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NERI Technical Note No. 208

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Data sheet

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Abstract:	The report gives a detailed description of the national methodology, national statistics and data background used for the first time implementation of Waste Category 6B in the National Inventory Report. Emissions of methane and nitrous oxide from wastewater handling have been estimated from the reference year 1990 to 2003.
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Preface

This report documents the national statistics, data background and methodology used for implementing waste category 6B in the National Inventory Report. Emissions have been estimated from the reference year 1990 to 2003 and have been reported for the first time in the National Inventory Report 2005 (NERI, 2005). Minor corrections in the data sources have occurred based on corrections from the Danish Environmental Protection Agency (DEPA) who reviewed the report. Corrections had no influence on the estimated emissions. The authors acknowledge the comments and improvements to the report during the review process performed by Niels Iversen, Section of Environmental Engineering Department of Life Sciences, Aalborg University, Denmark, and Mette Wolstrup Pedersen, Water office, DEPA.

Summary

There have not previously been any country-specific methodologies developed for estimating CH_4 or N_2O emissions from wastewater handling in Denmark. The methodology developed for this submission for estimating the emission of methane from wastewater handling is following the IPCC Guidelines (1996) and IPCC Good Practice Guidance (2000). The methodology is based on the calculation of a so-called gross emission of methane, which is the theoretical maximum possible emission. This gross emission is based on the total methane potential of the total amount of degradable organic matter at the wastewater treatment plants (WWTPs). The amounts of methane or methane potential that are recovered by biogas production or combusted are subtracted from the gross emission. The resulting net methane emission is an estimate of the actual amount of emitted methane during wastewater treatment at Danish WWTPs. Key parameters are the fraction of sewage sludge that are treated anaerobically and the total organic degradable waste quantified by the biological oxygen demand (BOD) of the wastewater influent.

A national methodology for calculating the emission of nitrous oxide from wastewater treatment processes (direct N_2O emission) and from the effluent wastewater (indirect N_2O emission), respectively, has been developed. The IPCC default methodology only includes N_2O emissions from human sewage based on annual per capita protein intake. The methodology account for nitrogen intake, i.e. faeces and urine, only and neither the industrial nitrogen input nor non-consumption protein from kitchen, bath and laundry discharges are included. All aspects have been included in the present methodology for estimating the emission of nitrous oxide from waste category 6B.

The data on the inlet and outlet amounts of industrial and municipal wastewater and treatment processes are according to the official registration performed by DEPA. Data are documented in the report series *Wastewater from municipal and private wastewater treatment plants* (Danish title: *Spildevandsslam fra kommunale og private renseanlæg*), DEPA 1989, 1999, 2001, 2003 and 2004, and *Point sources* (Danish title: *Punktkilder*), DEPA 1994, 1996, 1997, 1998, 1999, 2001, 2002 and 2003. Some of the data can be found in the DEPA database *Environment Data* and for point sources before 2003 in the Statistics Denmark's database *StatBank Denmark.* For the check method, data on Population are found in *Statbank Denmark*. Data on protein consumption are found in the FAOSTAT database.

Until year 2002 the Statistics Denmark registered the load of nitrogen, phosphorus and organic matter in effluent wastewater from different types of point sources. Data on the nitrogen in effluents are extracted from the Statistics Denmark's database and point source data reported within the Danish Monitoring programme by the Danish EPA (report series from the DEPA with English title: *Point Sources*).

Sammenfatning

Der har ikke tidligere eksisteret nogen national metode til estimering af emissionen af metan og lattergas fra behandling af spildevand i Danmark.

Den metode der anvendes til estimering af metan fra spildevandsbehandling er i overensstemmelse med IPCC Guidelines (1996) and IPCC Good Practice Guidance (2000). Meget kort er metan emissionsberegningerne baseret på en teoretisk maksimal emission kaldet brutto emissionen af metan. Denne brutto emission baserer sig på emission fra hele metanpotentialet i den mængde organisk nedbrydeligt materiale der er i indløbsspildevandet på rensningsanlæggene. Fra denne teoretisk maksimale emission fratrækkes det metan potentiale som anvendes til biogas eller forbrændes. Den resulterende netto metan emission er et estimat af den reelle emission af metan under spildevandsbehandlingen på renseanlæggene. Centrale parametre er fraktionen af spildevandsslam som behandles anaerobt udtrykt ved metan omdannelsesfaktoren samt den totale mængde nedbrydeligt organisk materiale kvantificeret ved det biologiske ilt forbrug i indløbsspildevandet.

For lattergas er der udviklet en national emissionsberegningsmetode. Lattergas emissionsberegningerne er opdelt i et bidrag fra spildevandsbehandlingsprocesserne på renseanlæggene kaldet direkte emission, samt et bidrag fra udløbsspildevandet kaldet indirekte N_2O emission. Metoden der er beskrevet i IPCC guidelines inkluderer kun det humane bidrag baseret på aktivitetsdataene: årligt protein indtag per indbygger og populationstallet. Metoden inkluderer således kun human udskillelse af nitrogen via faeces og urin. Hverken det industrielle eller øvrige husholdningsbidrag til nitrogen i indløbsspildevandet på renseanlæg er inkluderet i IPPC metoden. Nitrogen bidrag til husholdningsspildevand fra køkken, bad og vask samt industri er inkluderet i den metode som er præsenteret i denne rapport.

Centrale kilder til input data er mængden nitrogen og organisk stof i ind og udløbsspildevand på private og kommunale rensningsanlæg samt behandlingprocesser og slutdisponeringskategorier for spildevandsslam. Dissektivitetsdata er rapporteret i miljøstyrelsens rapport serier *Spildevandsslam fra kommunale og private renseanlæg*, DEPA 1989, 1999, 2001, 2003 and 2004, and *Punktkilder*, DEPA 1994, 1996, 1997, 1998, 1999, 2001, 2002 and 2003. Nogle data kan findes i Miljøstyrelsens Miljødata mens aktivitetsdata for årene før 2003 er taget fra Danmarks Statistikbank (Danmarks Statistik). Til IPPCs "check metode" (som ikke kræver nationalspecifikke data), som er anvendt som reference til den nationalspecifikke metode, anvendes populationsdata fra Danmarks statistik og protein indtag fra FAOSTAT databasen (FAOSTAT data, 2004).

1 Emission from wastewater treatment plants (6B)

Wastewater treated by wastewater treatment plants (WWTPs) includes domestic and industrial wastewater as well as rainwater. About 90% of the Danish households are connected to a municipal sewer system. Wastewater is received from the sewer system and most WWTPs treats wastewater by several combined processes, i.e. mechanical treatment (e.g. settlement tank, separation facility, septic tank), biological treatment of wastewater, chemical removal of phosphorus, nitrification and supplemental treatment processes as e.g. sand filter, chemical precipitation etc.. In the mechanical treatment, wastewater and sludge is separated, i.e. particles, sand and oils are removed from the wastewater and the sludge is dehydrated and stabilised by different additional processes. Overall stabilisation can be split into two processes, i.e. biological and chemical. The biological processes include anaerobic stabilisation where the sludge is digested in a digesting tank and aerobic stabilisation by long-term aeration (DEPA 2002, Miljøprojekt Nr. 704). Overall the Danish wastewater treatment processes can be divided into the following steps:

M=Mechanical
B=Biological
N=Nitrification (removal of nitrogen)
D=Denitrification (removal of ammonia)
C = Chemical

The more steps the higher cleaning level regarding nitrogen, phosphorus and dissolved organic matter (DOC). The development in the effectiveness of reducing the nutrient content of the effluent wastewater is illustrated in Table 1.

Table 1. Per cent reduction in nutrient content of effluent wastewater.

Effluent % reduction	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003
BOD	76	83	87	92	94	94	94	94	96	96	96
N	46	49	56	68	76	74	74	77	79	77	82
P	71	74	80	85	89	90	90	91	92	91	93

The WWTPs have been upgraded significantly since 1987 when the first Water Environment Action Plan was launched by the Danish Parliament. The plan included more strict emission standards for nutrients and organic matter for WWTPs with a capacity above than 5,000 PE and, thus, rendered technological upgrading of the majority of Danish WWTPs necessary. Today, about one fifth of the biggest WWTPs treat almost 90% of the total volume of sewage in Denmark (cf. Table 2). Typically, these plants have mechanical treatment and biological treatment including removal of nitrogen and organic matter in activated sludge systems, a chemical precipitation step and finally settling of suspended particles in a clarifier tank. The chemical processes include lime stabilisation. Many are, in addition to this, equipped with a filter or lagoon after the settling step. In addition to hygienization, dewatering and stabilisation of the sludge, the sludge may be mineralised, composted, dried or combusted. Composting and sanitation is attributed by a storage time of 3 to 6 months. For plants with mineralization of sludge the storage time is about 10 years.

In 2002 there was 1,267 Danish WWTPs bigger than 30 person equivalents (PE) (cf. Table 2). One PE expresses how much one person pollutes, i.e. 1 PE being defined as 21.9 kg BOD / year. BOD is the Biological Oxygen Demand, which is a measure of total degradable organic matter in the wastewater. The capacities of WWTPs are calculated based on the amount of organic matter in the influent wastewater and converted to number of PEs irrespective of the origin of the wastewater, i.e. domestic or industry. Therefore it is not possible to calculate the emission contribution from industry and household separately. The per cent contribution from industry is, however, known (cf. Table 3).

Table 2. Size distributions of the Danish WWTPs in the year 2002 (DEPA 2003, Point sources 2002).

WWTP capacity	Number of WWTPs	Load in % of total load on all WWTPs
>30 PE	1267	1
>500 PE	658	1
>2000 PE	441	5
>5000 PE	274	10
>15000 PE	130	15
>50000 PE	63	20
>100000 PE	30	48

In 1989 only 10% of the wastewater treatment processes included reduction of N, P and BOD, in 1996 the number was 76%. Today 85% of the total wastewater is treated at so-called MBNDC-WWTPs, which is indicative of a high removal of N, P and DOC at the WWTP.

2 Emission of CH_4 from wastewater treatment plants

The emission of methane from wastewater handling is calculated according to the IPCC Guidelines (1996) and IPCC Good Practice Guidelines (GPG) (2000). The emission is to be calculated for domestic and industrial wastewater and the resulting two types of sludge, i.e. domestic and industrial sludge. This approach is not suitable for the information available for the Danish wastewater treatment systems as a significant fraction of the industrial wastewater are treated at centralised municipal WWTPs. Therefore the IPPC methodology for domestic wastewater has been applied by accounting for the industrial influent load.

Regarding the industry, only data concerning effluents from on-site wastewater treatment to surface waters are available, which is not contributing the methane emission from wastewater handling. At this point information regarding industrial on-site wastewater treatment processes or final sludge disposal in numbers are not available at a level of data that allows for calculation of the on-site industrial contribution to CH_4 emissions. The degree to which the industry is covered in the emission estimated is therefore dependent on the amount of industrial wastewater connected to the municipal sewer system. Emissions from industrial on-site wastewater treatment are not covered at this stage.

Since the Water Environmental Action Plan 1987, the fraction of industrial influent wastewater load at municipal and private WWTPs has increased from zero to a constant level of around 41.4 % from 1998 and forward. The fraction of industrial sources discharges to city sewers contributing to the influent wastewater load in the national WWTPs are given in per cent based on PEs (1 PE = 60g BOD/day) in Table 3.

Table 3. The fraction of wastewater from industrial sources discharged to city sewers, i.e. industrial load of wastewater relative to total influent load at WWTPs* (DEPA 1994, 1996, 1997, 1998, 1999, 2000, 2001, 2002, 2003, 2004, Point sources).

	1984-1993	1993	1997	1998	1999	2000	2001	2002	2003
% industrial load	0-5	5	-	48	41	42	38	38	37

* based on information on influent loads in wastewater amounts and/or the amount of organic matter in the industry catchment area belonging to each WWTP.

