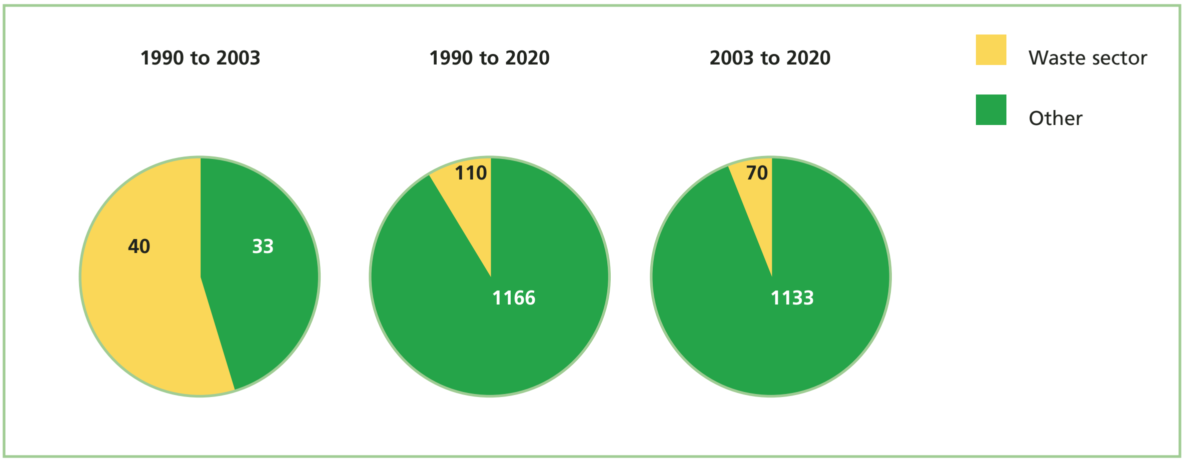


Table 4.3: *Waste quantities in the EU-15 countries and breakdown among the main disposal paths for 2000 in million t (European Commission 2003)*

Member States	Recycling	Biowaste Compost	Biowaste Waste incineration plant with Compost Energy	Waste incineration plant without Energy	Landfill Total	Total
Austria *2	1.0	1.9	0.5		1.6	4.9
Belgium *1	2.0	0.8	0.1	0.2	1.5	4.7
Denmark	7.7	0.6	1.9		0.4	10.5
Finland			0.3		1.6	1.9
France	3.6	3.0	8.8	1.5	14.3	31.2
Germany	**16.5**	**4.0**	**10.5**		**14.6**	**45.6**
Greece	0.4	0			2.3	2.7
Ireland	0.3	0			2.1	2.4
Italy *2	2.6	2.2	2.1		21.8	28.7
Luxembourg *2	0	0	0.1		0.1	0.2
Netherlands	2.4	2.3	3.7		1.3	9.7
Portugal	0.4	0.3	0.9		3.4	5.0
Spain	1.1	0.4	1.5		1.2	4.1
Sweden	1.8	3.1	1.7		10.3	16.9
United Kingdom	3.8		2.5	0.02	27.6	33.9
EU-15	**43.5**	**18.6**	**34.6**	**1.8**	**103.9**	**202.3**

**1: 1998, *2: 1999, discrepancies in the totals are due to rounding*

in the scenario "Municipal Waste 2020 Optimised" for Germany (see Table 2.7).

The component of 34 % for recycling contains the paths: waste paper, waste glass, waste wood from bulky waste, metals and lightweight packaging. In this scenario mechanical-biological treatment (MBT) serves only as an intermediate treatment process and is therefore not included in the determination of shares with regard to the total quantity.
It is however included in the determination of greenhouse gas emissions from the treatment of waste.

The specific credits for the individual disposal paths for the assessment of climate protection potential in the EU-15 countries are estimated on the basis of the corresponding data for Germany.

The debits due to landfill (resulting from methane emissions in particular) and the inputs required for collection, transport and treatment of the waste, and also the CO_2 emissions due to incineration, can be taken over unchanged.

For recycling it is assumed that the breakdown among the individual paths is the same as in Germany, so the weighted average of the individual credits can be used. Since the differences in the net contributions of the individual recovery paths with the exception of metals are only slight, a different distribution of

Table 4.4: *Power plant mix in the EU-15 countries*

Electricity generation mix for EU-15	2000	2005	2020
Uranium	33.6 %	31.5 %	22.5 %
Water and wind	13.4 %	14.6 %	16.1 %
Coal	25.6 %	22.3 %	20.7 %
Oil (including refinery gas)	6.4 %	4.8 %	1.7 %
Gas	17.7 %	22.8 %	34.5 %
Biomass and waste	2.9 %	3.4 %	4.0 %
Miscellaneous	0.5 %	0.5 %	0.6 %

** Source: Data according to GEMIS 4.3*

recovered materials would not influence the result significantly.

The credits for electricity output in the EU-15 countries are lower than in Germany, because the power plants cause lower emissions of CO_2 per kilowatt-hour of electricity (cf. Table 4.4).

Since the credits for waste incineration plants have a considerable influence on the result, it is necessary to adjust the electricity and heat offtake figures to the EU situation. The energy offtake for Europe is put at 10 % electricity and 20 % heat, which means the heat output is one third lower than in the German data. The following assumptions are made in the calculation of the credits:

- **The calorific value of the waste incineration input (mixture of residual waste and household-type industrial waste) is put at 10 MJ/kg overall.**

- **The debits for waste incineration, made up of climate-relevant emissions (CO_2 from fossil component) and the operating supplies input of 335 kg CO_2 equivalent per tonne of waste, can be taken over without any adjustment.**

- **In the actual scenario, electricity output is credited with the figure of 406 g CO_2 equivalent per kWh (GEMIS 2005) for the European electricity mix 2005 (EU-15).**

- **The electricity credit in the future scenario, as already described, makes a distinction between the existing situation and the increase. The existing situation is calculated on the basis of the European electricity mix 2020 with 388 g CO_2 equivalent per kWh, while the increase is based on 50 % electricity from gas-and-steam (412 g CO_2 equivalent per kWh) and 50 % from imported coal (868 g CO_2 equivalent per kWh).**

- **For heat output, the accounting figures for heat output in Germany are used.**

This results in specific credits for energy output (power and heat) of 342 kg CO_2 equivalent per tonne of waste in the actual scenario and 523 kg CO_2 equivalent per tonne of waste in the future scenario. After subtracting the debits, this leaves net credits of 8 kg CO_2 equivalent per tonne of waste in the actual scenario and 187 kg CO_2 equivalent per tonne of waste in the future scenario.

In the case of energy recovery, by contrast, it is not necessary to adjust the specific net contribution, since the recycling process mainly use thermal energy, for which the mix does not display such marked differences between the EU-15 countries.

The same applies to co-incineration, where the credits for the EU-15 countries are given for imported coal as the fuel replaced, just as in the case of Germany.

The actual scenario still shows an additional debit of 87 million t CO_2 equivalent. In the future scenario the municipal waste management sector in the EU-15 countries could contribute to a debit of 47 million t CO_2 equivalent (cf. Table 4.5) if the entire potential were rigorously implemented and if there were not, as in some of the EU-15 countries, plans to continue relying on landfill disposal of municipal waste.

This offers a reduction potential for the municipal waste sector in the EU-15 countries of 134 million t CO_2 equivalent from 2000 to 2020. The greater part of this, nearly 100 million t CO_2 equivalent, is due to the methane emissions avoided by discontinuing landfill deposition of waste that has not been rendered inert. Separate collection and use of biowaste accounts for a not inconsiderable part of this, as the methane produced is largely due to the biowaste in landfill sites.

