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Documents

Methane emissions from Norwegian landfills

Revised calculations for waste landfilled 1945-2004

Preface

Norway is bound by the Kyoto Protocol to limit its emissions of greenhouse gases. Norway's annual greenhouse gas emissions in the period 2008-2012 must be no more than 1 per cent above the 1990 level, taking trade with quotas and other Kyoto mechanisms into account.

In the autumn of 2005, Statistics Norway took over the operative responsibility for the model that estimates methane emissions from Norwegian landfills. The calculations are based on a model developed by Frøiland Jensen et al. in 1999, commissioned by the Norwegian Pollution Control Authority (SFT) and in compliance with guidelines from the United Nations Intergovernmental Panel on Climate Change (IPCC). The model combines data on waste quantities deposited at landfills, with information about the decomposition of waste, decay rate, content of methane-developing components in the waste, operational conditions at the landfills and the methane fraction of the landfill gas. Previously, SFT was responsible for the calculations, and in 2005 carried out some revisions in formulas and factors in the model, based on recommendations from the IPCC.

When Statistics Norway took over the responsibility for the methane calculations, it was decided to use the waste accounts as a source for the waste quantity deposited at landfills. This gave a significant break in the time series for different kinds of materials landfilled and created a need for revising the historical waste quantities in the model. At the same time, Statistics Norway and SFT decided to revise figures for the decay rate for some materials, based on IPCC's recommendations for Norwegian climatic conditions and other available knowledge.

Statistics Norway's revision of the methane calculations is carried out in cooperation with SFT.

Standardtegn i tabeller	**Symbols in tables**	**Symbol**
Tall kan ikke forekomme	Category not applicable	.
Oppgave mangler	Data not available	..
Oppgave mangler foreløpig	Data not yet available	...
Tall kan ikke offentliggjøres	Not for publication	:
Null	Nil	-
Mindre enn 0,5 av den brukte enheten	Less than 0.5 of unit employed	0
Mindre enn 0,05 av den brukte enheten	Less than 0.05 of unit employed	0,0
Foreløpige tall	Provisional or preliminary figure	*
Brudd i den loddrette serien	Break in the homogeneity of a vertical series	—
Brudd i den vannrette serien	Break in the homogeneity of a horizontal series	I
Desimalskilletegn	Decimal punctuation mark	, (.)

Contents

1 Introduction

1.1 The methane model - a side model to the emission inventory

The Norwegian emission inventory provides data on emissions to air of greenhouse gases, acidifying gases, heavy metals and persistent organic pollutants. The purpose is to show to what degree Norway fulfils its international environmental obligations. The inventory also provides information to the media, schools and other institutions or organisations. Regional emission figures can give counties and municipalities information about local status and development and form the basis for the evaluation of local measures against air pollution problems.

The emission inventory will be used in connection with measure assessments and the documentation of the fulfilment of the commitments under the Kyoto Protocol. Sanctions against Norway will be carried out on the basis of our data, and Norway's quotas of greenhouse gases will be determined, based on the emission inventory. The United Nations Framework Convention on Climate Change (UNFCCC) demands high quality data. It is vital that the inventory is published on time and that the documentation is of sufficient quality.

The emission inventory is continuously being improved. The model for calculating methane emissions from landfills was developed by Norconsult (Frøiland Jensen et al. 1999). In a revised version of the model, carried out by the Norwegian Pollution Control Authority (SFT 2005), some of the conditions were altered. This comprised for example how much of the waste is degradable, and also what components the gas from the landfills consist of. A consequence of the revision was that the calculated methane emission from landfills fell from 7 to 4 per cent of the aggregate greenhouse gas emissions in 2000.

When Statistics Norway took over the operational responsibility for the methane model in 2005, a thorough examination of the input data was undertaken. In agreement with SFT, the decay rate was changed for some types of waste, and figures for the extraction of gas from landfills were revised. It is now Statistics Norway's responsibility to ensure that input data from different waste statistics are being properly used in the model.

1.2 Waste quantities in the methane model

Statistics Norway's waste accounts consist of data from several sources, such as special surveys, register data and statistics, indirect data sources such as production statistics, foreign trade statistics and different factors combined with activity data. Data from all these sources are compiled and used in the waste accounts, which give an overview of waste quantities in Norway, distributed by type of product, material, industry and method of treatment. The methods in the waste accounts are documented in Statistics Norway 2006 (in prep.).