Due to the Water Environmental Action Plan, a lot of information regarding wastewater effluent quality parameters are quantified and published by the Danish Environmental Protection Agency. The degree of information regarding specific treatment processes at the WWTPs does not allow for higher tier process-specific calculations of emissions of CH_4 from the Danish WWTPs. This would require a characterisation of sub-processes at the individual types of WWTPs as well as a characterisation of the individual types of sludge from different industry categories.

2.1 Summary of the Methodology and Results

No country-specific methodologies have so far been developed for estimating CH_4 emissions from wastewater handling in Denmark. The emission of methane from wastewater handling is calculated according to the IPCC GL (IPPC, 1996) and IPCC GPG (IPPC, 2000).

Basically the IPCC defines the net methane emission as the gross emission minus the amount of methane recovered, flared or used for energy production:

Eq. 1 Net Emission = Gross Emission – Methane Recovery

The IPCC check method, which allows for calculation of the gross emission of methane from domestic wastewater, should be used if 1) no well-documented national method is available and 2) no data on wastewater source characterisation are available. The check method equation for calculation the gross methane emission is:

Eq. 2 $WM=P\times D\times SBF\times EF\times FTA\times 365\times 10^{-9}$

where WM is the annual CH_4 emission from domestic wastewater [Gg], P is the population number, D is a measure of the organic load given in units Biological Oxygen Demand [g BOD/person/day], SBF is the fraction of BOD that readily settles (defaults value of 0.5), EF is the emission factor (default value of 0.6 g CH_4/g BOD) and FTA is the fraction of sludge that degrades anaerobically (default value of 0.8). The check method is used as reference and for comparison purposes (cf. section 2.2).

If data is available the IPCC methodology applying country-specific parameters should be used. The Danish EPA publishes data statistics from municipal and private WWTPs each year which includes an overview of the influent load of wastewater at Danish WWTPs, treatment categories and processes, effluent quality parameters and sludge treatment processes at national level (DEPA 1989, 1999, 2001, 2003, 2004, Wastewater from municipal and private wastewater treatment plants). The IPCC methodology has been applied with country-specific parameters where these were available. The default methodology is based on equation 1, where the gross emission equals the total organic waste (TOW) times an emission factor (EF):

Eq. 3 Net Emission = (TOW×EF) – Methane Recovery

The emission factor (EF) is defined as:

Eq. 4 EF = Bo × weighted average MCF

Bo is the maximum methane producing capacity (kg CH_4/kg BOD or kg CH_4/kg COD), the default value of Bo is 0.25 kg CH_4/kg COD and 0.6 kg CH_4/kg BOD, respectively, adopting a verified conversion factor of 2.5 (IPCC, 2000). The weighted average MCF is an estimate of the fraction of BOD that will ultimately degrade anaerobically. The weighted average MCF may be derived from subfractions of the wastewater treated by individual treatment processes. Such data are not available for Denmark, but the fraction of sludge treated anaerobically is registered and known from national statistics. In accordance with the IPCC, the weighted average of MCF is set equal to the fraction of sludge treated anaerobically.

The default IPCC method for calculation of the activity data, i.e. TOW, used for deriving at the gross methane emission is:

Eq. 5 $$TOW = P \times D_{dom}$$

where TOW given in [kg BOD/yr] equals the population density, P, given in [1000 persons] multiplied by the degradable organic component, D_{dom}, given in [kg BOD/1000 persons/yr].

TOW was calculated based on the default method in eq. 5 and adjusted to include the contribution from industry to TOW. Data was compared to national data on the total organic degradable waste (BOD) as shown in Table 6 and 7.

Country-specific emission factors have been derived according to eq. 4 (IPCC, page 5.16, Eq. 5.7). National statistics on the fraction of wastewater sludge (in wet weight) treated anaerobically have been used as a measure of the Methane Conversion Factor (MCF), assuming that the treatment is 100% anaerobic. The MCF was multiplied by the default value of 0.6 kg CH_4/kg BOD to arrive at EF. A representative value of 0.15 kg CH_4/kg BOD was obtained for the Danish WWTPs.

From the default TOW data up-scaled according to the industrial contribution to TOW and the national statistics data on TOW, the gross emission of methane was estimated. Simple regression based on the country-specific gross emission data was used for data gap filling (cf. section 2.3.2).

No methodology for calculating the actual recovery of methane is given in the IPCC guideline. The national statistics on the amount of sludge used for biogas production have been used to derive the amount of recovered methane. In addition the theoretical amount of methane that could have been produced from the sludge used for combustion and reuse including combustion (cf. Table 10) have been calculated. The fractions that are used for biogas, combustion or reuse including combustion include methane potentials that are either recovered or emitted as CO_2. The amount of biogas and combusted methane potential is subtracted from the gross methane emission to arrive at the actual amount of emitted methane, i.e. the net emission of methane.

Based on the available data on the wastewater treatment system, it has, as mentioned above, not been possible to disaggregate data into individual MCFs for the individual process steps at the WWTPs. Of the total influent load of organic wastewater at the Danish WWTPs, the separated sludge has different final disposal categories, which have been registered. However, the “left over” methane potential of the sludge at the stage of final disposal categories registered by the Danish Environmental Protection Agency is not known. On the other hand, these data are the only data available for calculating the amount of recovered and not emitted methane. An EF value for the sludge disposal category biogas has been used to calculate the recovered and not emitted methane potential. The amount of methane not emitted or recovered was estimated as:

Eq. 6 $$CH_{4,\text{ not emitted}} = EF_{biogas} \times M_{\text{not emitted}}$$

The IPCC background paper (2003) estimates the maximum methane producing capacity to be 200 kg CH_4 / tonne raw dry solids (IPCC, 2003), which is also the emission factor (EF), as the methane conversion factor (MCF) is equal to unity for the biogas process ($EF = B_o \times MCF$). Data on the methane producing capacity of dry weight sludge at the Danish WWTPs used for biogas production was used together with national statistics on final disposal categories covering recovered or not emitted methane potentials (cf. section 2.3.3).

2.2 The Check Method (IPCC GPG 2000)

The IPCC GPG (2000) provides a check method for calculating the CH_4 emission from domestic wastewater. The check method is based on default values (cf. Box 5.1 in IPCC GPG, 2000), where the only input parameter is the population of the country. Results are provided in Table 4.

Table 4. Annual CH_4 emissions based on the check method (IPCC, 2000).

Year	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003
Population (1000) *	5140	5153	5170	5188	5208	5228	5248	5268	5287	5305	5322	5338	5351	5383
Total organic degradable waste (tonnes BOD/year)	112566	112851	113223	113617	114055	114493	114931	115369	115785	116180	116552	116902	117187	117897
CH4 emissions (Gg)**	27.0	27.1	27.2	27.3	27.4	27.5	27.6	27.7	27.8	27.9	28.0	28.1	28.1	28.3

* Source: Statistics Denmark

**$TOW_{default\ national}$=60 g BOD/person/day × 365 days/yr × P

The organic load used in the check method is based on domestic wastewater only, whereas there is a significant additional BOD load from the industry at the Danish WWTPs (cf. Table 3). Therefore, the BOD parameter is indicative of an underestimation of the CH_4 emission. On the other hand, the default value for the fraction of BOD that degrades anaerobically is 0.8, which is too high according to information from national statistics (cf. Table 5). Methane recovery is not included in the check method.

2.3 The IPCC Method (IPCC GPG 2000)

The CH_4 emission is defined as the total organic waste multiplied by a proper emission factor and then the CH_4 that is recovered have to be subtracted. Data on wastewater influent sources are not available other than the fact that there is not only domestic, but also industrial wastewater in the influent load at Danish WWTPs (cf. Table 3). Therefore there will be no disaggregation into domestic and industrial emissions of the national level of emission calculation. In the following sections, the parameters used for calculating the gross emission and recovered or not emitted methane potential are derived.

2.3.1 Activity data and EF for calculation of the gross emission

Estimation of the EF

It is not possible to find data regarding the maximum CH_4 producing capacity of specific types of wastewater or sludge types, so the default value, given in the IPCC GPG, of 0.6 kg CH_4/kg BOD is used. The emission factor is found by multiplying the maximum methane producing capacity (B_o) with the fraction of BOD that will ultimately degrade anaerobically, i.e. the methane conversion factor (MCF).

The fraction of sludge (in dry weight (dw) or wet weight (ww)) treated anaerobically is used as an estimate of the "fraction of BOD that will ultimately degrade anaerobically". This fraction, shown in Table 5, is set equal to MCF. By doing so it is assumed that all of the sludge treated anaerobically is treated 100 % anaerobically, i.e. no weighted MCF is calculated. The per cent sludge that is treated biological (anaerobically or aerobically) and by chemical stabilisation methods are given in Table 5.

Table 5. Stabilisation of sludge by different methods in tonnes dry weight (dw) and wet weight (ww), respectively (DEPA 1989, 1999, 2001, 2003, 2004, Wastewater from municipal and private wastewater treatment plants).

		Biological		Chemical		EF (IPCC 1996) [kg CH_4 / kg BOD]*
Year	Units	Anaerobic	Aerobic	Other	total	
1987	Sludge amount in tonnes dw	52401	24364	48760	125525	
1997		65368	66086	19705	151159	
1999		65268	70854	19499	155621	
2000		68047	69178	21677	158902	
2001		70992	68386	18638	158016	
2002		63500	58450	18071	140021	
1987	Sludge amount in % of total dw	41.7	19.4	38.9	100	0.25
1995		32	41	27	100	0.19
1996		32.7	41	26.3	100	0.20
1997		43.2	43.7	13.1	100	0.26
1999		41.9	45.5	12.5	100	0.25
2000		42.8	43.5	13.7	100	0.26
2001		45	43.3	11.7	100	0.27
2002		45	42	13	100	0.27
1997	Sludge amount in tonnes ww	363055	648686	149028	1160769	
1999		336654	829349	271949	1437952	
2000		459600	1110746	321427	1891773	
2001		494655	1217135	330229	2042019	
2002		262855	827703	279911	1370469	
1997	Sludge amount in % of total ww	31.3	55.9	12.8	100	0.19
1999		23.4	57.7	18.9	100	0.14
2000		24.3	58.7	17.0	100	0.15
2001		24.2	59.6	16.2	100	0.15
2002		19.2	60.4	20.4	100	0.12

*EF=Bo*MCF, where MCF equals the per cent amount of sludge treated anaerobically divided by 100 and Bo = 0.6 kg CH_4/kg BOD

For comparison both the emissions factors based on wet weight and dry weight are given in Table 5. The emission factor calculated from the dry weight fractions is fairly constant from year 1997 to 2002. It seems reasonable to assume a constant emission factor of 0.26 kg CH_4 / kg BOD based on the dry weight fraction of sludge treated anaerobically and an emission factor of 0.15 kg CH_4 / kg BOD based on the wet weight fraction of sludge treated anaerobically. The emission factor based on wet weight is used for calculating the gross CH_4 emission since it seems the most appropriate to use when combined with BOD data in the emission calculation procedure.

The uncertainty in the fraction of wastewater treated anaerobically is calculated as the spread of the average amount of sludge treated anaerobically divided by the average of amount of sludge treated anaerobically multiplied by 100%. Both the anaerobic fraction data based on wet and dry weight are included. The uncertainty is estimated to be 28%.

Estimation of the activity data – the total organic degradable component

The total organic waste in kg BOD/year based on the country-specific data is given in Table 6. Activity data on influent BOD data are needed in the unit tonnes BOD /year, which is obtained by using total influent amount of water per year multiplied by the measured BOD in the inlet wastewater given in the second row of Table 6 (DEPA 1994, 1996, 1997, 1998, 1999, 2000, 2001, 2002, 2003, 2004, Point sources).

Table 6. Total degradable organic waste (TOW) calculated by use of country-specific data.

year	1993	1999	2000	2001	2002	2003
BOD (mg/L)	129.6*	160	175	203	189	300
Influent water (million m^3 / year)	-	825	825	720	809	611
TOW (tonnes BOD/year)	129600	132000	144375	146160	152497	159858
TOW (tonnes BOD/year)**		148500	138600	142560	159858	160571

*BOD for the year 1993 is given in 1000 tonnes, whereas the amount of influent water is not given (DEPA 1994, Point sources).
** Calculated from country-specific COD data by use of BOD=COD/2.5.

