Review of "Source category 5D – Wastewater treatment and discharge" in Switzerland

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Summary

To check the quality assurance and quality control recorded by Switzerland's National Inventory Report - the following review examines Sector 5: Waste; Chapter 6: Wastewater treatment and discharge - of the 2006 IPCC Guidelines (IPCC Guidelines 2006).

The calculations of nitrous oxide (N_2O) emissions are carried out correctly as stated in the IPCC Guidelines and no methodological issues were detected.
A detailed assessment of the activity data showed that the nitrogen content in the protein consumption is a good indicator of nitrogen loads, but additional factors for unconsumed and industrial nitrogen lead to an overestimation for Switzerland. Furthermore, the sludge amount has not been adjusted in recent years. It is recommended that this amount be calculated via the per capita production. The emission factors used agree with the default values of the IPCC Guidelines and *best practice*.

The review of the methane (CH_4) emissions from wastewater treatment showed methodological differences from the IPCC Guidelines. The sewage gas usage is allocated to the waste sector, unlike in the guidelines. It is stated there that sewage gas usage in combination with energy recovery should be allocated to Sector 1: Energy and not Sector 5: Waste (IPCC Guidelines 2006). The allocation applied by FOEN is not explained in detail.
Furthermore, the activity data of the sewage gas is incomplete, i.e. the total amount of sewage gas production is not assessed and described correctly. It is assumed that the percentages for leakages and losses refer to the total production of sewage gas, but the calculations are carried out differently. The emission factors agree with the default values from the IPCC Guidelines and *best practice*.

Even though the N_2O IPCC methodology is applied correctly, the assessment does not represent the situation in advanced and well-managed wastewater treatment plants (WWTP) in Switzerland. It is recommended that a country-specific methodology be used for Switzerland. In this report, a method is proposed which is based on the same activity data but includes nitrogen removal from WWTP and country-specific emissions factors.

Methane emissions from WWTP, as currently calculated, are not in a plausible numerical range but are attributed to the wrong treatment steps for Switzerland's advanced and well-maintained plants. Therefore, a different method for CH_4 emissions is proposed in which CH_4 production from the sewers and losses from sewage sludge treatment are implemented.

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Abbreviations and acronyms

AD	Activity Data
BOD	Biological Oxygen Demand
CH_4	Methane
CHP	Combined Heat and Power use of heat engines for electricity and useful heat at the same time
CO_2	Carbon dioxide
CO_2eq	Carbon dioxide equivalent
COD	Chemical Oxygen Demand
Eawag	Swiss Federal Institute of Aquatic Science and Technologies
EF	Emission Factor
EMIS	Swiss Emission Information System
Empa	Swiss Federal Laboratories for Material Testing and Research
FOEN	Swiss Federal Office for the Environment (BAFU)
GHG	Greenhouse Gas
IPCC	Intergovernmental Panel on Climate Change
IPCC GL	“This guidance assists countries in compiling complete, national inventories of greenhouse gases. The guidance has been structured so that any country, regardless of experience or resources, should be able to produce reliable estimates of their emissions and removals of these gases.”
N	Nitrogen
$N_{INFLEUNT}$	Nitrogen load (all nitrogen species) in the influent
$N_{EFFLUENT}$	Nitrogen load (all nitrogen species) in the effluent
NH_3^+	Ammonia
NIR	National Inventory Report
N_2O	Nitrous oxide
Ppm	Parts per million
TOW	Total organically degradable matter
UNFCCC	United Nations Framework Convention on Climate Change
UNFCCC review guidelines	“Guidelines for the technical review of information reported under the Convention related to greenhouse gas inventories, biennial reports and national communications by Parties included in Annex I to the Convention”
SWA	Swiss Water Association (German: VSA - Verband Schweizer Abwasser- und Gewässerschutzfachleute)
WWTP	Wastewater Treatment Plant

1. Introduction

In Switzerland, wastewater is commonly collected in closed sewers. Most of the population (97% in 2016) are connected to sewer systems and their wastewater is treated in centralized plants (FOEN Indicator WS076 2018). Primary (physical barrier) and secondary (biological) treatment is applied at all advanced centralized plants in Switzerland. Tertiary treatment (removal of nutrients such as nitrogen and phosphorus and purification from micropollutants) is widely used and is implemented step-by-step at additional plants (SWA and FOEN 2011 / 2017). During wastewater treatment, the greenhouse gases CO_2, N_2O and CH_4 are emitted. These form a part of a country's impact on global climate and climate change. CO_2 emissions are not assessed, as these are of biogenic origin and not included in the inventories (IPCC Guidelines 2006).