Separate waste management of individual waste fractions results in a reduction in methane emissions. This reduction is only visible in the accounts from the fact that there is a massive reduction in emissions from landfill. The methane emissions avoided are not credited to the waste management paths concerned. This method of presentation fails in particular to illustrate adequately the effect of separate collection and recovery of biowaste.

The contribution due to biowaste fermentation could be increased still further by optimising utilisation of the gas (see also Chapter 3.2.2).

Landfill gas emissions can also be reduced by optimising the capture of gas from landfill sites. Regardless of any ban on landfill of untreated waste, considerable efforts are necessary in this sector to reduce methane emissions from existing landfill sites. However, since it is not possible to capture landfill gases completely, a ban on landfill must be introduced in the EU in the medium and long term.

The recycling share also makes a substantial contribution to the balance of the variants investigated, with 12 million t CO_2 equivalent (2002) and 19 million t CO_2 equivalent (2020). However, since the absolute increase is not as high as for the thermal recovery paths, the latter are of special importance for the reduction from 1990 to 2020 with approx. 30 million t CO_2 equivalent.

One important consideration is that the necessary additional incineration plants should be built in accordance with the latest technology (BREF 2005), to ensure that the energy output potential is fully exploited and that success in reducing CO_2 emissions is not bought at the cost of additional burdens of airborne pollutants.

Looking at the reduction potential of 134 million t CO_2 equivalent in the municipal waste sector in relation to the planned greenhouse gas reductions of 1,203 million t CO_2 equivalent in the EU-15 countries from 2003 to 2020 reveals a share of 11 %.

As explained above, the total contribution of the European municipal waste management sector to the overall CO_2 reductions from 1990 to 2020 cannot

Table 4.5: *Development of greenhouse gas emissions by the waste management sector in the EU-15 countries on the assumption that waste treatment is of similar quality to that assumed in the scenarios for 2020 in the balance for Germany*

Disposal paths	Actual 2000				Future 2020			
	Share of total	Waste quantity	Specific bonus	Net bonus	Share of total	Waste quantity	Specific bonus	Net bonus
	%	Mill. t	kg/t	Mill. t CO_2 equ.	%	Mill. t	kg/t	Mill. t CO_2 equ.
Recycling	22	43.5	-275	-12.0	34	68.8	-275	-18.9
Compost	9	18.6	25	0.5	18	36.4	-8	-0.3
Incineration with energy	17	34.6	-8	-0.3	38	76.8	-187	-14.4
Incineration without energy	1	1.8	335	0.6	0	0	335	0
Landfill	51	103.9	928	96.4	2	4.0	20	0.1
Co-incineration					8	16.2	-1006	-16.3
MBT					16.7	33.8	27	0,9
Collection	100	202.3	9	1.8	100	22.3	9	1,8
Total	**100**	**202.3**		**87**	**100**	**202.3**		**-47**

be determined with the approach used here, owing to the poor data situation.

It can however be assumed that the difference between the reductions calculated here and the total reduction potential for the period 1990 to 2020 is due almost entirely to methane emissions from landfill sites, since the share due to recovery in the base year 1990 was very low. Moreover, the credits and debits for waste incineration more or less cancel each other out (cf. Table 4.5, scenario 2000).

On the basis of the reported CO_2 emissions from landfill sites (cf. Table 4.2) it is possible as a first approximation to estimate an additional 30 million t CO_2 equivalent for the period up to 2000. Nevertheless, in view of the differences mentioned in the way these data were obtained, this figure cannot be included in an overall potential.

4.2.2 | Reduction in landfill waste quantities in accordance with the requirements of the Landfill Directive

On the assumption that dumping of waste as landfill is not completely banned, but reduced in accordance with the requirements of the EU Landfill Directive of 1999, there is also sizeable potential for reductions in greenhouse gas emissions in the EU-15 countries. The Directive requires landfill quantities of biodegradable material to be reduced to 75 % of the 1995 figure by 2006, to 50 % by 2009 and to 35 % by 2016. Since on landfill sites it is solely the biodegradable quantity that gives rise to methane emissions, a corresponding reduction of the total waste input on landfill sites can be assumed for the purposes of the calculation model used here (cf. Appendix 7, Table A7.1). In Germany virtually no biodegradable waste will go for landfill from 2005 onwards, so the value here is corrected to zero.

Table 4.6 shows that merely ensuring rigorous compliance with the Landfill Directive up to 2016 offers a substantial greenhouse gas emission reduction potential of 74 million t CO_2 equivalent due to landfill gas.

If the waste that is no longer sent for landfill were to be used in corresponding quantities for material and energy recovery, as in the example above, this could bring about further savings in the region of 30 million t CO_2 equivalent a year (cf. Table 4.5) for these disposal paths.

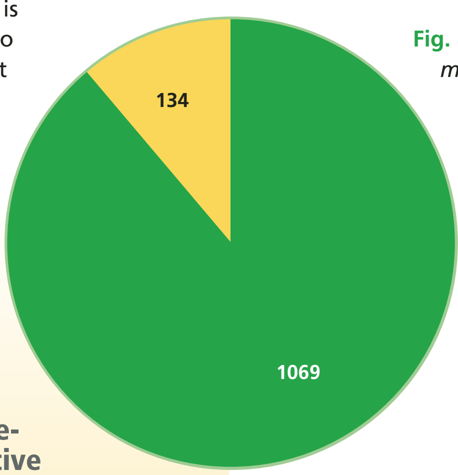


Fig. 4.5: *Possible contribution of municipal waste sector to the total planned reductions in climate gas emissions in the EU-15 countries in the period 2003 to 2020*

Table 4.6: *Landfill-induced greenhouse gas emissions in the EU-15 countries as a function of landfill quantities of biodegradable waste (specific debit 928 kg CO_2 equivalent per t of waste)*

		Waste	Greenhouse gases	Reduction on 2000
		'000 t	Mill. t CO_2 equiv.	
Base year	**1995**	**111,240**	**103**	-
Actual	**2000**	**103,858**	**96**	-
	2006	66,360	62	42
	2009	44,240	41	62
	2016	30,968	29	74

5 | Options for exploiting existing potential for improving efficiency in energy utilisation

Efficiency improvement potential can be seen in the following areas:

1. **Intensification of combined heat and power generation in waste incineration plants and substitute-fuel special-purpose power plants**

2. **Increased output and utilisation of process steam**

3. **Input of quality-assured secondary fuels into co-incineration processes**

4. **Intensification of efficient electricity generation in waste incineration plants, if possible in conjunction with combined heat and power generation.**

New incentives for co-incineration of waste have been created by emissions trading, and normally no additional assistance is required here.

In view of their biogenic component, quality-assured secondary fuels co-incinerated in highly efficient industrial combustion processes have a positive impact in the context of emissions trading. The combustion systems are usually power plants fired by coal or lignite, and cement works.

Thanks to improved sorting technologies (positive sorting) it will in future be possible to ensure consistent and targeted production of the fuel qualities desired by power plant operators and industrial users. This means that more plants can be recruited as users of secondary fuels. Intelligent combination of waste incineration plants and modern power plants (e.g. input of superheated steam from waste incineration plants into gas-and-steam systems) is another means of optimising energy output from waste incineration.

Measures to promote efficient use of energy could have a fundamental impact on the building of new plants. The aim here would be to make it uneconomic to waste usable energy potential and to release it as waste heat causing additional environmental burdens. Efficient use of energy should be an important criterion as early as the planning stage for new plants, and should for example be a major factor in the choice of location.