Methane from landfills is a considerable source of emissions of greenhouse gases in Norway. Before the revision of the calculations, this source accounted for about 4 per cent of the aggregate Norwegian greenhouse gas emissions in 2003 (Statistics Norway 2005). This may seem a modest contribution, but the methane calculations are one of the most important sources of uncertainty in the Norwegian greenhouse gas emission inventory.

The methane is formed by the decomposition of organic waste in landfills. The decay rate varies from material to material. Wet organic waste (food, etc.) has the highest decay rate with a half-life of 3 years, while wood waste has the lowest decay rate with a half-life estimated at 23 years. Other materials do not emit methane at all, either because they are inorganic (metal, glass, etc.) or because they break down extremely slowly (plastic). It is therefore of vital importance for the calculations that

the waste quantities used as input to the model are correct, both with regard to total quantity and the allocation to material.

When Statistics Norway took over the responsibility for the methane model in 2005, considerable deviations were discovered between Statistics Norway's waste statistics, based on the waste accounts, and waste statistics data already used in the model, based on general waste statistics from Statistics Norway combined with sorting analyses. In addition, it was suspected that there were errors in the calculation of manufacturing waste deposited at the plants' own disposal sites, which could be vital to the calculated methane emissions. It was on this basis that Statistics Norway initiated a quality check of the waste calculations in the methane model in November 2005.

Statistics Norway's quality check of the methane calculations also comprises an updating of the decay rate for wood, paper and wet organic waste, and new data series for the extraction of methane from Norwegian landfills.

2 Definitions

C_{org} = organic bound carbon
DOC = degradable organic carbon
Manufacturing equivalent waste = wood-containing waste deposited at industrial disposal sites, calculated as DOC content equal to 170 kg C_{org} per tonne of waste.
Wood-equivalent waste = wood-containing waste deposited at industrial disposal sites, calculated as DOC content equal to 400 kg C_{org} per tonne of waste.
Wood-equivalent sludge = wood-containing sludge deposited at industrial disposal sites, calculated as DOC content equal to 400 kg C_{org} per tonne of waste. A sub-group of wood-equivalent waste.

3 Calculation methods

3.1 Industrial disposal sites

Up to the mid 1990s, large amounts of wood-containing waste from manufacturing (sludge, bark and wood) were deposited at industrial disposal sites every year. These amounts contribute considerably to methane emissions from Norwegian landfills. Frøiland Jensen et al. 1999 presented annual figures on these waste amounts, which seemed very high compared with figures in Statistics Norway's waste accounts. The basis for the figures in Frøiland Jensen et al. 1999 was data from Statistics Norway's surveys of waste from manufacturing for 1993 and 1996, and literature data from the beginning of the 1970s.

When Statistics Norway checked these data, it was found necessary to correct the following elements:

1. The amount of wood-containing sludge from manufacturing for 1993 was reported to be exclusive of water, but it was actually inclusive of about 50 per cent water. In 1996, however, the waste amount was exclusive of water, as reported in Frøiland Jensen et al. 1999.
2. 230 000 tonnes of wood-containing waste deposited at own disposal sites in the manufacturing industry was in Frøiland Jensen et al. 1999 reported as sludge. An amount of 85 000 tonnes of other wood waste was added, based on the survey of industrial waste from 1996. The revision revealed that the 230 000 tonnes included other wood waste, and that the 85 000 tonnes should therefore not be added.

3. Frøiland Jensen et al. 1999 estimates 85 000 tonnes of wood waste from the manufacturing industry to own disposal sites in 1996 based on the total amount at own disposal sites, minus the amount of inert mass at own disposal sites. Calculations using basic data from the survey of industrial waste from 1996 show 76 000 tonnes of wood at own disposal sites.
4. The amount of wood-containing sludge is in Frøiland Jensen et al. 1999 calculated as "manufacturing equivalent" waste with a DOC content equal to 170 kg C_{org} (=organic carbon)/tonne of waste. Usually, wood waste has a DOC content of 400 kg C_{org}/tonne of waste. Here, manufacturing equivalent waste was added to the wood waste, regardless of the difference in DOC content. In the revised calculations, the sludge is calculated as wood-equivalent sludge with DOC content of 400 kg C_{org} per tonne of waste.
5. A fraction of organic material (wood) in the sludge corresponding to wet sludge (50 per cent water content) was used for both 1993 and 1996 in Frøiland Jensen et al. 1999, while the sludge in 1996 was reported in dry weight.
6. The amount of sludge was not multiplied with the DOC content of wood after being divided with the DOC content of "manufacturing equivalent" waste.