The total organic waste in kg BOD/year based on the default method, is calculated for comparison and regression purposes. The total organic waste in kg BOD/year based on the IPCC default method is given in Table 7. The default region-specific TOW value is 18250 kg/BOD/1000 persons/yr (cf. IPCC, 1996, Table 6.5) for Europe. The total organic degradable waste is estimated by multiplying the default value by the population number (Statistics Denmark). Furthermore, per cent contribution from the industry to the Danish WWTPs is calculated in PEs, which allows for the default TOW data to be up-scaled by a factor corresponding to the "missing" industrial contribution to the influent load TOW.

Table 7. Total degradable organic waste (TOW) calculated by use of the IPCC default BOD value for European countries and corrected for the industrial influent load of degradable organic waste.

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003
Population-Estimates (1000)	5140	5153	5170	5188	5208	5228	5248	5268	5287	5305	5322	5338	5351.0	5383
A. TOW (tonnes BOD/year), default BOD IPCC	93805	94042	94353	94681	95046	95411	95776	96141	96488	96816	97127	97419	97656	98247
B. Inlet BOD contribution from the industry (%)*	2.5	2.5	2.5	5.0	15.5	23.9	32.3	40.7	48	41	42	38	38	37
C. TOW (tonnes BOD/year), default BOD IPCC corrected for industrial contribution**	96150	96393	96711	99415	109778	118214	126712	135270	142802	136511	137920	134438	134765	134599

**C=A+(A×(B/100))
*For the year 1990 to 1992 the industrial influent load is set to an average of 2.5 %. From the year 1993 to 1997 the percentages are assumed to increase continuous, registered data given in Table 3.

By comparing the estimated TOW by use of country-specific data (cf. Table 6) and TOW by use of default European data on the inlet BOD (cf. Table 7), it can be observed that the default parameter method underestimates the TOW. This underestimation becomes less pronounced by increasing the TOW data according to the industrial contribution to the TOW (last row in Table 7).

The default methodology, including corrections for industrial contribution to TOW, underestimates the country-specific TOW data to a lesser degree, and the difference may reflect an increased thickness of industrial wastewater, i.e. an increased concentration of dissolved organic matter in the industrial influent wastewater compared to household wastewater.

The uncertainty is calculated as the standard deviation on TOW data divided by the mean TOW value multiplied by 100% for each year (Table 6 and last row of Table 7). The highest uncertainty value is 26 %.

The country-specific TOW (Table 6) is multiplied with the emission factor of 0.15 kg CH_4/kg BOD for calculating the gross emission of CH_4 (cf. Table 8, column 4 and 5).

2.3.2 Gross CH_4 emission

Due to uncertainty in the country-specific TOW data and for the purpose of extrapolation of data needed outside the scope of the NIR, it was decided to develop a regression concept based on a consistent methodology through all the years. For this purpose a comparison between country-specific and default IPCC methodology time trends was performed taken into account the contribution from industry.

Table 8. The gross-emission data based on raw (original) TOW data

Year	Contribution from industrial inlet BOD %	Population-Estimates (1000)	Gross CH_4 emission (Gg), country-specific data (based on BOD data)*	Gross CH_4 emission (Gg), country-specific data (based on COD data)*	Gross CH_4 emission (Gg), country-specific data (based on BOD data)*, household only	Gross CH_4 emission (Gg), country-specific data (based on COD data)*, household only	Gross CH_4 emission (Gg), National default TOW data
1990	2.5	5140					14.0
1991	2.5	5153					14.1
1992	2.5	5170					14.1
1993	5	5188	19.4		18.5		14.2
1994	15.5	5208					14.2
1995	23.9	5228					14.3
1996	32.3	5248					14.3
1997	40.7	5268					14.4
1998	48	5287					14.4
1999	41	5305	19.8	22.3	11.7	13.1	14.5
2000	42	5322	21.7	20.8	12.6	12.1	14.5
2001	38	5338	21.9	21.4	15.6	13.3	14.6
2002	40.3	5351	22.9	24.0	17.1	14.3	14.6
2003	42	5383	24.0	24.1	15.1	15.2	14.7

*When based on measured COD data, BOD=COD/2.5

The uncertainty on BOD data are judged higher than for COD data due to differences in methodologies of measurements from year to year caused by reporting varying BOD data measured as modified, unmodified and sometimes reported as the average of the two measurement methods. Therefore, it was decided to use the regression line based on the COD derived gross emission data as shown in Figure 1 below.

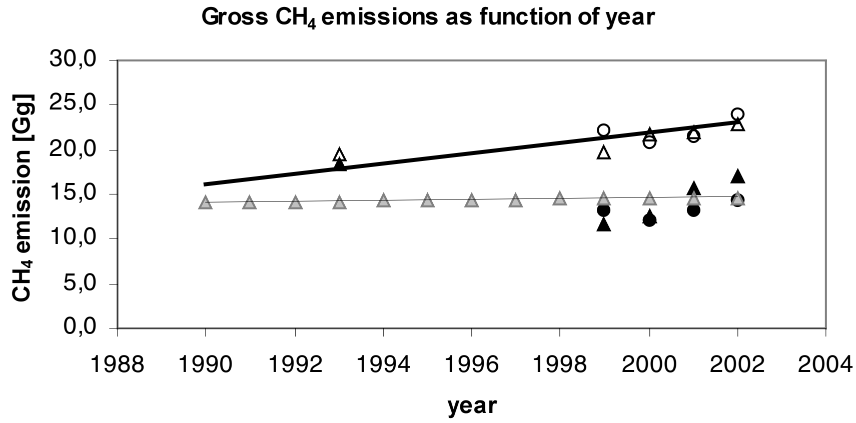

Figure 1. The open triangles and circles represent the country-specific gross emission derived from measured BOD and COD values, respectively. The grey triangles represent the gross emission based on the IPCC GL default value for Europe of 18250 kg BOD/1000 persons/yr. The black triangles and circles represent the country-specific gross emission derived from measured BOD and COD values, respectively, where the industrial contribution to the influent TOW has been subtracted. The data point from 1993 indicates that the industrial contribution to the TOW at the WWTPs may have been underestimated. The data point from 2003 was not available at the time of NIR preparation and has not been included in the regression used for interpolation (cf. Table 9).

As observed from the emission based on measured BOD data in 1993, where the industrial influent load is registered to be 0-5 % of the total influent, the default methodology underestimates the methane emission.

Data gap-filling and results

For data gap filling backward it is assumed reasonable to use the interpolated linear regression equation. For future trend analyses it may be considered to use a correction for non-linearity dependent on the national statistics on TOW. At this stage, the gross emission estimates of methane are based on an average of the above regression equation and the default IPCC methodology. A constant contribution from the industry of 0.417, which is an average of the contribution from 1997 and forward where the industrial contribution seems to have stabilised, was used. The results of the regression approach and the adjusted default IPPC approach is given in Table 9.

Table 9. Gross emissions of methane (Gg) by the corrected IPCC method, the country-specific method and average of the two methods.

Gross emission [Gg]	Population (1000)	Corrected default IPCC methodology derived *	Regression based on country-specific Gross emissions	Average
1990	5140	20.0	16.1	18.0
1991	5153	20.0	16.7	18.3
1992	5170	20.1	17.2	18.7
1993	5188	20.2	17.8	19.0
1994	5208	20.2	18.4	19.3
1995	5228	20.3	18.9	19.6
1996	5248	20.4	19.5	20.0
1997	5268	20.5	20.1	20.3
1998	5287	20.5	20.7	20.6
1999	5305	20.6	21.2	20.9
2000	5322	20.7	21.8	21.2
2001	5338	20.7	22.4	21.6
2002	5351	20.8	22.9	21.9
2003	5383	20.9	23.5	22.2

*using an average industrial input of 0.417 for all years.

The use of a constant industrial influent load of 0.417 in spite of the known low industrial influent load of BOD in the earliest years (cf. Table 3) was done to fit the available data from 1993 better (cf. Table 8 and 9). Furthermore, due to the fact that the regression based on COD-data indicated a higher industrial influent load than registered in 1993 in addition to the gross emission point derived from BOD-data (cf. Figure 1 and 2). An average between the corrected IPCC default method and the country-specific regression was considered the most accurate approach for interpolation of the gross emission calculated from national registered TOW data.

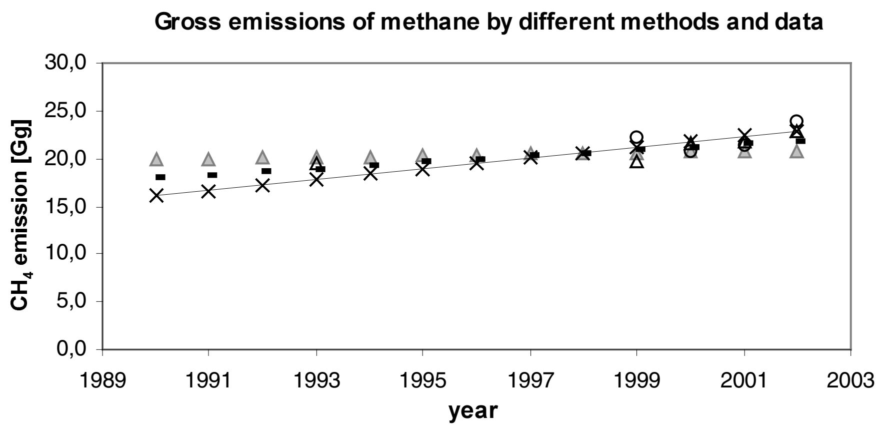

Figure 2. The open triangles and circles represent the country-specific gross emission derived from measured BOD and COD values, respectively. The grey triangles represent the default derived gross emission based on the IPCC GL default value for Europe of 18250 kg BOD/1000 persons/yr; corrected by increasing the degradable organic component 41.4% due to industry. The crosses represent the country-specific gross emission regression equation derived from the measured COD values. The average reported values are presented by the dots.

As mentioned above it is at this point not possible to quantify a non-linear trend curve for the gross emission, and therefore it seems most reasonable to use the average value of the two methods.

The average values, given in the last column of Table 9, have been reported as the result on gross CH_4 emission for the NIR 2005 report (NERI, 2005).

To arrive at the net CH_4 emission the amount of methane recovery has to be subtracted. The theoretical amount of CH_4 that is not emitted, i.e. recovered and flared or used for energy should be subtracted from the gross emission to arrive at the actual or net emission of methane (IPCC 1996, 2000). The recovered or not emitted amount of methane is presented in section 2.3.3, while the net emission is given in section 2.3.4 on final results.

2.3.3 Activity data and EF for calculation of the recovered or non emitted methane

As described above, the amount of the methane that is reused as in e.g. biogas production should be subtracted from the gross-emission. Furthermore, the amount of methane potential that is combusted must be subtracted. Therefore the theoretical methane production from the final disposal categories: biogas, internal and external combustion and other (covering the amount of sludge treated by new/alternative methods by purpose of reuse) needs to be calculated and subtracted from the gross emission data. The category "other" is assumed to cover mainly sludge combusted, i.e. reduced to inorganic material reused in the processing of sandblasting products (DEPA 1989, 1999, 2001, 2003, 2004, Wastewater from municipal and private wastewater treatment plants).

Estimation activity data – amounts of sludge

The Danish EPA provided data on the final disposal of sludge. A collection of data available from different years are given in Table 10 which includes the categories biogas and combustion, i.e. categories where the methane producing capacity of the sludge is burned up or collected and used for energy purposes.

Table 10. Sludge in tonnes dry weight (dw) according to disposal categories of relevance to CH_4 recovery (DEPA 1989, 1999, 2001, 2003, 2004, Wastewater from municipal and private wastewater treatment plants).