However, there is nothing to be gained from keying instruments solely to the construction of new plants, since no appreciable building of new plants for energy recovery from waste is to be expected in the years ahead. For this reason such instruments must be aimed in particular at improvements in existing plants. This chapter gives a brief description of conceivable instruments, but without making a definite recommendation in favour of a specific instrument or combination of instruments. This could only be done after a detailed analysis of the existing situation in the course of economic and environmental impact analyses.

5.1 | Heating networks

A lack of heating networks at the site of the plant is frequently given as a reason for not being able to find customers for heat from waste incineration plants. Measures to promote district heating networks would increase the utilisation of heat from other plants as well. This applies not only to conventional energy generation or production plants, but also to the production of renewable energy, e.g. in biomass CHP plants and solar systems.

If this barrier to investment in the construction or expansion of heating networks were eliminated, then waste incineration plants could, thanks to the low heat infeed prices they permit, exploit benefits compared with production plants which mostly had to generate superheated steam that occurs in any case in waste incineration, coal-fired and biomass power plants as a result of the processes used.

To promote heating networks it would be necessary to introduce an investment assistance programme that provided subsidies of the order of 25 – 35 %[17] of the investment costs or offered equivalent terms of finance (reduced interest rates).

This instrument could be financed by coupling it with other measures discussed here. Furthermore, there is a need to lay down the infeed terms for heat from renewable fuels and CHP (at least on standard market terms) into the subsidised heating networks.

5.2 | Renewable heat act

Using the renewable components in residual waste results in the output of renewable energy, which could be regulated in a future Renewable Heat Act. One possible means of promoting heat utilisation would be a heat infeed payment that (on the lines of the electricity infeed payment in the Renewable Energies Act) subsidised heat input into heating networks above and beyond the market price by means of a payment to be borne by all heat customers. However, since heat utilisation is even more effective if the producer and customer are directly adjacent or even form a joint system, direct heat utilisation should also be regulated in the context of an act promoting the use of renewable heat.

The payment would have to be based on a survey and a jointly agreed definition of the renewable C components in the waste, which in turn would have to be checked and updated at regular intervals. Otherwise it would be necessary to measure and monitor this during operation, with all the input this entails.

Promoting the utilisation of heat from the renewable components of the waste indirectly supports the use of heat from the fossil component, which after all profits equally from infrastructure development.

Since such subsidies can basically only be aimed at the heat components that would otherwise be unusable, it would be necessary to define the status quo of heat offtake from waste incineration as the basis for assessment. The funding of such payments would in general have to be made available by the system itself with a more or less neutral impact on revenue. For the heating market, where there is frequently a special framework of conditions for each individual case, such a funding system is much more difficult to find than in the electricity market.

5.3 | Waste heat charge

A waste heat charge would be more likely to achieve a profitable situation for heat offtake, since the effect of revenue for the heat supplied would be joined by avoidance of charges, i.e. the system would have a double effect. Use of the charges levied would have to be on an earmarked basis, in other words it would have to pursue the same goal as the charge itself (Öko-Institut 1997). The charge would thus have a steering effect from two points of view: through the levying of the charge itself, and through the way the revenue from the charge was used. Possible options here would be the instruments discussed, such as assistance for heating networks and a Renewable Heat Act.

The level of a waste heat charge should be differentiated. Existing plants where profitability cannot be achieved despite the use of instruments to promote waste heat utilisation should be subject to lower charges than new plants. The waste heat charge should also take account of the available technology. In other words the charge would only apply to plants that produced more waste heat than they would with the best available technology.

17 *During the period 1977 to 1981 the ZIP 1 programme for investment in the future, by providing 730 million DM of assistance, gave rise to investment of 2.6 billion DM, which corresponds to a subsidy of 28 % (AGFW 2000)*

The disadvantage of a waste heat charge is that it would be difficult to gain acceptance for such a measure among the parties affected. Apart from the additional financial burdens, the extra administrative work is frequently cited as an objection.

On the demand side, charges for heat users who do not obtain at least a prescribed share of their heat from CHP or heat from renewable fuels could increase demand for CHP heat. Similarly, heating network operators could be required to obtain a minimum share of their heat from CHP or renewable fuels.

5.4 | Promotion of premium power/heat

Plant operators could also receive a premium for electricity and heat due to increased output resulting from efficiency improvements. To this end it would be necessary to define the standard of energy utilisation in waste incineration. The additional energy offtake in optimised plants would be subsidised as "premium power" or "premium heat".

Such programmes are operating successfully in the Netherlands. The advantage is that assistance is given on a targeted basis only for that part of the energy output which is used above and beyond the normal level. This would also benefit plants that had achieved good efficiency levels in the past and had thus played a pioneering role. The energy market itself would have to provide the resources needed to fund this instrument.

5.5 | Assistance for CHP electricity

Assistance for CHP electricity and hence indirectly for CHP heat is regulated in the Act of 1 April 2002 on the maintenance, modernisation and expansion of combined heat-and-power generation (CHP Act). An increase in the bonus rates could make heat offtake a more attractive economic proposition. However, network operators display little acceptance of the idea of funding increased bonuses for CHP electricity.

5.6 | Investment programme for promoting future technologies

In general, an investment programme for promoting future technologies could provide effective assistance for energy recovery from municipal waste. For example, utilisation of waste heat could be stepped up by developing and improving modern heat utilisation technologies, such as mobile heat storage (e.g. using zeolites), use of heat to supply refrigeration, drying processes based on low-temperature steam etc. In particular there is a need to develop and improve suitable uses for the heat available at times of low heating requirements (at night and in the summer months). Even more important than the promotion of new technological development, however, is support for the market introduction of new technologies that are just reaching a marketable stage.

5.7 | Joint Implementation/Clean Development Mechanism

The project-related mechanisms Joint Implementation (JI) and Clean Development Mechanism (CDM) are instruments laid down in the Kyoto Protocol that allow the industrial and threshold countries to redeem part of their greenhouse gas reduction commitments under the Kyoto Protocol at the lowest possible cost outside their own territory. The "Linking-Directive" (2004/101/EC) regulates the link between this Kyoto mechanism and the European emissions trading system. Under this Directive, enterprises covered by the emissions trading system can in future also meet their commitment to dispose of emission rights by selling emission credits issued in the context of such projects for emission reductions achieved.

The Act concerning the introduction of project-related mechanisms, which has already been passed by Bundestag and Bundesrat, creates the national legal basis for undertaking project activities in accordance with international requirements and for the implementation of the Linking Directive.

In accordance with the requirements of the Linking Directive and the Kyoto Protocol, it will be possible to use emission credits from JI projects in EU emissions trading from 2008 onwards and credits from the CDM right from the start, or at least upon the entry into force of this legal basis.

These instruments are aimed at bringing greater flexibility to the international efforts to reduce greenhouse gas emissions. As a look back at the starting phase of the Kyoto mechanisms reveals, landfill gas projects play an outstanding role in the context of such instruments. Their international replication value is extremely high.

6 | Ways and means of improving the efficiency of energy recovery from residual waste

This chapter takes a rather closer look at the system-related opportunities and problems associated with increasing energy offtake, using the example of waste incineration.