By correcting these conditions, the amount of wood equivalent waste from manufacturing deposited at industrial disposal sites was considerably reduced for the year 1993 and somewhat less for the year 1996. The 1993 adjustment gave an extra effect on the methane emissions, because this year is a reference year for the interpolation of the years 1975-1993.

Today we also have basic statistics of wood waste deposited at industrial disposal sites in 1999 (Statistics Norway 1999), which have been used in the revised calculation.

Table 1 below shows the calculation of wood-containing waste from manufacturing deposited at industrial disposal sites for the years 1993, 1996 and 1999. Historic literature data used in Frøiland Jensen et al. 1999 are also used here, with one exception: wood-containing waste is converted to wood-equivalent waste with DOC content of 400 kg C_{org}/tonne of waste. In this connection, a DOC content of 320 kg C_{org}/tonne of waste is used for bark, based on information in Frøiland Jensen et al. 1999 saying that bark and wood deposited at industrial sites have an average DOC content of 350 kg C_{org}/tonne of waste. The estimate of 320 kg C_{org}/tonne of waste is regarded as conservative.

Table 1: Calculation of wood-containing waste deposited at industrial disposal sites. 1993, 1996 and 1999.

Year	Calculation
1993	Amount of wood-containing waste = 230 000 tonnes.
	Distribution: 80% sludge and 20% wood/bark. Wood/bark equally distributed between wood (10%) and bark (10%).
	Sludge calculated as wet weight. Content of dry matter = 50%. Wood fraction of the sludge (dry matter) = 45%.
	Bark has a DOC content of DOC_{bark}= 320kg C_{org}/tonne of waste.
	Wood has a DOC content of DOC_{tre} = 400kg C_{org}/tonne of waste.
	Amount of wood-equivalent waste = 230 000 tonnes of wood-containing waste * ((80% sludge * 50% dry matter * 45% wood in the sludge (dry matter)) + (10% wood) + (10% bark * DOC_{bark}= 320 / DOC_{tre}= 400)) = **82 800 tonnes**
1996	Amount of wood/bark: 76 000 tonnes. Equally distributed between wood and bark.
	Amount of sludge: 52 000 tonnes dry weight.
	Other values as in 1993.
	Amount of wood-equivalent waste = 52 000 tonnes of sludge (dry matter) * 45% wood in the sludge (dry matter) + (76 000 * 50%) tonnes of wood + (76 000 * 50%) tonnes of bark * (DOC_{bark}= 320 / DOC_{tre}= 400) = **91 800 tonnes**
	Amount of wood-equivalent sludge = 52 000 tonnes of sludge (dry matter) * 45% wood in the sludge (dry matter) = **23 400 tonnes**
1999	Amount of wood/bark = 23 437 tonnes. Equally distributed between wood and bark.
	Amount of sludge = 10 508 tonnes. Sludge calculated as wet weight.
	Other values as in 1993.
	Amount of wood-equivalent waste = 10 508 tonnes of sludge * 50% dry matter * 45% wood in the sludge (dry matter) + (23 437 / 2) tonnes of wood + (23 437 / 2) tonnes of bark * (DOC_{bark}= 320 / DOC_{tre}= 400) = **23 458 tonnes**
	Amount of wood-equivalent sludge = 10 508 tonnes of sludge * 50% dry matter * 45% wood in the sludge (dry matter) = **2 364 tonnes**

Source: Statistics Norway 1993, 1996 and 1999.

Other years are calculated on the basis of figures for 1993, 1996 and 1999, combined with information from Frøiland Jensen et al. 1999, interpolations and extrapolations.

From 1995 onwards, the waste accounts are an important source of statistics on waste landfilled. The waste accounts do not distinguish between waste deposited at industrial sites and other waste landfilled. Thus, wood and bark deposited at industrial sites are included in the amount of deposited wood waste from the waste accounts, and therefore not added to the total amount of deposited wood waste after 1995. However, the wood content of wood-containing sludge is added, because wood in the waste accounts does not include wood-containing sludge, and statistics on deposited sludge do not distinguish between organic and inorganic sludge. The method for calculating the amount of wood-equivalent sludge on industrial sites is also shown in table 1.

For the years before 1995, small amounts of other degradable waste deposited at industrial sites are also added. This comprises about 2 000 tonnes of wet organic waste, 1 000 tonnes of paper waste, 2 000 tonnes of textiles (degradable fraction) and 1 000 tonnes of plastics. The amounts are based on statistics from the surveys of waste from manufacturing, and are supposed to be constant in the period 1970-1993, and to go down gradually back to 1945, in step with the amount of industrial waste[1] for the same material type.