Unit	Year	Combustion internal	Combustion external	Biogas	Other*
Per cent of total final amount of sludge	1987		24.6		18.5
	1997	15.5	6.2	1.5	0.8
	1999	7.4	14.8	1.9	9.1
	2000	15.0	9.2	1.6	14.4
	2001	14.8	6.3	1.0	11.3
	2002	11.4	4.4	0.9	10.0
Waste strategy goals	2008		20*		25*
Total tonnes dw	1987	23330	11665		7667
	1997	23500	9340	2338	1211
	1999	23008	9845	2972	14140
	2000	11734	23591	*2476*	22856
	2001	23653	14543	1588	17883
	2002	15932	6120	1262	13989
Waste strategy goals	2008	20667***	10333***		38750

*the category "other" represents sludge which is combusted in cement furnaces and is used in further combusting processes for the production of sandblasting products.
**Target line according to the "Waste Strategy 2004-2008" (Waste Strategy, 2003) set up by the Danish Government.
***Approximate goal divided into an average of 2/3 internal and 1/3 external combustion

The methane producing capacity of the final disposal categories

The fraction of the gross CH_4 emission, not emitted in reality, is calculated as the dry weight of the category biogas multiplied by the EF of 200 kg CH_4 / tonne raw dry solids (IPCC, 2000). For comparison, the biogas yield, i.e. EF, is given to be within 250 to 350 m^3/tonne organic solids for sewage sludge in a report on biogas systems (IEA Bioenergy). The density of methane gas is 0.715 kg/m^3 at standard conditions, which give an average EF of 214.5 kg CH_4 / tonne raw dry solids.

The IPCC GPG value of 200 kg CH_4/ tonne raw dry solids is used for calculating the amount of recovered or not emitted amount of methane. This EF value is probably too high as the final disposal amounts have been through several treatment processes at the WWTPs and therefore can not be regarded as "raw dry solids".

The calculated theoretical CH_4 not emitted, based on registered data as well as by interpolation, are given in Table 11. Compared with the uncertainty level in the calculations in general it seems reasonable to fill out data gaps by interpolation based on simple linear regression (cf. Figure 3). The availability and results of gap filling by interpolation is shown in Table 11.

Table 11. Theoretical CH_4 amount not emitted to the atmosphere [Gg]

	Regression by interpolation				Country-specific data			
	CH_4 potential, external combustion	CH_4 potential, internal combustion	CH_4 potential internal combusted and reused for production of sand-blasting products	CH_4 potential used for production of biogas	CH_4 potential , external combustion	CH_4 potential, internal combustion	CH_4 potential internal combusted and reused for production of sand-blasting products	CH_4 potential used for production of biogas
1987	2.34	4.91	0.76	0.17	2.33	4.67	1.53	0.00*
1990	2.39	4.67	1.20	0.24				
1991	2.41	4.60	1.34	0.27				
1992	2.43	4.52	1.49	0.30				
1993	2.44	4.44	1.63	0.32				
1994	2.46	4.36	1.78	0.35				
1995	2.47	4.29	1.92	0.38				
1996	2.49	4.21	2.07	0.40				
1997	2.51	4.13	2.21	0.43	1.87	4.70	0.24	0.48
1998	2.52	4.05	2.36	0.45				
1999	2.54	3.98	2.50	0.48	1.97	4.60	2.83	0.62
2000	2.56	3.90	2.65	0.51	4.72	2.35	4.57	0.51
2001	2.57	3.82	2.79	0.53	2.91	4.73	3.58	0.33
2002	2.59	3.75	2.94	0.56	1.22	3.19	2.80	0.26
2003	2.61	3.67	3.08	0.58				
2008**	2.07	4.13	7.75					

*The biogas production is assumed zero in 1987.

** Data given for support of extrapolation to 2030; cf. section 4 and below.

Due to missing data linear regression was performed based on the country-specific CH_4 potentials, given in the last four columns of Table 11: non CH_4 emitted from 1990 to 2002.

The variation in the time trends is high as illustrated in Figure 3. No uncertainty on the regression lines has been calculated. At this stage the uncertainty is estimated for each year, and provided as the maximum or average uncertainty estimated. Based on the percent distance between country-specific data to regression line, an estimate of the average uncertainty is around 30%. The maximal uncertainty estimated for internal combustion is around 25%, while the uncertainty for external combustion, combustion for production of sandblasting product and biogas is around 70%. The variations/uncertainties are originating from the activity data given in Table 13 (cf. section 2.3.5 Uncertainty estimates and 5 Further work).

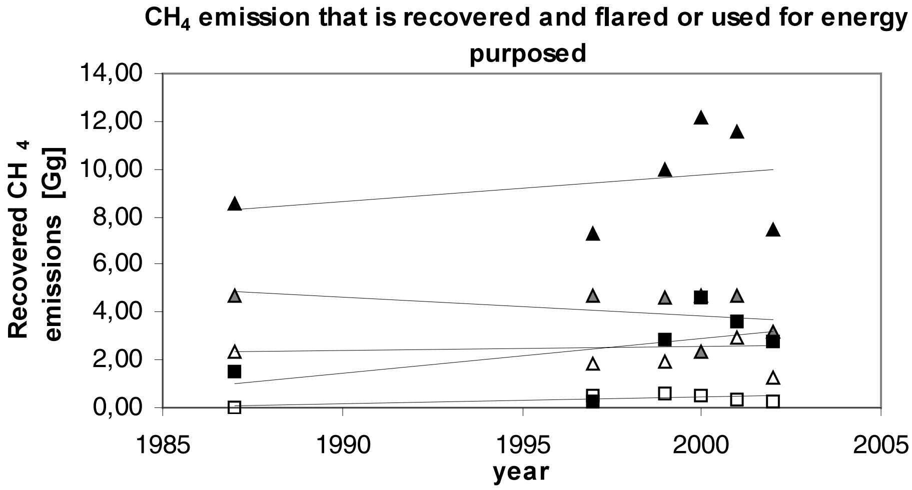

Figure 3. From top to bottom based on 1987 data points: The upper regression line represents the total methane potential not emitted. The grey triangles and decreasing regression line represents the trend in internal combusting. The open triangles and regression line of insignificant slope represents external combustion. The black quadrants and increasing regression line represents the methane potential internal combusted and reused for production of sandblasting products (corresponds to the category "Other" in Table 10). Lastly the open quadrants and regression line with no or slightly positive slope represents the methane potential used for biogas production.

As visualised by Figure 3, the external combustion seems to be more or less constant, and the estimated goal of the waste strategy for 2008 was reached some years ago (cf. Table 10 and 11). The internal combustion is slightly decreasing and the overall amount of combusted sludge is below the 2008 goal of 20% (cf. Table 10). The amount of sludge reused in sandblasting products is increasing which results in an increased combusted methane potential. Lastly, the biogas production reached its maximum in 1999 (cf. Table 11) after which it has been decreasing.

Average emission data are based on regression estimates and country-specific calculated data where available. Regression estimates, based on available data in the last four columns of Table 11, are used where no country-specific data are available (cf. Table12).

2.3.4 Final Results and net emission of CH_4

The net emission of methane is calculated as the gross emission minus the amount of methane recovered and flared or used for energy production. The recovered or not emitted methane, is calculated as the amount of sludge used for biogas (and thus included in the CO_2-emission from energy production) or combusted (and thus included in the calculation of CO_2-emission from combustion processes). A summary of the final results on the emission of methane from 1990 to 2003 is given in Table12.

Table 12. CH_4 emissions recovered and flared or used for energy production, total methane potential not emitted, Gross and net emission data [Gg].

Year	CH_4, external combustion	CH_4, internal combustion	CH_4, sandblasting products	CH_4, biogas	CH_4 potential not emitted	CH_4, gross	CH_4, net
1990	2.39	4.67	1.20	0.24	8.51	18.03	9.52
1991	2.41	4.60	1.34	0.27	8.62	18.34	9.72
1992	2.43	4.52	1.49	0.30	8.73	18.66	9.93
1993	2.44	4.44	1.63	0.32	8.84	18.98	10.14
1994	2.46	4.36	1.78	0.35	8.95	19.30	10.35
1995	2.47	4.29	1.92	0.38	9.06	19.63	10.57
1996	2.49	4.21	2.07	0.40	9.17	19.95	10.78
1997	2.19	4.42	1.23	0.46	8.29	20.28	11.99
1998	2.52	4.05	2.36	0.45	9.39	20.60	11.21
1999	2.25	4.29	2.67	0.55	9.76	20.92	11.16
2000	3.64	3.12	3.61	0.51	10.88	21.24	10.36
2001	2.74	4.28	3.19	0.43	10.63	21.55	10.92
2002	1.91	3.47	2.87	0.41	8.65	21.86	13.21
2003	2.61	3.67	3.08	0.58	9.94	21.39	11.45

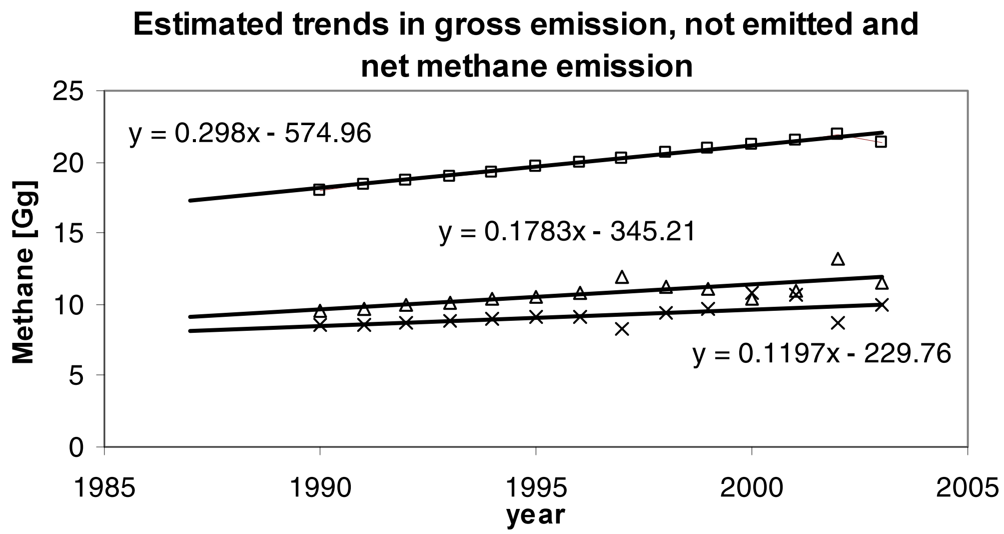

Figure 4. Estimated time trends for the gross emission of methane (open squares), not emitted; i.e. sum of column 2 to 5 in Table 4.12 (crosses) and net emission (open triangles).

Based on the above estimated time trends, the net emission of methane from this source from source category 6B increases 0.2 Gg per year, which is a result of an increase in the gross emission of on average 0.3 Gg per year, and a minor increase in the amount of methane potential not emitted of 0.1 Gg per year. The increasing net emission is a result of the industrial influent load of TOW, which has increased from 0-5% in the year 1984 to 1993 to an average contribution of 42% in the years 1997 to 2003. In addition, technical upgrades of the WWTPs, with the goal of reducing the effluent loads of nutrient according to the Water Environment Action Plan, may result in an increased emission from anaerobic treatment processes.

Based on the above figures, on average 50% of the methane potential are combusted throughout the period 1990-2003. The decrease in the internal combustion is accompanied by a parallel increase in the external combustion and combustion processes included in the production and reuse of sludge in sandblasting products.

2.3.5 Uncertainty estimates

Table 13. Uncertainties for main parameters used for calculating the methane emission for wastewater handling.