6.1 | Electricity offtake from waste incineration

6.1.1 | Available technology

When assessing the efficiency of waste incineration plants with regard to energy yield, it must always be borne in mind that the main purpose of waste incineration is the treatment of waste, and that the resulting energy is only used as a by-product. Important differences from the production of energy from primary energy sources are:

- **the non-homogeneous composition of waste as a fuel and**

- **the higher pollutant levels in the waste.**

There are therefore technical and/or economic limits to energy recovery from waste incineration. The main reasons for this are:

1. Limits on steam parameters
   Owing to the high chlorine content of waste and its corrosive character, boilers cannot be equipped with expensive high-temperature steels and can therefore only be run at sub-optimal pressures and temperatures. Common steam parameters in waste incineration plants are therefore temperatures of around 400 C° and pressures of around 40 bar. This compromise still permits high steam generator availability and a theoretical power generation efficiency of 31.8 % (Schirmer 2002a). If the steam produced is used to generate electricity only, the best German waste incineration plants from an energy production point of view achieve an efficiency of approx. 21 %.[18]

2. High energy consumption
   The internal (parasitic) energy consumption of waste incineration plants is much higher than in power plants burning primary fuels. This is due to the greater input for the fuel handling and flue gas cleaning processes. The internal energy requirements of waste incineration plants, measured in terms of the energy introduced in the waste, are currently put at an average of about 4 % electricity, 6.5 % heat and 3.5 % external energy (Öko-Institut 2002, Reimann 2005).

3. Flue gas losses
   The thermal efficiency of an incineration plant is limited by the heat exported with the flue gas. The more flue gas leaves the boiler and the higher its temperature, the higher are the losses. Safe destruction of the pollutants in the waste requires a high level of excess air in the combustion gas, which results in large amounts of flue gas. Flue gas cleaning requires a minimum temperature in the flue gas which limits its use in the boiler. Thus boiler outlet temperatures of less than 170°C are hardly possible without expensive reheating of the flue gas.

4. Fuel-related heat losses
   Owing to the large proportion of non-combustible material (inert substances) in the waste, losses occur as a result of heat removed with the ash. The high moisture content of the waste (approx. 30 %) leads to losses because heat is needed to evaporate it.

6.1.2 | Technological options

A number of plants, however, operate at steam temperatures and pressures well below 400°C and 40 bar. In these plants an increase in the live steam parameters is technically possible, at least in the medium term during renewal of the steam generation facilities, despite the considerable investment required.

With increased steam pressures and temperatures it is basically possible to achieve higher efficiency levels. For example, 100 bar and 500°C can be calculated to result in a theoretical efficiency of approx. 34 %. However, boiler pressures that are even higher bring a number of disadvantages:

- **Release of pressure to the usual vacuum (0.05 bar) results in a steam moisture level that the turbine can not withstand, which means that intermediate superheating is required to "dry" the steam.**

- **Higher steam pressure also means higher boiler temperatures in the region of the evaporator, which increases the corrosive action of the salt component in the combustion space.**

- **Temperatures in excess of 500°C and pressures in excess of 120 bar require pipework materials whose brittle properties cause problems in view of the mechanical stresses typical of waste incineration plants. Moreover, such materials also display a much lower resistance to chlorine.**

Another measure to optimise heat utilisation consists in reducing the excess air by means of optimised combustion management, with a consequent reduction in the volume of combustion air. The smaller the quantity of combustion air, the smaller the flow of flue gas with its associated losses due to reheating etc.

The salt corrosion problems can be avoided if the steam parameters necessary for efficient energy utilisation can be achieved by combined use of waste and high-grade fuels, e.g. natural gas. The waste is only used to heat the steam to a level where corrosion problems do not occur or can be kept within limits. The high-grade fuel is then used to reach the steam temperatures needed for optimum efficiency.

This can be illustrated by two practical examples.

The waste incineration plant in Mannheim operates a pick-a-back steam generator heated with high-grade fuel, which reaches steam pressures of 120 bar and temperatures of 500°C. The additional energy requirement supplied by the high-grade fuel is around 15 % of the heat from the waste input. Similar concepts have been implemented in plants in Denmark and the Netherlands (Schirmer 2002b).

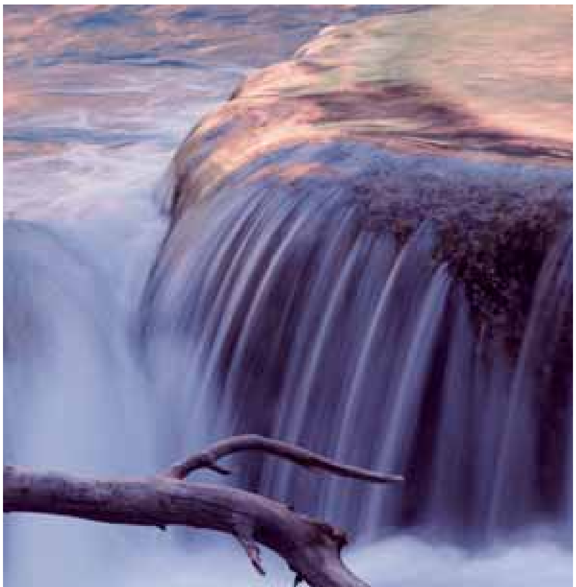
In Mainz a waste incineration plant is operated in conjunction with a gas-fired gas-and-steam power plant. There the live steam from the waste incineration plant (400°C, 40 bar) is heated up further by the flue gas from a 400-MW gas-and-steam system and fed into the medium and low pressure zones of the steam turbine in the gas-and-steam unit, making it unnecessary to use additional high-grade fuels. This considerably increases the efficiency of the waste incineration plant compared with conventional incineration plants, since the larger steam turbine of the gas-and-steam plant works more efficiently than a turbine designed for waste incineration steam alone.

6.2 | Problems with utilisation of CHP heat and process steam

In additional to outputting electricity, waste incineration plants have a considerable potential for the use of steam in the form of district heating and process steam. With electrical efficiency levels of 5 to 15 %, overall efficiency levels of up to 70 % are possible using combined heat-and-power generation (CHP). For example, the five German plants with the highest energy efficiency figures not only output an average of 7.6 % of the fuel energy as electricity, but also some 60 % heat from waste in the form of district heating or process steam. Other plants achieve overall efficiency levels of only about 18 %, of which an average of 46 % is due to electricity output (Öko-Institut 2002). This indicates that a considerable proportion of the steam generated in such plants cannot be used.

There are various reasons for this:

- **The infrastructure necessary for utilisation of the steam in the form of district heating and process steam networks does not exist.**



18 In the Netherlands the power generation efficiency of one plant has been increased to 29 % as a result of targeted assistance for electricity. (In this connection see also the study by Wandschneider and Gutjahr, June 2005, for Switzerland on the expansion of energy utilisation in sewage sludge incineration plants.)

- **District heating from waste incineration plants is to some extent used to cover medium and peak loads. As a rule, heat-and-power plants fired by fossil fuels are used to cover the basic load. In many cases, district heating supplies by waste incineration plants to meet basic loads would compete with the heat-and-power plants operated by the municipal energy utilities and would reduce the efficiency and profitability of these coal-fired and gas-fired heat-and-power plants.**

- **Potential customers for process steam and district heating do not exist in the vicinity of the plant.**
- **Plants are bound by contracts restricting output to certain quantities.**
- **The demand for district heating is subject to large seasonal fluctuations. Particularly in the summer season there is a marked reduction in demand for heating purposes.**

One way of exploiting the potential for district heating and process steam output is basically that of expanding networks. Such expansion is a useful means of energy optimisation for waste incineration plants if there is little or no opportunity for output of district heating or process steam at the site of the waste incineration plant.

The expansion or establishment of district heating networks presupposes an adequate customer density (at least 15 MW/km^2, preferably over 40 MW/km^2), since otherwise the heat losses on the one hand and the capital cost on the other (currently around 500 € per metre of district heating pipeline) make network establishment or expansion unrealistic (AGFW 1998). In exceptional cases, if local conditions are favourable, aggregation of existing heating networks using modern laying techniques and plastic-jacketed pipes may even result in cost reductions. In particular, this is the case if the alternative would be to reconstruct a natural gas network or build a completely new one.