[1] For textiles, the amount of textiles in the household waste is used to calculate the development back to 1945, because textiles is not a fraction of the industrial waste before 1970.

3.2 Municipal landfills 1990-2002

In the period 1990-2002, the data basis for the waste calculations is regarded as good. Preceding Statistics Norway's revision of the waste amounts in the methane model, the amounts of waste deposited at municipal sites were calculated on the basis of municipal waste (waste statistics from Statistics Norway), combined with sorting analyses (Hancke et al. 1974, Heie 1998) and adjusted for waste sorted for recovery and incineration (SFT 2005). In Statistics Norway's revised calculations, the amounts of waste landfilled, allocated to material, for the period 1995-2002 come from the waste accounts (Statistics Norway 2005), with two exceptions:

- Wood content in sludge deposited at industrial sites is added to the amount of deposited wood from the waste accounts. The amount of sludge deposited at industrial sites decreases to 0 in the year 2000.
- Textiles are supposed to consist of 50 per cent plastics (SFT 2005). The fraction of plastics in deposited textiles is therefore subtracted from the amount of deposited textiles and added to deposited plastics.

The revised calculations do not distinguish between municipal waste and industrial waste after 1995, except for wood-containing sludge. However, a table has been drawn up (table 2) that shows the amount of municipal waste landfilled, both according to the revised calculations and the original figures. The figures do not include bark and wood at industrial sites. Table 2 shows considerable deviations between amounts of waste deposited at municipal sites in the period 1995-2002 according to the waste accounts and the figures used by the Norwegian Pollution Control Authority prior to this last revision (SFT 2005).

Table 2: Municipal waste, by material[2], 1995-2002. Revised figures (Statistics Norway) and original figures (SFT 2005). Tonnes.

	1995	1996	1997	1998	1999	2000	2001	2002
Wet organic (revised)	324 064	308 096	266 690	253 284	201 878	218 020	221 792	240 583
Wet organic (original)	354 786	344 565	315 079	345 631	276 771	260 266	275 569	222 716
Paper (revised)	468 489	461 823	430 737	451 707	373 379	417 517	344 416	350 459
Paper (original)	525 088	481 122	414 962	505 156	403 253	407 442	442 633	389 054
Wood (revised)	154 634	124 445	119 024	113 604	109 389	124 431	128 586	129 165
Wood (original)	349 069	341 455	276 111	290 333	185 614	170 680	247 112	189 755
Textiles (revised)	34 193	34 815	36 006	38 396	36 887	37 800	39 546	39 849
Textiles (original)	17 659	16 037	16 146	18 300	16 024	15 379	14 006	12 224
Plastic[2] (revised)	292 070	324 606	314 034	324 936	317 988	316 690	318 379	324 051
Plastic[2] (original)	190 075	187 540	174 949	192 366	162 048	159 229	169 570	142 570

The most important reasons for the deviations are assumed to be:

1. The calculation methods used in the waste accounts have taken several different data sources into consideration (Statistics Norway 2006, in prep.) and are regarded as less uncertain than calculations where sorting analyses have been used.
2. The sorting analysis for household waste (Heie 1998) that was used in the original calculations does not contain bulky waste. This kind of waste has another composition than the usual household waste (Søre Sunnmøre Reinhaldsverk 1992), and accounts for approximately 20 per cent of the household waste.
3. The composition of industrial waste varies a lot. The allocation of landfilled industrial waste to material is based on sorting analyses, and is therefore highly uncertain.

[2] Even though plastics are not assumed to develop methane in these calculations, plastics is still a material category in the model. This makes the model easy to update if the United Nations Intergovernmental Panel of Climate Change (IPCC) subsequently decides that plastics are degradable and contribute to methane emissions.

Statistics Norway's waste accounts also have uncertainties. Deviations are revealed between amounts of waste landfilled according to the waste accounts, and waste amounts calculated by combining statistics on municipal waste with statistics on waste to own disposal sites from Statistics Norway's surveys on industrial waste. The total deviation for the fractions included in the methane model is 20 per cent in 1995 (the waste accounts give the lowest result) and 4 per cent in 2002 (the waste accounts give the highest result). In this case, we have regarded the waste accounts as the most reliable. At the same time, it must be expected that the figures on waste landfilled will be updated back to 1995, as the waste accounts may also be further revised and harmonised in the future.

Despite this, the waste accounts are regarded to be a more reliable source than the calculations in Frøiland Jensen et al. 1999. In addition, there will be regular quality controls of the waste accounts in the future. Statistics Norway therefore chooses the waste accounts as the source of data on waste amounts landfilled.