In a WWTP, nitrous oxide is produced in the nitrification and denitrification steps (Wunderlin 2013). The IPCC GL does not specify any production mechanisms. The discharge of nitrogen to the effluent can lead to the production of N_2O in natural water bodies and its subsequent emission to the atmosphere.

The degradation of organic material under anaerobic conditions leads to the production and emission of methane. In Switzerland, anaerobic conditions arise mostly in the sewer system, but are rarely found in centralized plants. During sewage sludge treatment, anaerobic processes take place and methane is produced. The sewage gas (mostly methane and carbon dioxide) can leak and be emitted to the atmosphere in uncovered processes or is captured and used in energy recovery systems. Both scenarios result in methane leakage, which should be considered.

The aim of this report is to review the application of Sector 5 – Chapter 6 - Wastewater treatment and discharge for Switzerland of the 2006 IPCC Guidelines. The National Inventory Report and the calculation files are reviewed and assessed in terms of their completeness, consistency, accuracy, transparency and potential for improvement. This task is further described in the document "Experten-Review: Anforderungen und Anregungen, 05.02.2018" (Bock 2018) and the methodology is described in the IPCC GL (IPCC Guidelines 2006).

The following files were received from FOEN and were assessed in this review:

- EMIS Kommentar: 5 D 1_5 D 2_Kläranlagen THG_20170412.pdf
- Guidelines: http://www.ipcc-nggip.iges.or.jp/public/2006gl/vol5.html
- 5_Kläranalagen__EMIS-Bericht-ohne-Mesap-Formeln-20180308.xls
- NIR_5_Waste_EMIS-Bericht-Ohne-Mesap-Formlen_20180308.xls
- NIR_CHE_2018_Master_Kap7-5.pdf
- CHE_2018_2016_01032018_122642_started.xls

2. Methodology on the basis of the IPCC guidelines

The current methodologies for accounting N_2O and CH_4 emissions from wastewater treatment, as described in the 2006 IPCC Guidelines, are summarized below (IPCC Guidelines 2006).

2.1 Methodology for N_2O emissions

The IPCC accounts for direct emissions from advanced centralized wastewater treatment plants – originating from nitrification and denitrification processes – and emissions from effluent containing nitrogen. It is stated that the emissions from WWTP are minor while N_2O emissions from wastewater treatment effluent are typically more substantial. A scheme of the perceived emission locations and nitrogen flows is shown in Figure 1.

Direct emissions from WWTP are assessed on the basis of the number of persons, an additional factor for industry loads and a per capita emission factor (Equation 1). The emission factor is based on field testing by Czepiel et al. in the United States (Czepiel et al. 1995). Where direct emissions are estimated, the amount of nitrogen directly emitted as N_2O must be considered in the calculation of the effluent nitrogen load.