Another basic possibility is to equip existing incineration plants with facilities for offtake of process steam. Process steam can be taken off directly without converting the steam into electricity for internal requirements by taking it either from the turbine, or in the case of back-pressure turbines at the outlet from the turbine. However, expansion of process steam offtake is closely linked to framework conditions at the site. In view of the high capital cost of up to 2,000 € per metre of steam pipe, and in order to avoid losses, the steam customers should be located in the immediate vicinity of the waste incineration plant (vgl. Dehoust et al. 1999).

Especially where new waste incineration plants are being constructed, greater attention should be paid to the possibility of steam offtake. New plants are frequently planned without heat offtake, indicating that there is a need to improve the framework conditions for efficient energy offtake from waste incineration plants by means of appropriate incentive programmes.

7 | Conclusion

The greenhouse gas reduction commitments entered into under the Kyoto Protocol by Germany and the EU-15 countries are a hitherto unique challenge in the field of environmental protection. The ambitious targets can only be achieved if all existing potential is rigorously exploited.

The findings of this study show clearly that the municipal waste sector makes a significant contribution to achieving the climate protection objectives in Germany. Especially through the ban on landfill of untreated waste and the resulting reduction in methane emissions, the waste sector accounts for a large share – 20 % – of the reductions achieved to date. The share due to the waste sector will however remain considerable in the future as well: this sector can in future contribute up to 4.6 % of the ambitious reduction target of 40 % compared with 1990, if the estimated potentials for waste wood and sewage sludge are included.

Table 7.1 shows the bandwidths of the shares of the municipal waste sector's reduction potential that are due to the main disposal paths as indicated by the accounts and estimates. This indicates that given optimised use of energy, waste incineration plants contribute about one third of the reduction potential. All energy processes together contribute about 90 % to the attainable reduction potential under the framework conditions of these accounts. The study did not investigate any potential increases that may be possible for recovery of material.

Table 7.1: *Range of potential reduction in 2020 compared with 2005*

	Reduction	
	from mill. t CO_2 equiv.	**to mill. t CO_2 equiv.**
Waste incineration	-1.5	-3.0
Co-incineration	-1.4*	-3.6**
Waste wood	-1.4	-1.4
Biowaste	0.1	-0.3
Materials recovery	-0.2	-0.8
Total	**-4.4**	**-9.1**

* *without sewage sludge*
** *with sewage sludge*

The contributions to the total greenhouse gas reductions from 1990 to 2020 are 76 % from reductions in landfill gas emissions, around 7 % from energy recovery, 5 % from materials recovery, and 9 % from waste incineration plants.

However, the future potential of the municipal waste sector can only be exploited if assistance is provided for the output of additional energy from thermal utilisation of waste. None of the options discussed will on its own be in a position to blaze the necessary trail. Thus only a mix of several measures can lead to success. This mix must be adapted as closely as possible to the situation of the existing waste incineration plants and the market conditions at the various locations. To this end the study recommends round-table cooperation by all the actors concerned, in order to decide the optimum mix of instruments. For this purpose an inventory of the specific situation at the individual sites should be made as soon as possible and assessed in an environmental and economic impact analysis. This should take account of the specific obstacles at the individual plants and design the necessary assistance programme accordingly.

Such a programme should support the changeover from aerobic to anaerobic treatment in biowaste recovery – including optimum utilisation of the energy from the biogas. Use can be made here of the instrument for assistance provided by the Renewable Energies Act, which is already in place. The actors concerned should be informed about how they can exploit the possibilities of the Renewable Energies Act to the full.

In the EU-15 countries as well, the municipal waste sector has a great potential for compliance with the climate protection targets, with a contribution of 11 %. To exploit this potential, municipal waste must be systematically sent for energy and materials recovery, instead of dumping it untreated as landfill as in the past. A pan-European ban on landfill of untreated waste could be a milestone on the way along this road. This requires nationwide separation and recovery of biowaste and other materials for recovery in the case of dry waste. The remaining quantities should then be used to produce energy.

At all events attention should be paid from the outset to ensuring optimised offtake of electricity and heat in energy recovery from waste and biogas. The preconditions for this must be created as early as the plant planning stage, for example by selecting plant sites so that customers can be found for the heat produced.

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9 | Appendix

Appendix 1: Waste paths

Table A1.1: *Waste destinations as shown in the accounts (waste quantities in tonnes)*

Disposal path	1990	2005	2020 Basis I	2020 Basis II	2020 Optimised
Waste paper	1,604,758	7,599,985	7,599,985	7,599,985	7,599,985
Waste glass	1,314,393	3,171,583	3,171,583	3,171,583	3,171,583
Lightweight packaging		2,121,948	2,121,948	2,121,948	2,121,948
Organic waste under treatment	1,005,790	7,604,000	7,604,000	7,604,000	7,604,000
Household waste, household-type commercial waste, bulky waste (from municipal household collection)		685,833	685,833	685,833	685,833
Bulky waste (delivered separately)	107,205	1,000,000	1,000,000	1,000,000	1,000,000
Household-type commercial waste	312,271	1,794,000	1,794,000	1,794,000	1,794,000
Total input for recovery *1	**4,344,417**	**23,977,349**	**23,977,349**	**23,977,349**	**23,977,349**
Total input MBT *2		**6,221,000**	**7,122,000**	**7,122,000**	**7,122,000**
Paper sludge	72,281	396,544	396,544	396,544	396,544
Waste from sorting of lightweight packaging		452,622	558,539	558,539	558,539
Household-type commercial waste *3		440,000	440,000		
Secondary fuels from MBT		1,244,200	1,424,400	2,136,600	2,136,600
Total input co-incineration	**72,281**	**2,093,366**	**3,529,483**	**3,531,683**	**3,531,683**
Household waste, household-type commercial waste, bulky waste (from municipal household collection)	5,586,510	9,303,637	8,402,637	8,402,637	8,402,637
Bulky waste (delivered separately)	366,863				
Household-type commercial waste	1,789,968	2,366,940	1,216,940	1,926,940	1,926,940
Organic waste in waste incineration	28,208				
Residues from biowaste treatment		4,000	4,000	4,000	4,000
Garden, Park and cemetery waste		382,000	382,000	382,000	382,000
Total primary waste to incineration	**7,771,549**	**12,056,577**	**10,005,577**	**10,715,577**	**10,715,577**
Waste from paper sorting	76,143	75,247	75,247	75,247	75,247
Reject material from de-inking	7,948	43,604	43,604	43,604	43,604
Waste from glass processing (labels, caps)	7,744	19,233	19,233	19,233	19,233
Waste from sorting/processing of lightweight packaging		658,021 340,738	700,016 340,738	700,016 340,738	700,016 76,040
Waste from composting	50,290	39,462	39,462	39,462	304,160
Waste from fermentation					
Sorting residues MBT to incineration		186,630	213,660	213,660	213,660
MBT residues to incineration			4,799,658	4,148,423	4,148,423
Total secondary waste to incineration	142,124	1,362,934	6,231,618	5,580,383	5,580,383
Grand total input incineration *4	7,913,673	13,419,511	16,237,195	16,295,960	16,295,960
Bottom ash from incineration *5	1,301,799	2,300,279	2,806,489	2,806,698	2,806,698

Table A1.1 continued: *Waste destinations as shown in the accounts (waste quantities in tonnes)*