The waste statistics for the period 1990-1994 is not covered by the waste accounts. In order to calculate the allocation to material for this period, the allocation to material of the waste landfilled in 1995 was used as a basis. These figures were then combined with statistics on total waste amounts deposited at municipal sites, from the original methane calculations (Frøiland Jensen et al. 1999). These calculations are founded on Statistics Norway's statistics on municipal waste, and are regarded as reliable.

The allocation of municipal waste to material in 1990-1994 was estimated with the allocation in 1995 as a starting point, and corrected due to an uneven growth in the sorting for recovery for different waste types from 1990 to 1995 (Statistics Norway 1996). Paper waste showed a particularly high growth. The correction is partly based on estimates. The revised and originally estimated allocation to material (percentage) of waste landfilled at municipal sites from 1990-2002, are shown in table 3:

Table 3: Composition of municipal waste 1990-2002, revised figures (Statistics Norway) and original figures (SFT 2005). Per cent.

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002
Wet organic (revised)	21.6	21.7	21.8	21.9	22.0	22.1	21.5	19.9	18.6	16.8	17.1	16.9	17.9
Wet organic (original)	19.5	20.7	19.5	20.4	20.4	18.9	19.9	20.2	19.7	20.4	19.8	20.5	18.4
Paper (revised)	36.9	35.9	34.9	33.9	32.9	31.9	32.2	32.1	33.2	31.1	32.7	28.4	28.3
Paper (original)	30.4	26.4	28.6	27.5	27.7	28.0	27.8	26.6	28.7	29.7	31.0	32.9	32.2
Wood (revised)	10.0	10.1	10.2	10.3	10.4	10.5	8.7	8.9	8.4	9.1	9.8	10.6	10.4
Wood (original)	14.9	16.0	17.0	16.5	16.1	17.1	18.6	16.4	15.3	12.9	12.2	17.6	14.9
Textile (revised)	4.7	4.7	4.7	4.7	4.7	4.7	4.9	5.4	5.6	6.2	5.9	6.5	6.4
Textile (original)	1.0	1.0	0.9	0.9	0.9	0.9	0.9	1.0	1.0	1.2	1.2	1.0	1.0
Plastic (revised)	14.6	15.2	15.8	16.4	17.0	17.6	20.2	20.7	21.1	23.4	21.9	23.0	23.0
Plastic (original)	9.0	9.5	9.5	9.9	10.1	10.1	10.8	11.2	10.9	12.0	12.1	12.6	11.8

The biggest difference between the two calculations is the development of the plastics fraction. In Statistics Norway's revised calculations, the plastics fraction shows a strong growth from 1990 to 2002, while this fraction is quite stable in the original calculations. Since the sorting of plastics for recovery has grown more slowly than the sorting of biodegradable waste (such as wet organic waste, paper and wood), and it has been an increased focus towards keeping biodegradable waste away from the landfills, the growth in the plastics fraction in Statistics Norway's revised calculations is regarded as probable. Since plastics are not supposed to develop methane, this difference itself will be of no consequence for the calculated methane emissions.

However, the growing plastics fraction makes it more likely that the fraction of biodegradable waste decreases during the same period, which is not the case in the original calculations. This leads to increasingly downscaled methane emissions from 1990 onwards in the revised calculations, compared to the original ones.

3.3 Municipal landfills 1965-1989

In the period 1965-1989, the data material for waste calculations is more scarce and the estimations correspondingly more uncertain. Among other things, statistics on recovery in this period is lacking. Data on waste from this period have, nevertheless, great significance for the estimated methane emissions, and even more so for the development from 1990 to the present. Going back to the 1960s, it is mainly the amounts of wood waste that influence the methane emissions, whereas other waste types have less significance because of a higher decay rate. In the 1980s, however, all degradable waste types influenced the emission calculations, particularly in the reference year 1990.

The revised calculations are based on waste data from Frøiland Jensen et al. 1999, which was also used in SFT 2005. Frøiland Jensen et al. use statistics on landfilled household and industrial waste. These statistics are regarded as comparatively reliable, and at the same time the likelihood of finding better data is small. Thus, in this revision the focus has been on the composition of the waste. Frøiland Jensen et al. 1999 took its starting point in two sorting analyses presented in Meløy et al. 1976, which also form a part of the foundation for Statistics Norway's revised calculations. In the revised calculations, these two sorting analyses have been supplemented with several additional surveys of household and industrial waste from the same source material, together with sorting analyses from Hancke et al. (1974), covering other parts of the country. Table 4 compares the composition of the waste in the revised (Statistics Norway) and original calculations (SFT 2005, Frøiland Jensen et al. 1999) for the period 1965-1989.