Parameter	Uncertainty	Note	Emission type
TOW (U_{TOW})	±30%	Default IPCC value (IPCC, 2000); maximum uncertainty in the country-specific data is 28%	Gross CH_4 emission
Maximum methane producing Capacity (U_{Bo})	±30%	Default IPCC value (IPCC, 2000)	
Fraction treated anaerobically, i.e. the methane conversion factor (U_{MCF})	±28%	Based on spread in registered data given in Table 5 including fraction treated anaerobic based on both wet weigh and dry weight to arrive at maximum uncertainty	
Methane potential (U_{pot})	±50%	Judged based on IPCC GL background paper (IPCC, 2003) thereby taking into account the inability to arrive at a weighted MCF	Not emitted CH_4
Final disposal category data (U_{disp})	±30%	Judged to be equal to the uncertainty in influent loads of organic matter	

The uncertainty (IPCC, 2000) in estimating the gross emission of CH_4, U_{gross} is calculated as:

Eq. 7 $$U_{gross} = \sqrt{U_{TOW}^2 + U_{Bo}^2 + U_{MCF}^2}$$

derived from equation 3 and 4 and equals 50,8%

The uncertainty in estimating the recovered or not emitted CH_4, $U_{not\ emitted}$, is calculated as:

Eq. 8 $$U_{notemitted} = \sqrt{U_{disp}^2 + U_{pot}^2}$$

and equals 58,3%.

The uncertainty in the net emission of methane, U_{net}, is derived based on equation 3, and is calculated as :

Eq. 9. $$U_{net} = \frac{\sqrt{(U_{gross} \cdot x_{gross})^2 + (U_{notemitted} \cdot x_{notemitted})^2}}{x_{gross} + x_{notemitted}}$$

where the uncertainty quantities x_{gross} and $x_{notemitted}$ equals the average yearly fraction of dry weight sludge treated anaerobically (given in Table 5) and sum of the final categories resulting in "not emitted methane potentials" (given in Table 10). The resulting uncertainty on the net emission of methane is calculated to be approximately 40%.

The methane potential not emitted may be overestimated due to the fact that a portion of the MCF may not be equal to one for the final disposal categories.

At this point information regarding industrial on-site wastewater treatment processes are not available at a level of data that allows for calculation of the on-site industrial contribution to CH_4 emissions. The degree of how many industries covered in the emission estimate are therefore dependent on the amount of industrial wastewater connected to the municipal sewer system. Any emissions from pre-treatment on-site are not covered at this stage of method development.

3 Emission of N_2O from wastewater handling

3.1 Direct emissions from wastewater treatment processes

Emissions of nitrous oxide from WWTPs are not accounted for in the IPCC methodology. However, nitrous oxide (N_2O) may be generated by nitrification and denitrification processes during biological treatment of the wastewater. About 90 % of the Danish wastewater is treated at centralised WWTPs with advanced treatment processes including biological treatment. N_2O may be generated both under aerobic and anaerobic conditions. Starting material in the influent may be urea, ammonia and proteins which are converted to nitrate by nitrification (aerobic process). Denitrification is an anaerobic biological conversion of nitrate into dinitrogen. N_2O is an intermediate of both processes. Danish investigations indicate that N_2O is formed during aeration steps in the sludge treatments process as well as during anaerobic treatments, the former contributing the most to the N_2O emissions during sludge treatment (Gejlsbjerg et al., 1999).

A German estimate of the emission factor for direct emission of N_2O from wastewater treatment processes, not including industrial influents, is 7 g N_2O / person per year (Schön et al. 1993). In a Dutch investigation, the emission factor is suggested to be 3.2 g N_2O / person per year (Czepiel et al., 1999*)*. Similar to the German estimated EF, this emission factor does not account for co-discharges of industrial nitrogen. To take into account the contribution from non-household nitrogen, the difference between residential (decentralised) WWPTs and the centralised loading averages of influent nitrogen as suggested in Scheehle and Doorn (Scheehle and Doorn, 1997). As the decentralised WWTPs are assumed to have no influent wastewater load from the industry, whereas the centralised WWTPs receives most of the industrial wastewater, the difference in average influent loads may be used to derive an estimate of the fraction of industrial nitrogen influent load. The estimated fraction of industrial influent nitrogen load is used in combination with the Dutch emission factor to arrive at an EF corrected for industrial influent nitrogen load. In the United States a correction factor of 1.25 was obtained resulting in an emission factor of (1.25*3.2) 4 g N_2O / person per year (Scheehle and Doorn, 1997) including the contribution from industrial nitrogen influent load. An analogue approach has been used for calculating the Danish direct emission of N_2O upon wastewater treatment.

Key data on nitrogen influent load distribution according to small, medium and large WWTPs are available from the Danish Water and Wastewater Association (DANVA, 2001). The data are based 20-25 WWTPs located in five big city areas in Denmark and are reported for the years 1998 to 2001. Based on these data an average factor of 3.52 was calculated as the average influent nitrogen for the large (centralised) WWTPs minus the average influent nitrogen load for the medium (decentralised) WWTPs divided by the average nitrogen load for the medium WWTPs.

Table 14. Correction factors (CF) to adjust the emission factor (EF) to include influent loads of N to WWTPs from industry.

year	WWTP-large [tonne N / year]	WWTP-medium [tonne N/year]	CF	EF [N_2O / person per year]
1987			1	3.2
1998	1081	233	3.64	11.7
1999	1042	220	3.74	12
2000	1016	222	3.58	11.5
2001	894	216	3.14	10.0

The use of this factor, to correct the emission factor based on domestic wastewater only, is based on the assumption that the emission factor is the same for household and industrial wastewater respectively. The correction factor in 1987 is equal to 1 corresponding to zero contribution from industry. Emission factors are equal to CF * 3.2 g N_2O / person per year. The average resulting emission factor for direct emission of N_2O is (3.52*3.2) 11.3 g N_2O / person per year. However, the contribution to the Danish WWTPs from industry has changed from close to zero in 1990 up to an average of 41 % since 1998. Therefore, the per cent industrial wastewater influent loads from 1987 (where it was zero) and the years 1998 to 2001, for which a corrected emission factor can be estimated, was used in a simple regression of % industrial wastewater influent load versus the corrected emission factors. Regression equation 10 was used for estimation of the emission factor for all years 1990-2002.

Eq. 10 $$EF_{N2O.WWTP.direct} = 0.1887 \cdot I + 3.2816$$

where I is the per cent industrial influent load given in Table 15.

The estimated Danish emission factors as function of the increase in industrial influent load in the Danish WWTPs are given in Table 14. The direct emission from wastewater treatment processes are calculated according to the equation:

Eq. 11 $$E_{N_2O,WWTP,direct} = N_{pop} \cdot F_{connected} \cdot EF_{N_2O,WWTP,direct}$$

where N_{pop} is the Danish population number, $F_{connected}$ is the fraction of the Danish population connected to the municipal sewer system (0.9) and $EF_{N2O.WWTP.direct}$ is the emission factors given in Table 14 or calculated from equation 10.

Table 15. Direct emissions from wastewater treatment processes in Danish WWTPs, given in tonnes N_2O.

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003
N_{pop} (1000)	5140	5153	5170	5188	5208	5228	5248	5268	5287	5305	5322	5338	5351	5383
$F_{connected}$	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9
I (% industrial load)	2.5	2.5	2.5	5.0	15.5	23.9	32.3	40.7	48.0	41.0	42.0	38.0	38.0	42.0
$EF_{N2O.WWTP.direct}$	3.8	3.8	3.8	4.2	6.2	7.8	9.4	11.0	12.3	11.0	11.2	10.0	10.4	11.3
$E_{N2O.WWTP.direct}$	17.4	17.4	17.5	19.7	29.1	36.7	44.3	52.0	55.4	57.1	54.8	48.3	50.3	51.7

Original data on the industrial wastewater influent loads (cf. Table 3) given in Table 15 has been judged for the purpose of obtaining data for all years 1990 to 2002. For the year 1990 to 1992 the industrial influent load is set to an average of 2.5 %. From the year 1993 to 1997 the percentages are assumed to increase continuous as shown in Table 15. The Danish emission factors are based on a regression of per cent industrial loads versus the corrected emission factors given in Table 14. The average fraction of industrial nitrogen influent is considered constant from the year 1997 and forward. This is consistent with a fairly constant industrial wastewater influent fraction from 1997 and onwards.

The uncertainty in the EF for direct emission of N_2O from wastewater treatment is judged to be 30% and the uncertainty on the direct emission of N_2O 31% (cf. Table 22).

3.2 Indirect emissions - from sewage effluents

The IPCC default methodology only includes N_2O emissions from human sewage based on annual per capita protein intake. The methodology account for nitrogen intake ("outcome"), i.e. faeces and urine, only and neither the industrial nitrogen input nor non-consumption protein from kitchen, bath and laundry discharges are included. The default methodology used for the 10 per cent of the Danish population not connected to the municipal sewage system is multiplied by a factor 1.75 to account for the fraction of non-consumption nitrogen (Scheehle and Doorn, 1997). For the remaining 90 % of the Danish population national activity data on nitrogen in effluent wastewater are available. These data are used in combination with default methodology for the 10 per cent of the Danish population not connected to the municipal sewer system. The effluent N load is added 10 per cent to account for the WWTPs not included in the statistics (DEPA 1994, 1996, 1997, 1998, 1999, 2000, 2001, 2002, 2003, 2004, Point sources). The formula used for calculation of the emission from effluent WWTP discharges is:

Eq. 12 $$E_{N_2O,WWTP,effluent} = \left[\left(P \cdot F_N \cdot N_{pop} \cdot F_{nc} \cdot F\right) + \left(D_{N,WWTP} + \left(D_{N,WWTP} \cdot 0.1\right)\right)\right] \cdot EF_{N_2O,WWTP,effluent} \cdot \frac{M_{N_2O}}{2 \cdot M_N}$$

where the first part of the equation, i.e. ($P \cdot F_N \cdot N_{pop} \cdot F_{nc} \cdot F$) simply equals effluent data from scattered houses, $D_{not\ connected}$, in the country-specific calculations and:

P is the annual protein per capita consumption per person per year (FAOSTAT data, 2004).

F_N is the fraction of nitrogen in protein. i.e. 0.16 (IPCC, 1996)

N_{pop} is the Danish population number (Statistics Denmark)

F_{nc} is the fraction of the Danish population not connected to the municipal sewer system, i.e. 0.1 (DEPA 1994, 1996, 1997, 1998, 1999, 2000, 2001, 2002, 2003, 2004, Point sources)

F is the fraction of non-consumption protein in domestic wastewater. i.e. 1.75 (Scheehle and Doorn, 1997)

$D_{N.WWTP}$ is the effluent discharged sewage nitrogen load (added ten per cent to account for data not included in the statistics)

$EF_{N2O.WWTP.effluent}$ is the IPCC GL default emission factor of 0.01 kg N_2O-N/kg sewage-N produced (IPCC,1996)

M_{N2O} and M_{N2O} are the mass ratio. i.e. 44/28 to convert the discharged units in mass of total N to emissions in mass N_2O.

3.2.1 Activity data

Data on the nitrogen in effluents are extracted from the Danish Statistical database (Statistics Denmark*)* and point source data reported within the Danish Monitoring programme by the Danish EPA (DEPA 1994, 1996, 1997, 1998, 1999, 2000, 2001, 2002, 2003, 2004, Point sources).

Table 16. Discharges of nitrogen from point sources included in the Danish monitoring programme in tonnes.

*	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003
Separate industrial discharges	n.r.	n.r.	n.r.	2574	2737	2471	1729	1800	1428	863	897	812	752	509
Rainwater conditioned effluent	n.r.	921	882	1025	1207	867	629	800	968	975	762	758	1005	685
Scattered houses, DEPA**	n.r.	n.r.	n.r.	1280	1210	1141	1143	1123	997	972	979	1005	968	957
Effluent from scattered houses, IPCC***	10685	11186	11117	11309	11603	11888	11644	12108	12574	12633	12368	12744	12775	12852
Mariculture and fish farming	n.r.	n.r.	n.r.	1737	1684	1735	1543	1494	1241	1418	2714	1757	1487	1162
Municipal and private WWTPs	16884	15111	13071	10787	10241	8938	6387	4851	5162	5135	4653	4221	4528	3614

*n.r.: not reported

**(DEPA 1994, 1996, 1997, 1998, 1999, 2000, 2001, 2002, 2003, 2004, Point sources)

*** Effluent from scattered houses, IPCC= $P \cdot F_N \cdot N_{pop} \cdot F_{nc} \cdot F$ have not been included in the NIR 2005 as data from the national statistics on effluents from scattered houses are considered more reliable (personal communication with the Danish EPA). The IPCC method including correction for effluents from non-consumption Nitrogen overestimates the effluent N by a factor of ten to twelve.