Disposal path	1990	2005	2020 Basis I	2020 Basis II	2020 Optimised
Ferrous metals from incineration and MBT plants	**109,390**	**309,916**	**354,532**	**447,852**	**447,852**
NF metals from incineration and MBT plants		**12,833**	**15,041**	**52,534**	**52,534**
Household waste, household-type commercial waste, bulky waste (from municipal household collection)	24,874,343				
Bulky waste (delivered separately)	2,952,624				
Household-type commercial waste	13,136,219				
Organic waste	948,308				
Total primary waste to landfill	41,911,494	0	0	0	0
Inert waste from paper sorting	73,744	0	0	0	0
Inert waste from glass sorting	30,650	31,716	31,716	31,716	31,716
Inert waste from fermentation		31,570	31,570	31,570	243,328
Total sorting residues to landfill	104,394	63,285	63,285	63,285	275,044
Bottom ash from incineration plants to inert substance landfill	83,094	146,826	179,138	179,151	179,151
Coarse ash from co-incineration	2,703	33,172	79,803	72,479	72,479
Filter ash biomass CHP plants		1,258	1,258	1,258	1,258
Other incineration residues to landfill sites for hazardous waste	175,258	285,642	345,061	346,428	346,428
Incineration residues to landfill	261,055	466,899	605,260	599,315	599,315
MBT residual waste to landfill	0	3,260,799	0	0	0
Grand total input to landfill	**42,276,943**	**3,790,983**	**668,546**	**662,601**	**874,359**

*1 *The quantities for dry waste in sorting are determined on the basis of total volume less secondary waste to waste incineration plants and landfill after sorting.*

*2 *Household waste, household-type commercial waste, bulky waste (through municipal collection), on the assumption that the capacities according to LAGA are fully utilised.*

*3 *Household-type commercial waste allocated to power plants on capacity grounds.*

*4 *The capacities for waste incineration plants result from the accounts calculated after entering the capacities for mechanical-biological treatment, co-incineration and recovery as fixed parameters. In fact LAGA states waste incineration capacities of 16.3 million t for 2005 and 17.7 million t in the longer term.*

*5 *After separation of metals, the bottom ash from waste incineration plants leaves the system without any account being taken of inputs for further processing of the ash or credits for construction materials replaced, since the construction materials replaced do not possess any relevant CO_2 reduction potential.*

Appendix 2: Electricity and heat credits

Table A2.1: *Credits for provision of electricity*

Credits for provision of electricity, per kWh of electricity

System limits: Entire life cycle including transport + material input, excluding waste management

Option (g/kWh$_{out}$)	Greenhouse gases		Cumulative energy consumption (CEC) (kWh$_{primary}$/kWh$_{out}$)		
	CO_2 equivalent	CO_2	CEC total	CEC non-renewable	CEC renewable
Power plants D 2000	626.6	594.0	2.90	2.57	0.33
Power plants D 2005	**624.4**	**593.7**	**2.82**	**2.52**	**0.29**
Power plants D 2010	622.3	593.4	2.73	2.48	0.26
Power plants D 2020	**694.3**	**665.5**	**2.52**	**2.24**	**0.27**
Power plants D 2030	741.8	713.2	2.29	1.96	0.34
Coal imports 2000	949.4	896.7	2.62	2.62	0.01
Coal imports 2010	907.2	853.9	2.51	2.50	0.01
Coal imports 2020	**870.9**	**819.1**	**2.40**	**2.39**	**0.01**
Coal imports 2030	795.4	754.5	2.21	2.20	0.01
Gas-fired gas + steam 2000	432.4	401.3	2.05	2.05	0.00
Gas-fired gas + steam 2010	417.6	388.0	1.99	1.99	0.00
Gas-fired gas + steam 2020	**409.5**	**382.1**	**1.96**	**1.96**	**0.00**
Gas-fired gas + steam 2030	407.3	380.7	1.97	1.97	0.00
Lignite, Lausitz 2020	963				
Lignite, Rhineland 2020	991				

Results from GEMIS 4.3, as at Aug. 2005 (GEMIS 2005)

Table A2.2: *Credits for provision of heat*

Credits for provision of heat, per kWh of end energy

System limits: Entire life cycle including transport + material input, excluding waste management

Option (g/kWh_{end})	Greenhouse gases		Cumulative energy consumption (CEC) ($kWh_{primary}/kWh_{out}$)		
	CO_2 equivalent	CO_2	CEC total	CEC non-renewable	CEC renewable
Oil heating 2000	335.1	324.3	1.22	1.21	0.01
Oil heating 2005	333.9	323.9	1.22	1.21	0.01
Oil heating 2010	332.8	323.5	1.21	1.21	0.01
Oil heating 2020	331.2	323.4	1.21	1.20	0.01
Oil heating 2030	330.5	324.8	1.21	1.20	0.01
Gas heating 2000	256.5	230.0	1.17	1.17	0.01
Gas heating 2005	255.4	229.1	1.17	1.17	0.01
Gas heating 2010	254.3	228.1	1.17	1.17	0.01
Gas heating 2020	255.3	229.3	1.18	1.17	0.01
Gas heating 2030	259.3	232.8	1.20	1.19	0.01
Gas heating plant, average 2000	260.3	232.6	1.20	1.19	0.01
Gas heating plant, average 2005	260.4	232.8	1.20	1.19	0.01
Gas heating plant, average 2010	260.5	233.1	1.20	1.19	0.01
Gas heating plant, average 2020	262.2	235.0	1.20	1.19	0.01
Gas heating plant, average 2030	266.7	239.0	1.22	1.21	0.01
Lignite boiler, fluidised bed 2000	475.0	426.8	1.21	1.21	0.00
Lignite boiler, fluidised bed 2005	474.1	425.9	1.21	1.21	0.00
Lignite boiler, fluidised bed 2010	473.2	425.1	1.21	1.20	0.00
Lignite boiler, fluidised bed 2020	473.3	425.2	1.20	1.20	0.00
Lignite boiler, fluidised bed 2030	473.2	425.1	1.20	1.19	0.00

Results from GEMIS 4.3, as at Aug. 2005

Appendix 3: Tables of results
Greenhouse gas potential

Table A3.1: *Shares of global warming potential due to individual disposal paths, in million t CO_2 equivalent*

	Municipal waste 1990				
	Credit million t	Input million t	Net bonus million t	Balance quantity t	Specific bonus kg/t
Waste incineration	-3.29	2.29	-1.00	7,913,673	-126
Co-incineration	-0.05	0.0018	-0.05	72,281	-635
Biowaste	-0.013	0.12	0.10	1,005,790	102
Lightweight packaging	0	0	0	0	0
Waste paper	-0.55	0.24	-0.31	1,604,758	-191
Waste glass	-0.39	0.01	-0.39	1,314,393	-294
Bulky waste/waste wood	-0.02	0.01	-0.005	107,205	-45
Metals	-0.28	0.0020	-0.28	109,390	-2,568
Collection	0.00	0.48	0.48	54,027,460	9
MBT	0	0	0	0	0
Landfill		39.23	39.23	42,276,943	928

disregarding C sinks

Table A3.2: *Shares of global warming potential due to individual disposal paths, in million t CO_2 equivalent*

	Municipal waste 2005				
	Credit million t	Input million t	Net bonus million t	Balance quantity t	Specific bonus kg/t
Waste incineration	-6.97	4.50	-2.47	13,419,511	-184
Co-incineration	-3.94	1.79	-2.16	2,093,366	-1,030
Biowaste	-0.70	0.89	0.19	7,604,000	25
Lightweight packaging	-1.90	1.36	-0.54	2,121,948	-254
Waste paper	-3.00	1.29	-1.71	7,599,985	-226
Waste glass	-0.63	0.02	-0.61	3,171,583	-192
Bulky waste/waste wood	-0.37	0.10	-0.27	1,000,000	-272
Metals	-0.79	0.0044	-0.78	322,749	-2,424
Collection		0.36	0.36	40,935,410	9
MBT		0.21	0.21	6,221,000	34
Landfill		0.09	0.09	3,790,983	25

disregarding C sinks

Table A3.3: *Shares of global warming potential due to individual disposal paths, in million t CO_2 equivalent*