Table 4: Composition of municipal waste 1965-1989, revised calculation (Statistics Norway) and original calculation (SFT 2005, Frøiland Jensen et al. 1999). Per cent.

		Wet organic	Paper	Wood[1]	Textile[2]	Plastic	Other combustible[3]	Other non-combustible[4]	Total
Revised	Industrial[5]	8.9	30.6	..	..	7.2	25.7	27.6	100
Original	Industrial	4.5	26.5	..	..	6.0	31.0	32.0	100
Revised	Household[6]	36.9	34.3	..	1.7	6.0	8.0	13.2	100
Original	Household	34.0	36.0	..	3.0	4.0	11.3	15.7	104
Revised	Municipal[7]	21.6	32.3	..	0.7	6.7	17.7	21.1	100
Original	Municipal[7]	17.3	30.2	..	1.3	5.0	21.9	24.3	100

[1] Not separate category in the data material for the period 1965-1989. Included in "Other combustible".
[2] Not separate category in the data material for the composition of industrial waste in the period 1965-1989. Included in "Other combustible".
[3] Including 1/4 of fine material (coffee grounds, vacuum cleaner bags, sawdust, etc.).
[4] Including 3/4 of fine material (ashes, cat sand, cement, earth, gravel, etc.).
[5] Including half of park and garden waste.
[6] Including bulky waste and half of park and garden waste.
[7] Sum of industrial and household waste. Material composition estimated as weighted average.

In the originally estimated composition of household waste, the total amounted to 104 per cent. After correcting this error and calculating average composition of all municipal waste, the remaining difference is mainly caused by the revised calculations giving a higher share of wet organic waste and a lower share of other combustible. Other combustible waste is, as in the original calculations, regarded as wood waste, but with a DOC content of 370kg C_{org}/tonne waste, as stated in Frøiland Jensen et al. (1999), instead of 400kg C_{org} /tonne waste, as in SFT (2005).

The difference between the revised and the original calculations is rather small, but the revised calculations show a somewhat faster decrease in methane emissions from 1990, because wet organic waste has a higher decay rate than wood.

3.4 Municipal landfills 1945-1964

In the period 1945-1964, data are very scarce, and the figures on waste amount and composition in Frøiland Jensen et al. 1999, which have also been used in SFT 2005, are to a large extent based on suppositions and extrapolations. Waste from this period, however, liberates far less methane in the period 1990-2010, and uncertainties in estimated waste amounts thus have little significance for the uncertainty in calculated methane emissions for the period 1990-2010.

The waste figures from Frøiland Jensen et al. 1999 for the period 1945-1964 have to a great extent been used also in the revised calculations, but the waste composition has been slightly altered. The waste composition 1945-1964 is based on the composition 1965-1989, combined with suppositions on the waste development in the period. Changes in the waste composition in the period 1965-1989 also lead to changes for 1945-1964. The suppositions in Frøiland Jensen et al. 1999 have been maintained, with the exception that Frøiland Jensen et al. 1999 assumes that there was less paper, wet organic waste and plastic in household waste in the period 1945-1964 than in 1965-1989. Nothing is said about the development in the proportions of combustible and non-combustible fractions, but the outcome is a relative increase for these two material types. The proportion of combustible fractions (including wood and ¼ fine material with the same half-lives as wood) increases even more than the proportion of non-combustible fractions, but no reasons are given for this.

Statistics Norway doubts that the share of combustible waste from households was considerably higher in the period 1945-1964 than in 1965-1989, as the use of scrapped wood for fuel was customary in the years after World War II. Statistics Norway considers it a conservative estimate to keep the share of wood in household waste constant from 1945-1964 to 1965-1989.

The proportion of combustible fractions and fine material in industrial waste increased more than non-combustible fractions, in terms of percentage, from 1965-1989 to 1945-1964, without any reasons for this being given. Statistics Norway is of the opinion that reasons for such a difference should be given in order to make it acceptable. As no reasons are given, we have made corrections for the period 1945-1964, so that the development in the proportion of combustible fractions, fine material and other non-combustible fractions is equal, in terms of percentage. Fractions other than wood from this period have little influence on the methane emissions from 1990 onwards because of short half-lives.