In Table 17 the separate discharges from industry is given in detail, as these activity data are available from the national statistics (Statistics Denmark*)*. The data allows for the contribution from individual industrial trades to the total N_2O emissions to be assessed (cf. Table 20).

Table 17. Separate industrial discharges of nitrogen divided into tonnes N for individual trades.

	1997	1998	1999	2000	2001	2002
Fishing industry	346	386	133	242	227	228
Fish meal industry	422	276	265	156	80	63
Paper- and cellulose industry	236	102	38	7	4	4
Sugar mills	131	133	125	122	115	114
Waste deposits etc.	164	168	6	171	178	177
Airports	135	98	41	16	29	17
Breweries and Distilleries	-	5	4	19	4	6
Chemicals industry	20	20	57	34	28	37
Enzyme production etc.	210	137	-	-	-	-
Pharmaceutical industry	-	1	1	16	4	15
Dairies etc.	-	7	6	5	15	2
Foodstuff etc.	-	-	-	24	20	9
Deprecating arrangements	-	-	-	11	10	8
Oils refineries etc.	-	-	-	18	32	26
Pesticide industry	20	25	-	-	-	-
Shipyards etc.	-	-	-	0	0	0
Slaughterhouses	-	24	28	26	31	19
Textile factories etc.	-	5	5	4	3	4
Wood industry	-	-	-	25	5	4
Others	116	40	260	5	26	22
Total	1800	1427	969	901	811	755

As seen from Table 17, the Fishing and Fishing Meal industry have the highest effluent loads, while the Paper and Cellulose industry has improved their cleaning of wastewater significantly from 2001 to 2003 and has moved to one of the lowest levels of effluent nitrogen load compared to the remaining trades.

3.2.2 N_2O Emissions

Table 18. Emission of N_2O from effluents based on people not connected to the municipal sewer system in tonnes N_2O/year.

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002
Protein (tonne protein/ cap/year) *	0.074	0.078	0.077	0.078	0.080	0.081	0.079	0.082	0.085	0.085	0.083	0.085	0.085
$E_{N2O.}$ effluent for people not connected to a WWTP **	168	176	175	178	182	187	183	190	198	199	194	200	201

*Source:FAOSTAT data, 2004

**As seen from table 16 the resulting nitrous oxide emissions are overestimated by the IPCC corrected method (cf. fourth row of Table 17). However, by considering that the WWTP reduces the effluent N by 60 to 80% (cf. Table 1), the emission from people not connected to a WTTP would be on average 38% using a reduction of 80%. This number is still too high but comparable to emission from people not connected to a WWTP based on national statistics. In Denmark only a minor fraction of N is expected to contribute to the effluent N as the private households not connected to a WWTP have special treatment plants, e.g. septic tanks or percolation systems with and without drain, which is emptied by sludge-collection vans and included in the wastewater treatment at the national WWTPs. Therefore, the IPCC methodology does not apply to Danish conditions.

Table 19. Emission of N_2O from effluent-recipient nitrogen discharges from point sources given in tonnes according to equation 12.

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002
$E_{N2O.}$ effluent.from separate industry discharges	0	0	0	40	43	39	27	28	22	14	14	13	12
$E_{N2O.}$ rainwater conditioned effluent	0	14	14	16	19	14	10	13	15	15	12	12	16
$E_{N2O.}$ effluent from scattered houses*	0	0	0	20	19	18	18	18	16	15	15	16	15
E_{N2O}. effluent from mariculture and fish farming	0	0	0	27	26	27	24	23	20	22	43	28	23
E_{N2O}. effluent from municipal and private WWTPs	265	237	205	170	161	140	100	76	81	81	73	66	71
E_{N2O}. effluents in total tonnes	265	252	219	273	268	238	180	158	154	147	157	134	137

*(DEPA 1994, 1996, 1997, 1998, 1999, 2000, 2001, 2002, 2003, 2004, Point sources)

Below, the emission originating from effluents from separate industrial discharge (first row in Table 19) is given.

Table 20. Emission of N_2O from separate industry divided into specific trades given in tonnes N_2O.

	1997	1998	1999	2000	2001	2002
Fishing industry	2.58	2.64	0.09	2.69	2.80	2.78
Fish meal industry	-	-	-	0.17	0.16	0.13
Paper- and cellulose industry	2.12	1.54	0.64	0.25	0.46	0.27
Sugar mills	-	0.08	0.06	0.30	0.06	0.09
Waste deposits etc.	0.31	0.31	0.90	0.53	0.44	0.58
Airports	3.3	2.15	-	-	-	-
Breweries and Distilleries	5.44	6.07	2.09	3.80	3.57	3.58
Chemicals Industry	6.63	4.34	4.16	2.45	1.26	0.99
Enzyme production etc.	-	0.02	0.02	0.25	0.06	0.24
Pharmaceutical industry	-	0.11	0.09	0.08	0.24	0.03
Dairies etc.	-	-	-	0.38	0.31	0.14
Foodstuff etc.	1.82	0.63	4.09	0.08	0.41	0.35
Deprecating arrangements	3.71	1.60	0.60	0.11	0.06	0.06
Oils refineries etc.	-	-	-	0.28	0.50	0.41
Pesticide Industry	0.31	0.39	-	-	-	-
Shipyards etc.	-	-	-	-	-	-
Slaughterhouses	-	0.38	0.44	0.41	0.49	0.30
Textile factories etc.	2.06	2.09	1.96	1.92	1.81	1.79
Wood industry	-	0.08	0.08	0.06	0.05	0.06
Others	-	-	-	0.39	0.08	0.06
Total	28	22	15	14	13	12

3.3 Final results on direct and indirect N_2O emissions

The emission of N_2O by wastewater handling is calculated as a sum of contribution from wastewater treatment processes at the WWTPs and sewage effluents. Emissions from effluent wastewater are derived from registered activity data effluent wastewater nitrogen loads from point sources as given in Table 21, which includes a summary of the final results.

Table 21. N_2O emission from: effluents from point sources, wastewater treatment processes and in total tonnes.

Year	N_2O, effluent from separate industry discharges	N_2O, rainwater conditioned effluent	N_2O, effluent from scattered houses	N_2O, effluent from mariculture and fish farming	N_2O, effluent from municipal and private WWTPs	N_2O, effluents in total tonnes	N_2O,WWTP, direct	N_2O,WWTP, direct and indirect
1990	0	0	0	0	265	265	17	283
1991	0	14	0	0	237	252	17	269
1992	0	14	0	0	205	219	17	237
1993	40	16	20	27	170	273	20	293
1994	43	19	19	26	161	268	29	297
1995	39	14	18	27	140	238	37	275
1996	27	10	18	24	100	180	44	224
1997	28	13	18	23	76	158	52	210
1998	22	15	16	20	81	154	59	213
1999	14	15	15	22	81	147	53	200
2000	14	12	15	43	73	157	54	211
2001	13	12	16	28	66	134	50	185
2002	12	16	15	23	71	137	50	188
2003	8	11	15	18	57	109	52	161

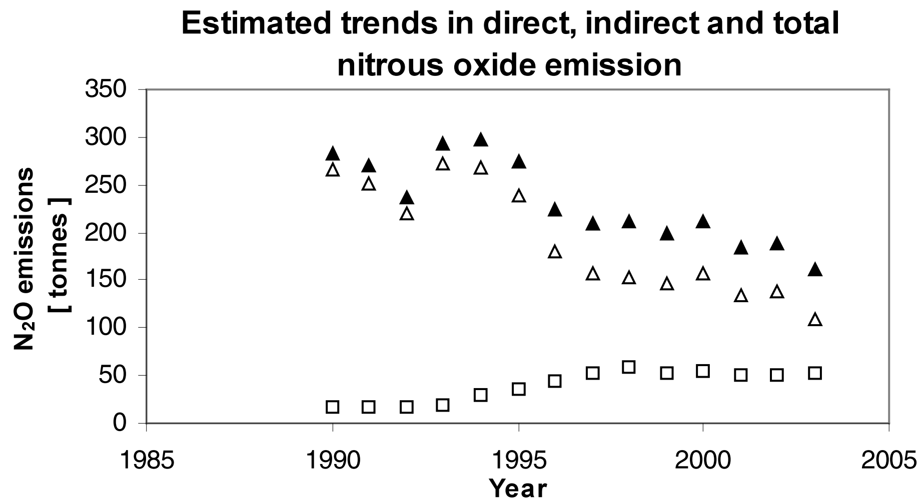

Figure 5. Time trends for direct emission of N_2O (open squares), indirect emission, i.e. from wastewater effluents (open triangles) and total N_2O emission (black triangles).

The direct emission is slightly increasing reaching a stable level from 1997 and onwards. The decrease in the indirect emission from effluent wastewater is due to the technical upgrade of the WWTPs and resulting decrease of effluent wastewater nitrogen loads. The indirect emission, which is the major contributor to the emission of nitrous oxide, is not expected to decrease much more as effluent reduction of N has increased from 65% in 1993 to around 80% in 2003.

3.4 Uncertainty estimates

Table 22 Uncertainties for main parameters of emissions for wastewater handling.

Parameter	Uncer-tainty	Note	emission type
$EF_{N2O,direct}$ ($U_{EFdirect}$)	±30%	Calculated from average and standard deviation on data from Table 13, the uncertainty is around 10%. Due to uncertainty in the Y-data as well, i.e. the industrial influent load, the uncertainty is at this point set to 20%	Direct N_2O emission
$F_{connected}$ ($U_{Fconnect}$)	±5%	set equal to uncertainty on population	
N_{pop} is the Danish population number (U_{pop})	±5%	default from IPCC GPG (IPCC, 2000)	
P is the annual protein per capita consumption per person per year (U_P)	±30%	not known /our estimate	
F_N is the fraction of nitrogen in protein (U_{FN})	0%	empirical number without uncertainty	
N_{pop} is the Danish population number (U_{pop})	±5%	default from IPCC GPG (IPCC, 2000)	
F_{nc} is the fraction of the Danish population not connected to the municipal sewer system (U_{Fnc})	±5%	set equal to uncertainty on population	
F is the fraction of non-consumption protein in domestic wastewater (U_F)	±30%	not known /our estimate	Indirect N_2O emission
$D_{N.WWTP}$ and $D_{not\ connected}$ is the effluent discharged sewage nitrogen load ($U_{effluent}$)	±30%	not known /our estimate	
$EF_{effluent}$ is the IPCC default emission factor of 0.01 kg N_2O-N/kg sewage-N produced ($U_{EFeffluent}$)	±30%	not known /our estimate	
M_{N2O}	0%	empirical number without uncertainty	

The uncertainty (IPCC, 2000) in the estimated direct N_2O emission, U_{direct}, is derived from equation 11 and calculated as:

Eq. 13. $$U_{direct} = \sqrt{U_{pop}^2 + U_{Fconnect}^2 + U_{EFdirect}^2}$$

U_{direct} is calculated to be 30,8%.

The uncertainty in the estimated indirect N_2O emission, $U_{indirect}$, has been calculated as the uncertainty in the emission from people connected and not connected to a WWTP, respectively (cf. equation 12). The first part of the equation is not used, as this derivation of N_2O emissions from people not connected was considered not applicable for Danish conditions (cf. Table 18). For comparability the calculated uncertainty of the method is:

Eq. 14 $$U_{notconnected,IPCC} = \sqrt{U_P^2 + U_{FN}^2 + U_{pop}^2 + U_{Fnc}^2 + U_F^2 + U_{EFeffluent}^2}$$

The uncertainty on the IPCC method for calculating the nitrous oxide emission from wastewater effluents from people not connected to a WWTP is 52.4%.