	Municipal waste 2020 Basis I				
	Credit million t	Input million t	Net bonus million t	Balance quantity t	Specific bonus kg/t
Waste incineration	-8.99	5.07	-3.93	16,237,195	-242
Co-incineration	-6.53	3.02	-3.51	3,529,483	-995
Biowaste	-0.71	0.99	0.28	7,604,000	37
Lightweight packaging	-1.44	0.81	-0.63	2,121,948	-299
Waste paper	-3.00	1.35	-1.65	7,599,985	-217
Waste glass	-0.63	0.02	-0.61	3,171,583	-192
Bulky waste/waste wood	-0.41	0.11	-0.30	1,000,000	-304
Metals	-0.91	0.01	-0.90	369,573	-2,445
Collection		0.36	0.36	40,935,410	9
MBT		0.19	0.19	7,122,000	27
Landfill		0.01	0.01	668,546	21

disregarding C sinks

Table A3.4: *Shares of global warming potential due to individual disposal paths, in million t CO_2 equivalent*

	Municipal waste 2020 Basis II				
	Credit million t	Input million t	Net bonus million t	Balance quantity t	Specific bonus kg/t
Waste incineration	-9.35	5.26	-4.09	16,295,960	-251
Co-incineration	-6.57	3.02	-3.55	3,531,683	-1,006
Biowaste	-0.71	0.99	0.28	7,604,000	37
Lightweight packaging	-1.44	0.81	-0.63	2,121,948	-299
Waste paper	-3.00	1.35	-1.65	7,599,985	-217
Waste glass	-0.63	0.02	-0.61	3,171,583	-192
Bulky waste/waste wood	-0.41	0.11	-0.30	1,000,000	-304
Metals	-1.55	0.01	-1.55	500,386	-3,094
Collection		0.36	0.36	40,935,410	9
MBT		0.19	0.19	7,122,000	27
Landfill		0.01	0.01	662,601	21

disregarding C sinks

Table A3.5: *Shares of global warming potential due to individual disposal paths, in million t CO_2 equivalent*

	Municipal waste 2020 optimised				
	Credit million t	Input million t	Net bonus million t	Balance quantity t	Specific bonus kg/t
Waste incineration	-10.69	5.26	-5.42	16,295,960	-333
Co-incineration	-6.57	3.02	-3.55	3,531,683	-1,006
Biowaste	-0.74	0.68	-0.06	7,604,000	-8
Lightweight packaging	-1.44	0.81	-0.63	2,121,948	-299
Waste paper	-3.00	1.35	-1.65	7,599,985	-217
Waste glass	-0.63	0.02	-0.61	3,171,583	-192
Bulky waste/waste wood	-0.41	0.11	-0.30	1,000,000	-304
Metals	-1.55	0.01	-1.55	500,386	-3,094
Collection		0.36	0.36	40,935,410	9
MBT		0.19	0.19	7,122,000	27
Landfill		0.02	0.02	874,359	20

disregarding C sinks

Appendix 3: Tables of results
Fossil fuels

Table A3.6: *Shares of savings in fossil fuels due to individual energy sources, calculated as CER, in petajoules*

	Municipal waste 1990				
	Credit PJ	Input PJ	Net bonus PJ	Material quantity t	Specific bonus MJ/t
Waste incineration	-47.65	0.02	-47.63	7,913,673	-6.02
Co-incineration	-0.38	0.01	-0.36	72,281	-5.02
Biowaste	-0.08	0.23	0.16	1,005,790	0.16
Lightweight packaging	0.00	0.00	0.00	0	0.00
Waste paper	-8.23	4.20	-4.02	1,604,758	-2.51
Waste glass	-3.77	0.13	-3.63	1,314,393	-2.76
Bulky waste/waste wood	-0.24	0.18	-0.06	107,205	-0.57
Metals	-2.59	0.20	-2.39	109,390	-21.89
Collection		6.16	6.16	54,027,460	0.11
MBT		0.00	0.00	0	0.00
Landfill		5.44	5.44	42,276,943	0.13

Table A3.7: *Shares of savings in fossil fuels due to individual energy sources, calculated as CER, in petajoules*

	Municipal waste 2005				
	Credit PJ	Input PJ	Net bonus PJ	Material quantity t	Specific bonus MJ/t
Waste incineration	-97.13	0.21	-96.92	13,419,511	-7.22
Co-incineration	-38.61	0.41	-38.20	2,093,366	-18.25
Biowaste	-1.94	3.63	1.69	7,604,000	0.22
Lightweight packaging	-29.23	7.80	-21.44	2,121,948	-10.10
Waste paper	-45.13	21.57	-23.56	7,599,985	-3.10
Waste glass	-6.66	0.28	-6.37	3,171,583	-2.01
Bulky waste/waste wood	-5.35	0.83	-4.52	1,000,000	-4.52
Metals	-7.74	0.44	-7.30	322,749	-22.63
Collection		4.68	4.68	40,935,410	0.11
MBT		2.47	2.47	6,221,000	0.40
Landfill		0.95	0.95	3,790,983	0.25

Table A3.8: *Shares of savings in fossil fuels due to individual energy sources, calculated as CER, in petajoules*

	Municipal waste 2020 Basis I				
	Credit PJ	Input PJ	Net bonus PJ	Material quantity t	Specific bonus MJ/t
Waste incineration	-125.85	0.96	-124.89	16,237,195	-7.69
Co-incineration	-63.50	0.76	-62.74	3,529,483	-17.78
Biowaste	-1.89	5.00	3.11	7,604,000	0.41
Lightweight packaging	-21.72	6.64	-15.08	2,121,948	-7.11
Waste paper	-45.13	20.59	-24.54	7,599,985	-3.23
Waste glass	-6.63	0.25	-6.38	3,171,583	-2.01
Bulky waste/waste wood	-4.80	0.74	-4.06	1,000,000	-4.06
Metals	-8.85	0.50	-8.35	369,573	-22.59
Collection		4.68	4.68	40,935,410	0.11
MBT		1.66	1.66	7,122,000	0.23
Landfill		0.18	0.18	668,546	0.26

Table A3.9: *Shares of savings in fossil fuels due to individual energy sources, calculated as CER, in petajoules*

	Municipal waste 2020 Basis II				
	Credit PJ	Input PJ	Net bonus PJ	Material quantity t	Specific bonus MJ/t
Waste incineration	-131.48	0.86	-130.62	16,295,960	-8.02
Co-incineration	-64.02	0.74	-63.28	3,531,683	-17.92
Biowaste	-1.89	5.00	3.11	7,604,000	0.41
Lightweight packaging	-21.72	6.64	-15.08	2,121,948	-7.11
Waste paper	-45.13	20.59	-24.54	7,599,985	-3.23
Waste glass	-6.63	0.25	-6.38	3,171,583	-2.01
Bulky waste/waste wood	-4.80	0.74	-4.06	1,000,000	-4.06
Metals	-16.48	0.64	-15.85	500,386	-31.67
Collection		4.68	4.68	40,935,410	0.11
MBT		1.66	1.66	7,122,000	0.23
Landfill		0.18	0.18	662,601	0.27

Table A3.10: *Shares of savings in fossil fuels due to individual energy sources, calculated as CER, in petajoules*