The waste amounts in Frøiland Jensen et al. 1999 have not been verified because of a lack of material, and have thus remained. Table 5 compares the waste composition in the original (Norwegian Pollution Control Authority) and the revised calculations (Statistics Norway) for the period 1945-1964.

Table 5: Composition of municipal waste 1945-1964, revised calculation (Statistics Norway) and original calculation (SFT 2005, Frøiland Jensen et al. 1999). Per cent.

		Wet organic	Paper	Wood[1]	Textiles[2]	Plastics	Other combustible[3]	Other non-combustible[4]	Total
Revised	Industrial[5]	5.9	28.9	..	..	3.6	29.7	31.9	100
Original	Industrial	3.0	25.0	..	..	3.0	35.0	34.0	100
Revised	Household[6]	27.1	28.5	..	1.7	3.0	8.0	31.7	100
Original	Household	25.0	30.0	..	3.0	2.0	18.3	21.7	100
Revised	Municipal[7]	15.6	28.7	..	0.7	3.3	19.9	31.8	100
Original	Municipal[7]	13.0	27.3	..	1.4	2.5	27.4	28.4	100

[1] Not separate category in the data material for the period 1965-1989. Included in "Other combustible".
[2] Not separate category in the data material for the composition of industrial waste in the period 1965-1989. Included in "Other combustible".
[3] Including 1/4 of fine material (coffee grounds, vacuum cleaner bags, sawdust, etc.).
[4] Including 3/4 of fine material (ashes, cat sand, cement, earth, gravel, etc.).
[5] Including half of park and garden waste.
[6] Including coarse waste and half of park and garden waste.
[7] Sum of industrial and household waste. Material composition estimated as weighted average.

3.5 Waste degrading

The time that passes from the depositing of the waste until methane is created is one of the factors that decides the annual amount of methane created. The breakdown of the waste follows the course of a chemical reaction of the first order. This means that the decay is fastest in the first phase and falls off exponentially. The decay rate is measured in half-lives, which is the time needed to break down half of the waste.

Recent research has shown that the half-lives formerly used in the model, were too short. In the guidelines from the UN's Intergovernmental Panel on Climate Change (IPCC), the recommended half-life is 23 years for wood, whereas it is 3 years for wet organic waste. The former recommendations from IPCC were 10.5 and 2.8 years, respectively.

IPCC recommends 23 years as the standard value also for paper, but because Norway is situated in a climate zone with colder and damper weather than that which the standard value allows for, we have chosen 12 years as the half-life of paper, which seems more appropriate (Oonk and Boom 1995). The former recommendation from IPCC was 8.4 years. The half-life of textiles has not been updated, and remains 10.5 years.

4 Results

By including the revised waste amounts in the calculation model, updating the half-lives of wood, paper and wet organic waste and using updated figures (as at 11 January 2006) from the Norwegian Pollution Control Authority for the extraction of methane from landfills, we get the following figures on methane emissions from Norwegian landfills:

Table 6: Methane emissions from Norwegian landfills, tonnes. Revised model (Statistics Norway) 1990-2004*, original model (SFT 2005) 1990-2003 and deviation between original and revised models.

Year	Revised model	Original model	Deviation
1990	86 979	117 296	-30 316
1991	87 220	116 487	-28 767
1992	87 429	114 428	-26 999
1993	87 757	114 778	-27 021
1994	87 930	114 908	-26 978
1995	87 298	113 885	-26 586
1996	86 209	114 185	-27 976
1997	84 808	113 400	-28 592
1998	79 496	107 820	-28 324
1999	73 852	106 158	-32 306
2000	75 175	106 631	-31 456
2001	72 615	102 387	-29 772
2002	69 960	99 975	-30 015
2003	69 697	97 584	-27 887
2004*	69 425	.	.

The deviations between Statistics Norway's revised calculations and the original calculations (SFT 2005) are significant. In CO_2 equivalents, the deviations constitute an annual reduction in emissions of 560 000-680 000 tonnes in the period 1990-2003. The reduction is 51 000 CO_2 equivalents greater in 1990 than in 2003, which corresponds to 1 per cent of Norway's permitted emission increase from 1990 until the period 2008-2012.

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Appendix

Waste landfilled 1945-2004*, revised calculations. Methane extracted 1988 - 2004. Calculated net methane emissions[3] 1945-2004. Tonnes.