The uncertainty on effluent from people not connected is based on knowledge of the effluent load of N, i.e. $D_{N,not\ connected}$, is calculated as:

Eq. 15 $$U_{indirect,country-specific} = U_{connected} = \sqrt{U_{effluent}^2 + U_{Efeffluent}^2}$$

The uncertainty in the emission from wastewater based on the fraction of people connected to a WWTP equals the total indirect emission if we only look at the total emitted effluents disregarding the origin. The uncertainty this way equals 42,4%.

The resulting total uncertainty by dividing the N_2O emission into contribution form people connected and not connected is judged to be around 26% at this stage calculated as:

Eq. 16 $$U_{total} = \frac{\sqrt{(U_{notconnected,country-specific} \cdot x_{notconnected})^2 + (U_{connected} \cdot x_{connected})^2 + (U_{direct} \cdot x_{direct})^2}}{x_{notconnected} + x_{connected} + x_{direct}}$$

The total uncertainty has been estimated based on uncertain quantities equal to the fraction of people connected an not connected respectively multiplied by the average effluent N from household (average of column 3, Table 14) and WWTPs including industry wastewater treatment (average of column 2, Table 14), respectively. When the uncertainty quantities are set equal to the fraction connected and not connected, i.e. $x_{notconnected}$=0,1 and $x_{connected}$=x_{direct}=0,9, the total uncertainty estimate is 25%.

At this point information regarding industrial on-site wastewater treatment processes are not available at a level of data that allows for calculation of the on-site industrial contribution to the direct N_2O emissions. The degree of how many industries are covered in the emission estimated are therefore dependent on the amount of industrial wastewater connected to the municipal sewer system. Any emissions from pre-treatment on-site are not covered at this stage of method development.

4 Extrapolation to 2030

4.1 Gross CH_4 emissions

The extrapolation from 2004 to 2030 is based on the generic European BOD parameter of 18250 kg BOD/1000 persons/yr multiplied by the population numbers and the country-specific emission factor of 0.15 kg CH_4/ kg BOD (cf. Table 5) and lastly corrected to include the contribution of degradable organic matter from the industry to the inlet wastewater. By this procedure it is assumed that the BOD content of industrial wastewater is similar to domestic wastewater. This assumption results in an underestimated gross emission of methane, which increases in the absolute number by year. The regression of country-specific gross emissions of methane based on COD data will on the other hand result in an overestimation of the gross emission, as the trend is not linear increasing, but expected to be reaching a stable level due to a stabilisation of the industrial wastewater inlet load. Four extrapolation trends have been included in deriving at an estimated average extrapolation trend. The first three extrapolation trends given in Table 23 are based on the three estimated population scenarios (Statistics Denmark) shown in Figure 6.

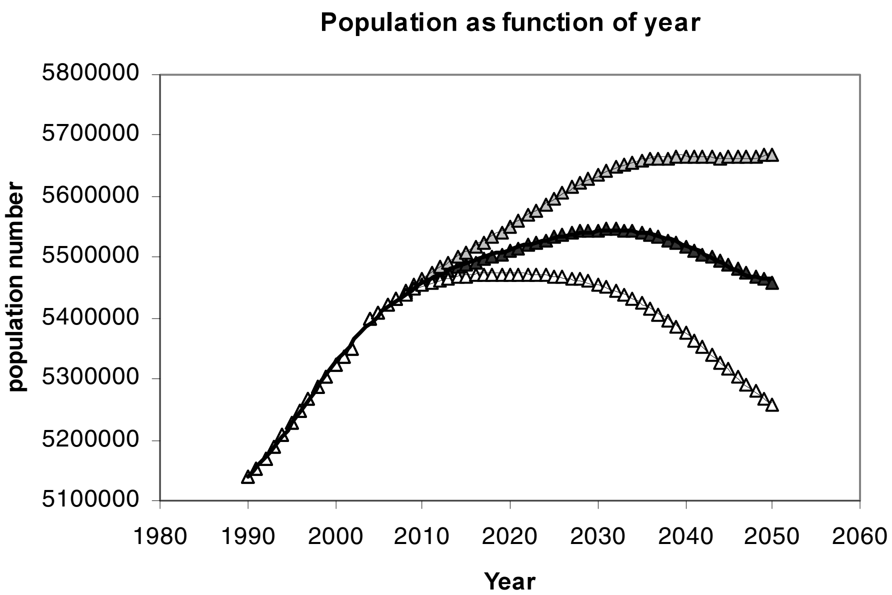

Figure 6. Population number as a function of year (Source: Statistics Denmark).

The fourth method is the linear regression of country-specific emission data (based on COD data) as function of year given in column 5 in Table 23 below. From this the regression and the three population scenarios derived extrapolation, a best possible trend, in terms of average gross CH_4 emissions, from 2004 until 2030 is provided.

Table 23. Estimated Gross emissions of methane by the use of 1) the generic BOD parameter (IPCC, 1996) based on three population scenarios and 2) extrapolation based on the country-specific method (IPCC, 2000) by linear regression as illustrated in Figure 1.

Year	Scenario 1: Gross emission [Gg]*	Scenario 2: Gross emission [Gg]*	Scenario 3: Gross emission [Gg]*	Regression based on country-specific Gross CH4 emissions, COD [Gg]**	Average Gross CH_4 emissions [Gg]	Standard deviations on estimated Gross CH_4 emissions [Gg]
2004	21.0	21.0	21.0	24.1	21.75	1.56
2005	21.0	21.0	21.0	24.7	21.92	1.82
2006	21.1	21.1	21.1	25.2	22.10	2.08
2007	21.1	21.1	21.1	25.8	22.27	2.35
2008	21.1	21.1	21.1	26.4	22.45	2.61
2009	21.2	21.2	21.2	26.9	22.61	2.88
2010	21.2	21.2	21.2	27.5	22.78	3.15
2011	21.2	21.3	21.2	28.1	22.95	3.42
2012	21.3	21.3	21.2	28.6	23.11	3.69
2013	21.3	21.3	21.2	29.2	23.27	3.97
2014	21.3	21.4	21.2	29.8	23.42	4.24
2015	21.3	21.4	21.2	30.4	23.58	4.52
2016	21.3	21.4	21.2	30.9	23.74	4.80
2017	21.4	21.5	21.3	31.5	23.89	5.07
2018	21.4	21.5	21.3	32.1	24.05	5.35
2019	21.4	21.5	21.3	32.6	24.20	5.63
2020	21.4	21.6	21.3	33.2	24.36	5.90
2021	21.4	21.6	21.3	33.8	24.51	6.18
2022	21.4	21.6	21.3	34.4	24.67	6.46
2023	21.5	21.7	21.3	34.9	24.82	6.73
2024	21.5	21.7	21.3	35.5	24.98	7.01
2025	21.5	21.7	21.2	36.1	25.14	7.29
2026	21.5	21.8	21.2	36.6	25.29	7.57
2027	21.5	21.8	21.2	37.2	25.44	7.84
2028	21.5	21.8	21.2	37.8	25.59	8.13
2029	21.5	21.9	21.2	38.3	25.74	8.41
2030	21.5	21.9	21.2	38.9	*25.89*	*8.69*

* The contribution from the industry to the wastewater inlet load of TOW is set equal 41.9 %, the average of the contribution per cent's from 1998 to 2002 where the contribution seems have reached a constant level (cf. Table 3)

**Calculated from the regression the equation: $y = 0.57x - 1119.2$. The regression is based on the emission data, represented by the open circles in Figure 1 and 2, i.e. country-specific emission data based on measured COD data (cf. Table 6).

4.2 Final results on gross, recovered and net CH_4 emissions from 2004 to 2030

The linear regression can only be used for interpolation in the case of recovered or combusted methane potential. Therefore is it judged to be most reliable to use an average of the theoretical CH_4 emissions produced as biogas and 2008 emission goal data for the remaining categories in arriving at extrapolated net CH_4 emission. An exception is the category combusted and reused in sand-blasting product, for which the slope of the linear regression is used for calculating the annual increase until the goal is reached in 2009. The resulting average gross, recovered and net CH_4 emissions are given in Table 24.

Table 24. Overall results on gross, recovered and net CH_4 emissions from 2004 to 2030 given in Gg.

	Average levels					
Year	$CH_{4, external combustion}$	$CH4_{, internal combustion}$	$CH_{4,sandblasting products}$	$CH_{4, biogas}$	$CH_{4, gross}$	**$CH_{4, net}$**
2004	2.07	4.13	3.76	0.39	21.75	**11.39**
2005	2.07	4.13	4.31	0.40	21.92	**11.01**
2006	2.07	4.13	4.93	0.41	22.10	**10.56**
2007	2.07	4.13	5.65	0.42	22.27	**10.01**
2008	2.07	4.13	6.46	0.43	22.45	**9.35**
2009	2.07	4.13	7.75	0.43	22.61	**8.58**
2010	2.07	4.13	7.75	0.44	22.78	**8.39**
2011	2.07	4.13	7.75	0.44	22.95	**8.56**
2012	2.07	4.13	7.75	0.44	23.11	**8.72**
2013	2.07	4.13	7.75	0.44	23.27	**8.88**
2014	2.07	4.13	7.75	0.43	23.42	**9.04**
2015	2.07	4.13	7.75	0.42	23.58	**9.21**
2016	2.07	4.13	7.75	0.42	23.74	**9.36**
2017	2.07	4.13	7.75	0.42	23.89	**9.52**
2018	2.07	4.13	7.75	0.42	24.05	**9.67**
2019	2.07	4.13	7.75	0.43	24.20	**9.82**
2020	2.07	4.13	7.75	0.43	24.36	**9.98**
2021	2.07	4.13	7.75	0.43	24.51	**10.13**
2022	2.07	4.13	7.75	0.43	24.67	**10.29**
2023	2.07	4.13	7.75	0.43	24.82	**10.44**
2024	2.07	4.13	7.75	0.43	24.98	**10.60**
2025	2.07	4.13	7.75	0.43	25.14	**10.76**
2026	2.07	4.13	7.75	0.43	25.29	**10.91**
2027	2.07	4.13	7.75	0.43	25.44	**11.06**
2028	2.07	4.13	7.75	0.43	25.59	**11.21**
2029	2.07	4.13	7.75	0.43	25.74	**11.36**
2030	2.07	4.13	7.75	0.43	25.89	**11.51**

The best judgement of both categories, external and internal combustion are that they have reached a stable level (cf. Table 11 and Figure 3). For both final disposal categories the amount corresponds to the goals set up by the national waste strategy (cf. Table 10) (Waste Strategy, 2003). The not emitted or theoretical amount of methane from external and internal combustion was set equal to the estimated potential emissions according to the national waste strategy (Waste Strategy, 2003).

The not emitted methane potential from the production of sandblasting products is judged to increase due to the focus on better reuse of sludge (Waste Strategy, 2003). The increase in the (not emitted) methane potential from the production of sandblasting products has been estimated by simple linear regression. The best judgement is at this stage that the increase will continue until the estimated goal of 7.75 Gg methane is reached as shown in Table 24. It is assumed that the amount will stabilise at the amount corresponding to 25% of the total produced sludge for final disposal (Waste Strategy, 2003) which will result in a constant CO_2 emission level corresponding to 7.75 Gg CH_4.

The national waste strategy does not include goals for the use of sludge in biogas production (Waste Strategy, 2003). This may be due to several unfavourable factors such as inhibited CH_4 production by the presence of xenobiotics in high concentrations as well as the low degradability of hazardous organic compounds under anaerobic conditions, the biogas production is expected to stay at a low level. The recovered methane potential form biogas production was set equal to the average recovered amount from 1990 to 2003.

Based on the above assumptions, the estimated CH_4 emissions are visualised in Figure 7.