MJ/t	Municipal waste 2020 optimised				
	Credit PJ	Input PJ	Net bonus PJ	Material quantity t	Specific bonus MJ/t
Waste incineration	-135.94	0.86	-135.08	16,295,960	-8.29
Co-incineration	-64.02	0.74	-63.28	3,531,683	-17.92
Biowaste	-4.51	2.13	-2.38	7,604,000	-0.31
Lightweight packaging	-21.72	6.64	-15.08	2,121,948	-7.11
Waste paper	-45.13	20.59	-24.54	7,599,985	-3.23
Waste glass	-6.63	0.25	-6.38	3,171,583	-2.01
Bulky waste/waste wood	-4.80	0.74	-4.06	1,000,000	-4.06
Metals	-16.48	0.64	-15.85	500,386	-31.67
Collection		4.68	4.68	40,935,410	0.11
MBT		1.66	1.66	7,122,000	0.23
Landfill		0.22	0.22	874,359	0.25

Appendix 4: Net bonus and specific contribution GWP

Table A4.1: *Net bonus GWP (global warming potential) and changes over period under review*

	1990 mill. t	2005 mill. t	Change from 1990 mill. t	2020 Basis I mill. t	Change from 2005 mill. t	2020 Basis II mill. t	Change from 2005 mill. t	2020 Optimised mill. t	Change from 2005 mill. t
Waste incineration	-1.00	-2.47	-1.47	-3.93	-1.46	-4.09	-1.62	-5.42	-2.96
Co-incineration	-0.05	-2.16	-2.11	-3.51	-1.36	-3.55	-1.39	-355	-1.39
Biowaste	0.102	0.19	0.09	0.28	0.10	0.28	0.10	-0.06	-0.25
Lightweight packaging	0	-0.54	-0.54	-0.63	-0.09	-0.63	-0.09	-0.63	-0.09
Waste paper	-0.31	-1.71	-1.41	-1.65	0.07	-1.65	0.07	-1.65	0.07
Waste glass	-0.39	-0.61	-0.22	-0.61	0.00	-0.61	0.00	-0.61	0.00
Bulky waste/ waste wood	0.00	-0.27	-0.27	-0.30	-0.03	-0.30	-0.03	-0.30	-0.03
Metals	-0.28	-0.78	-0.50	-0.90	-0.12	-1.55	-0.77	-1.55	-0.77
Collection	0.48	0.36	-0.12	0.36	0.00	0.36	0.00	0.36	0.00
MBT	0	0	0.21	0.19	-0.02	0.19	-0.02	0.19	-0.02
Landfill	39.23	0.09	-39.13	0.01	-0.08	0.01	-0.08	0.02	-0.08
Total	7.79	-7.69	-45.48	-10.68	-3.00	-11.53	-3.8	-13.20	-5.5

Given full utilisation of the forecast waste incineration plant capacities, the net bonus of the waste incineration plants in the 2005 scenario would be 20 % higher and in the 2020 scenarios some 10 % higher (cf. Table 4)

Table A4.2: *Specific credits or debits (specific bonus) of the individual disposal paths*

	1990 kg/t	2005 kg/t	2020 Basis I Kg/t	2020 Basis II kg/t	2020 Optimised kg/t
Waste incineration	-126	-184	-242	-251	-333
Co-incineration	-635	-1,030	-995	-1,006	-1,006
Biowaste	102	25	37	37	-8
Lightweight packaging	0	-254	-299	-299	-299
Waste paper	-191	-226	-217	-217	-217
Waste glass	-294	-192	-192	-192	-192
Bulky waste/waste wood	-45	-272	-304	-304	-304
Metals	-2,568	-2,424	-2,445	-3,094	-3,094
Collection	9	9	9	9	9
MBT	0	34	27	27	27
Landfill	928	25	21	21	20

Table A4.2 continued: *Specific credits or debits (specific bonus) of the individual disposal paths*

The specific net credits range from a debit of +928 kg CO_2 equivalent per tonne of waste for household waste landfill in 1990 to a credit of 3,094 kg CO_2 equivalent per tonne of metals sent for recovery.

The metals are a mixture of ferrous and non-ferrous metals (entered as 100 % aluminium). The higher the percentage of aluminium (2020 Basis II and 2020 Optimised), the higher the credit.

The specific figure for recycling of lightweight packaging is slightly reduced, since energy recovery from the sorting residues is attributed to co-incineration. There is a corresponding slight reduction in the credits for this fraction.

A similar situation applies to mechanical-biological treatment plants, to which only the debits due to the treatment process are attributed, but not the credits for recovery from the separated fractions. In spite of the credits for electricity production from fermentation in the 2005 scenario, mechanical-biological stabilisation performs slightly better in the 2020 scenarios because of the reduction in electricity requirements.

Appendix 5: Reported contribution of waste incineration plants (EU-15)

Table A5.1: *Contributions to CO_2 emissions from waste incineration in thousand t CO_2 equivalent, as reported by the Member States*

Member States	1990	2003	Difference
Austria	21	11	10
Belgium	339	344	-5
Denmark	0	0	0
Finland		0	
France	2,300	1,386	914
Germany			
Greece	0	0	0
Ireland			
Italy	493	168	325
Luxembourg	19	0	19
Netherlands			
Portugal	10	350	-340
Spain	750	178	572
Sweden	44	121	-77
United Kingdom	1,201	460	741

Source (after Deuber, Herold 2005)

Appendix 6: Waste quantities in the EU-15 countries for 1990

Table A6.1: *Waste quantities in the EU-15 countries and breakdown among the main disposal paths for 1990 in thousand t (European Commission 2000)*

Member States	Recycling	Compost	Waste incineration plant with Energy	Waste incineration plant without Energy	Landfill Total	Total
Austria	399	814	312		1,977	3,502
Belgium	318	247	983	576	2,232	4,356
Denmark*1	203	206	1,500		468	2,377
Finland	600	50	50		2,400	3,100
France*1	1,927	2,105	7,103	3,036	13,677	27,848
Germany	1,384	2,241	8,552		27,840	40,017
Greece	179				1,745	1,924
Ireland*3	118				1,432	1,550
Italy*3					24,000	24.000
Luxembourg*2			142			142
Netherlands*2	578	475	2,535		3,610	7,198
Portugal*1		448			1,488	1,936
Spain*2		1,898	476	159	10,289	12,822
Sweden	400	100	1,300		1,400	3,200
United Kingdom*3	2,020		1,450	1,160	23,990	28,620
EU-15	**8,126**	**8,584**	**24,403**	**4,931**	**116,548**	**162,592**

**1: 1993 *2: 1991 *3: 1995*

Appendix 7: Landfill waste quantities in the EU-15 countries for 1995

Table A7.1: *Waste quantities sent for landfill in the EU-15 countries in 1995 and reduction given compliance with requirements of Landfill Directive, in thousand t (European Commission 2003)*

Member States	1.995 Landfill	2006 75 %	2009 50 %	2016 35 %
Austria	1,626	1,220	813	569
Belgium	2,107	1,580	1,054	737
Denmark	503	377	252	176
Finland	1,366	1,025	683	478
France	13,651	10,238	6,826	4,778
Germany*	22,760	0	0	0
Greece**	1,763	1,322	881	617
Ireland	1,432	1,074	716	501
Italy	24,000	18,000	12,000	8,400
Luxembourg	65	49	33	23
Netherlands***	2,870	2,153	1,435	1,005
Portugal	2,007	1,505	1,004	702
Spain***	11,901	8,926	5,951	4,165
Sweden***	1,200	900	600	420
United Kingdom	23,990	17,993	11,995	8,397
EU-15	**111,241**	**66,360**	**44,240**	**30,968**

* *Average of 1993 and 1997*
*** *Average of 1993 and 1997*
*** *1994*

The reduction under the Landfill Directive relates to the biodegradable component. Since only this component makes a contribution to methane production, a first approximation to determining the resulting methane gas quantities in accordance with the calculation model used here on the basis of emission factors per tonne of waste input can be arrived at by making a corresponding reduction in the total landfill quantity.

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