Year	Wet organic	Paper	Wood	Textiles	Plastics	Methane extracted	Net methane emissions
1945	78 647	142 758	164 115	2 717	19 368		0
1946	81 154	147 310	169 768	2 804	19 986		943
1947	83 762	152 044	175 630	2 894	20 628		1 821
1948	86 352	156 744	181 453	2 983	21 266		2 646
1949	88 902	161 373	187 195	3 072	21 894		3 429
1950	121 350	220 271	255 043	4 193	29 885		4 176
1951	124 178	225 405	261 510	4 290	30 581		5 252
1952	127 068	230 651	267 958	4 390	31 293		6 272
1953	130 053	236 069	274 602	4 493	32 028		7 244
1954	133 080	241 563	281 334	4 598	32 774		8 179
1955	136 164	247 161	288 185	4 704	33 533		9 082
1956	139 228	252 723	294 994	4 810	34 288		9 960
1957	142 267	258 239	301 751	4 915	35 036		10 815
1958	145 334	263 806	308 566	5 021	35 791		11 651
1959	148 382	269 340	315 343	5 127	36 542		12 470
1960	177 793	322 726	376 883	6 143	43 785		13 276
1961	181 057	328 651	384 107	6 256	44 589		14 384
1962	184 379	334 680	391 451	6 370	45 407		15 452
1963	187 653	340 623	398 697	6 483	46 213		16 486
1964	190 965	346 635	406 021	6 598	47 029		17 490
1965	270 497	397 057	389 258	6 715	89 015		18 469
1966	275 337	404 161	396 491	6 835	90 607		19 827
1967	271 352	401 486	400 509	6 695	90 089		21 105
1968	267 408	398 870	404 585	6 555	89 585		22 247
1969	272 519	406 372	412 199	6 682	91 267		23 277
1970	292 796	436 137	429 542	7 185	97 940		24 281
1971	297 728	443 409	433 177	7 274	99 523		28 397
1972	302 917	451 059	437 001	7 368	101 188		32 178
1973	307 956	458 487	440 715	7 458	102 806		35 688
1974	314 372	471 056	448 506	7 546	105 638		38 967
1975	321 196	483 525	455 907	7 646	108 427		42 104
1976	327 876	495 760	456 175	7 745	111 164		45 125
1977	334 453	507 859	456 383	7 842	113 872		48 028
1978	342 799	521 565	456 909	7 979	116 900		50 828
1979	352 076	536 090	457 576	8 139	120 088		53 563
1980	361 322	550 583	458 233	8 298	123 270		56 253
1981	371 897	568 490	461 303	8 467	127 241		60 592
1982	382 242	586 291	464 432	8 630	131 195		64 779
1983	388 379	600 234	466 771	8 696	134 381		68 840
1984	388 019	606 031	465 731	8 631	135 838		72 725
1985	378 061	600 394	460 293	8 369	134 889		76 329
1986	348 489	564 157	438 742	7 768	127 225		79 500
1987	344 135	557 319	428 114	7 693	125 723		81 833

[3] Estimated gross methane emissions, exclusive of methane extracted. This model has been developed to calculate methane emissions from 1990 onwards. Estimated emissions in the first years of the time series will be far lower than the actual emissions, as waste data earlier than 1945 not are included in the model. This error will lessen its effect later in the time series, and from 1990 onwards, the error is close to 0.

Appendix (cont.)

Year	Wet organic	Paper	Wood	Textiles	Plastics	Methane extracted	Net methane emissions
1988	348 809	553 542	414 048	7 875	124 573	480	83 498
1989	354 928	553 212	402 343	8 072	124 214	606	85 370
1990	370 569	631 627	275 220	41 793	291 617	946	86 979
1991	370 924	612 294	269 291	41 647	300 777	2 672	87 720
1992	350 444	559 699	253 563	39 274	292 559	5 212	87 429
1993	333 509	514 955	239 402	37 301	286 322	6 215	87 757
1994	357 015	532 729	254 374	39 613	314 613	6 737	87 930
1995	326 000	469 388	243 434	36 150	294 786	8 631	87 298
1996	310 000	462 671	216 245	36 750	327 180	10 072	86 209
1997	268 000	431 423	188 043	37 300	315 805	11 549	84 808
1998	254 000	452 231	159 842	39 050	325 904	16 631	79 496
1999	202 000	373 741	132 846	36 900	318 153	22 155	73 852
2000	218 020	417 717	129 755	37 800	316 690	18 811	75 175
2001	221 792	344 454	128 586	39 546	318 379	20 582	72 615
2002	240 583	350 459	129 165	39 849	324 051	22 159	69 960
2003*	199 058	346 677	136 288	40 762	309 898	21 503	69 697
2004*	178 993	328 782	133 528	42 339	312 692	20 463	69 425

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