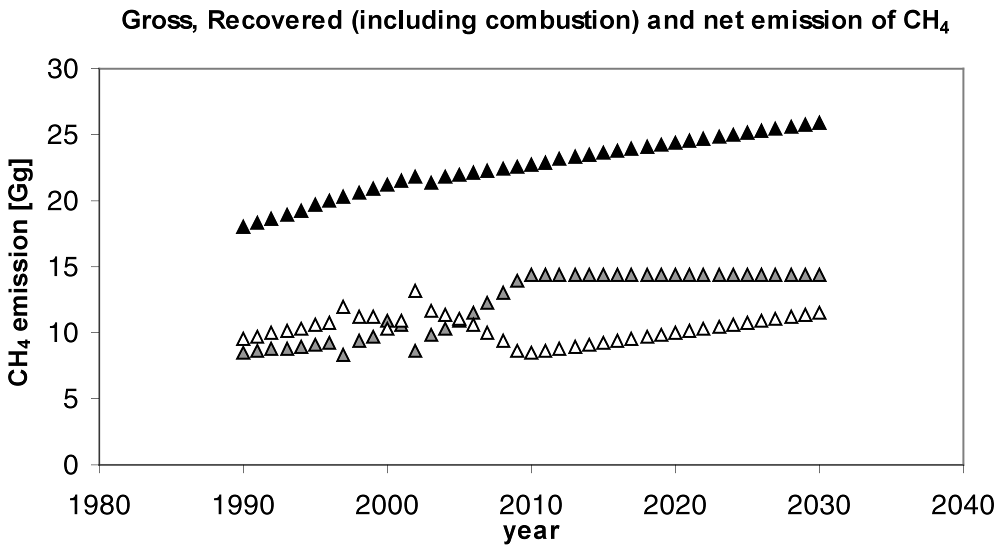

Figure 7. The upper black triangle curve represents gross CH_4 emissions, the white triangle curve represents recovered or combusted methane potential. The grey triangle curve represents net emissions of CH_4 from 1990 to 2030.

The estimated increase in gross methane emissions may be underestimated (cf. Figure 2) due to high increasing amount of influent organic degradable matter (cf. Table 6) which is underestimated by the adjusted IPCC approach (cf. Table 7 and 8) which may also be the case for the country-specific regression approach (cf. Table 8).

The slope of the net emission, or the actual emission, of methane from wastewater handling may be underestimated due to the use of the default IPCC methodology and chosen country-specific regression based on COD data excluding data from 2003.

4.3 Indirect N_2O emissions

The upgrading of the WWTPs by BAT (Best Available Technique) in wastewater treatment processes since 1987 when the first Water Environment Action Plan was launched by the Danish Government have resulted in reductions in the nutrient concentrations in the effluents wastewater from the WWTPs. The plan included more strict emission standards for nutrients and organic matter for WWTPs and the resulting per cent reduction in effluent BOD, nitrogen and phosphor (cf. Table 1).

Based on Table 1 and the observed trend in emissions from municipal sewage effluent, visualised in Figure 8 below, the indirect emission of N_2O from WWTPs is judged to have reached a constant level.

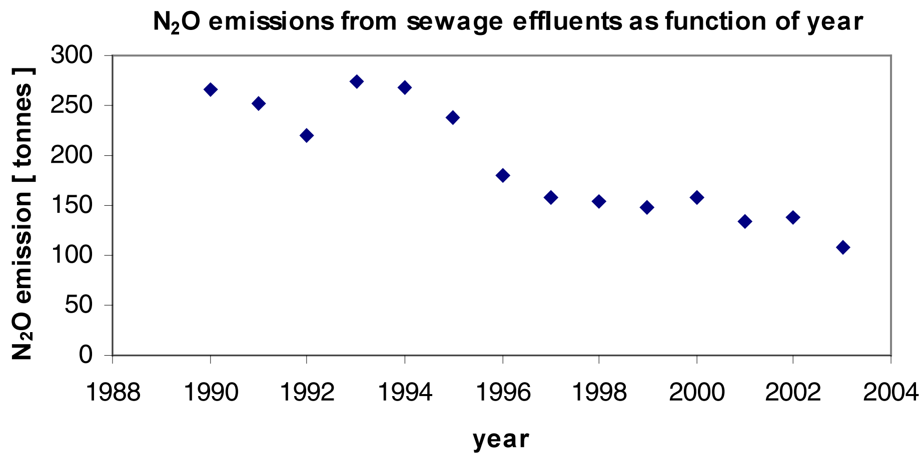

Figure 8. Emission in tonnes N_2O as function of year, visualising the effect of the improved reduction in total N, P and BOD by biological and chemical treatment processes from 1993 to 2002.

From 2004 to 2030, the total N_2O emissions from effluents has been set equal to the average of the emission from 1999 to 2003 assuming that the effluent level of nitrogen has reached its minimum value (cf. Table 1).

4.4 Final results on the direct, indirect and total N_2O emission

The direct emission from wastewater treatment processes at the WWTPs is calculated based on contributions from household protein intake, protein from other household types and from the industry. The emission factors (cf. Table 15) are very sensitive towards the annual variation in industrial inlet load proportion of nitrogen, which is seen from Figure 9.

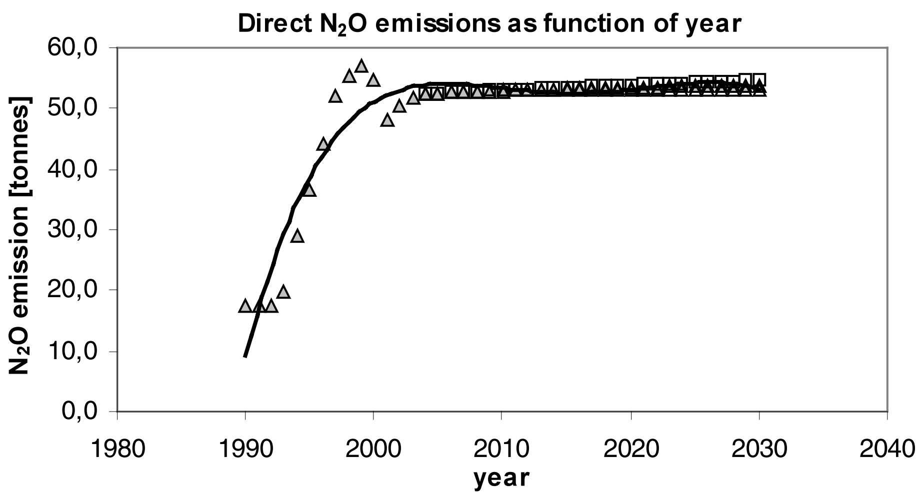

Figure 9. Direct emission of N_2O as function of year and given in tonnes. The observed maximum in 1998 visualises the uncertainty due to annual fluctuations in inlet wastewater nitrogen and average national data based on few measurements.

For the year 2003 and to 2030 an average EF, corrected for industrial influent N, has been adopted as the industry inlet wastewater level is assumed to have reached a constant level.

By comparing the units of the trends shown in Figure 8 and 9 it can be seen that the major contributor to N_2O emissions is the emission from effluent wastewater. The overall results of the extrapolations are given in Table 25.

Table 25. Estimated direct, indirect and total emission of N_2O [tonnes]. For the direct emission from the WWTPs, extrapolation from 2004 to 2030 is based on the three population scenarios (cf. Figure 6).

year	Scenario 1: $E_{N2O,WWTP,direct}$ (Danish EF)	Scenario 2: $E_{N2O,WWTP,direct}$ (Danish EF)	Scenario 3: $E_{N2O,WWTP,direct}$ (Danish EF)	Average, $E_{N2O,WWTP,direct}$ (Danish EF)	E_{N2O}, effluents	E_{N2O}, total
2004	52.36	52.36	52.36	52.36	144.03	196.39
2005	52.48	52.48	52.48	52.48	144.03	196.51
2006	52.59	52.60	52.59	52.59	144.03	196.62
2007	52.70	52.71	52.68	52.70	144.03	196.72
2008	52.79	52.82	52.77	52.79	144.03	196.82
2009	52.88	52.92	52.84	52.88	144.03	196.91
2010	52.96	53.02	52.90	52.96	144.03	196.99
2011	53.03	53.12	52.96	53.04	144.03	197.06
2012	53.10	53.20	52.99	53.10	144.03	197.12
2013	53.15	53.29	53.02	53.15	144.03	197.18
2014	53.20	53.36	53.04	53.20	144.03	197.23
2015	53.24	53.44	53.06	53.25	144.03	197.27
2016	53.29	53.51	53.07	53.29	144.03	197.31
2017	53.33	53.59	53.07	53.33	144.03	197.36
2018	53.37	53.67	53.08	53.37	144.03	197.40
2019	53.41	53.75	53.08	53.41	144.03	197.44
2020	53.45	53.84	53.08	53.46	144.03	197.48
2021	53.50	53.93	53.08	53.50	144.03	197.53
2022	53.54	54.02	53.08	53.55	144.03	197.57
2023	53.59	54.11	53.08	53.59	144.03	197.62
2024	53.63	54.21	53.07	53.64	144.03	197.66
2025	53.67	54.30	53.06	53.68	144.03	197.70
2026	53.71	54.39	53.05	53.72	144.03	197.74
2027	53.74	54.47	53.03	53.75	144.03	197.77
2028	53.77	54.55	53.00	53.77	144.03	197.80
2029	53.78	54.62	52.97	53.79	144.03	197.82
2030	53.79	54.68	52.93	53.80	144.03	197.83

The estimated N_2O emissions are visualised in Figure 10.

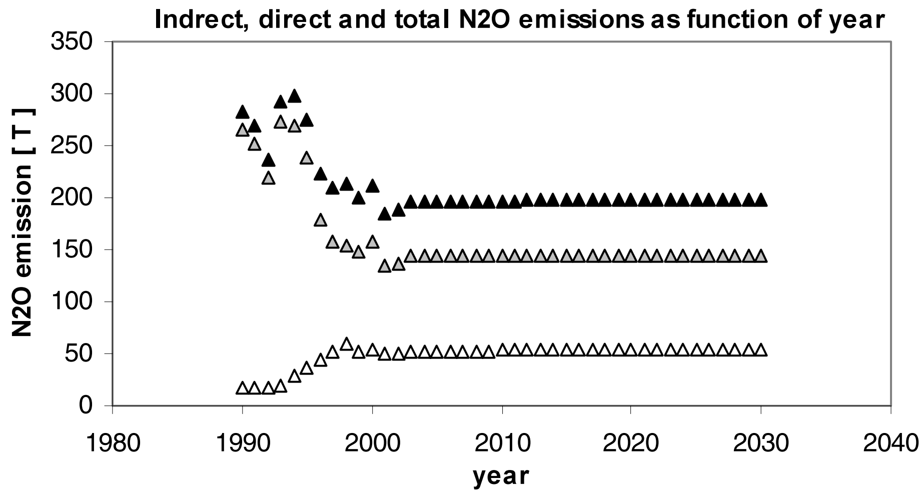

Figure 10. The upper black triangle curve represents the total N_2O emission. The middle grey triangle curve represents the contribution from indirect N_2O emission. The lower white triangle curve represents the contribution from direct N_2O emission to the total emission from 1990 to 2030.

As seen from Figure 10 the emission from the nitrous oxide emission is expected to have reached a minimum and stable level. However, further reductions may occur due to the still increased restrictions on effluent from e.g. scattered houses due to the European water framework directive and the Danish Water Environment Action Plan.

5 Further work

The default IPCC method for calculating the gross emission of methane has been based on the default European BOD value of 18250 kg BOD/1000 persons/yr. The Danish Environmental Protection Agency, however, uses one PE (Person Equivalent) of 60 g BOD/day yielding a BOD value of 21900 kg BOD/1000 persons/yr. Recalculation and comparison to the national-specific TOW data are planed for NIR2006.

A consistent methodology for uncertainty analysis for time trends, based on interpolation as well as extrapolations, is planned to be included in the next NIR. The methodology will be documented in a written manual as part of the improvements of the QA/QC-plan for the annual NIR preparations.

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