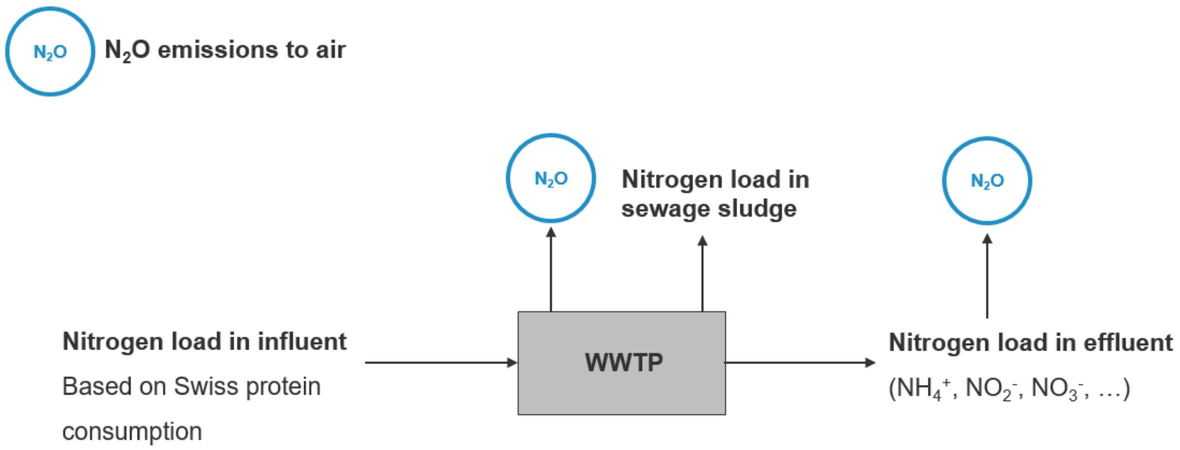

Figure 1: Simplified model of nitrogen flows for the assessment of nitrous oxide emissions according to the IPCC 2006 Guidelines

The influent nitrogen load is based on the per capita protein consumption multiplied by factors accounting for non-consumed protein and co-discharged industrial protein. It is *good practice* not to account for nitrogen in the sludge removal. However, if the data is available it can be incorporated in the calculation of the effluent nitrogen load (Equation 2).

N_2O emissions from the effluent are estimated from the nitrogen load in the effluent and an EF based on the literature (Equation 3).

Direct N_2O emissions from WWTP:

$$N_2O_{PLANT} = P * T_{PLANT} * F_{IND-COM} * EF_{PLANT} \quad (1)$$

Nitrogen load in effluent:

$$N_{EFFLUENT} = (P * Protein * F_{NPR} * F_{NON-CON} * F_{IND-COM}) - N_{SLUDGE} - N_{PLANTS} \quad (2)$$

N_2O emissions from WWTP effluent:

$$N_2O_{EFFLUENT} = N_{EFFLUENT} * EF_{EFFLUENT} \quad (3)$$

Parameters:

N_2O_{PLANT}	Nitrous oxide emissions from WWTP [kg N_2O-N / year]
P	Population [# person]
T_{PLANT}	Connection rate to WWTP [%]
$F_{IND-COM}$	Factor for industrial and commercial protein [-]
EF_{PLANT}	Emission factor for N_2O from WWTP [kg N_2O-N / kg N]
$N_{EFFLUENT}$	Nitrogen load in WWTP effluent [kg N / year]
Protein	Per capita protein consumption [kg protein / person / year]
F_{NPR}	Nitrogen in protein [%]
F_{NON_CON}	Factor for non-consumed protein [-]
N_{SLUDGE}	Nitrogen in sewage sludge [kg N / year]
N_{PLANTS}	Nitrogen in N_2O emissions from WWTP [kg N_2O-N / year]
$EF_{EFFLUENT}$	Emission factor for N_2O from effluent [kg N_2O-N / kg N]
$N_2O_{EFFLUENT}$	Nitrous oxide emissions from effluent [kg N_2O-N / year]

2.2 Methodology for CH_4 emissions

The default method is described in the 2006 IPCC Guidelines and accounts for emissions from wastewater treatment (IPCC Guidelines 2006). Emissions from sludge treatment are neglected in most countries.

The methodology categorizes three methods (Tiers 1 to 3), according to the data available and the methods applied. Tier 1 corresponds to the application of the default AD and EF for countries with limited data. Tier 2 follows the same method but allows country-specific data. The Tier 3 method applies country-specific methods and values for activity parameters and the EF.

In the default method, as shown in Figure 2, methane emissions are assessed with a daily BOD (organically degradable matter) load per capita (Equation 4). Different emission factors are assessed depending on the collection and treatment scenario. It is *good practice* to account for three categories: the rural population, the urban high-income population and the urban low-income population, applying different treatment systems to each category (Equations 5 and 6). It is *good practice* to neglect emissions from sewage sludge treatment, as only few countries have sludge-removal and CH_4 recovery data. If sludge treatment is considered, it is recommended to distinguish between flaring and CH_4 recovery for energy generation.

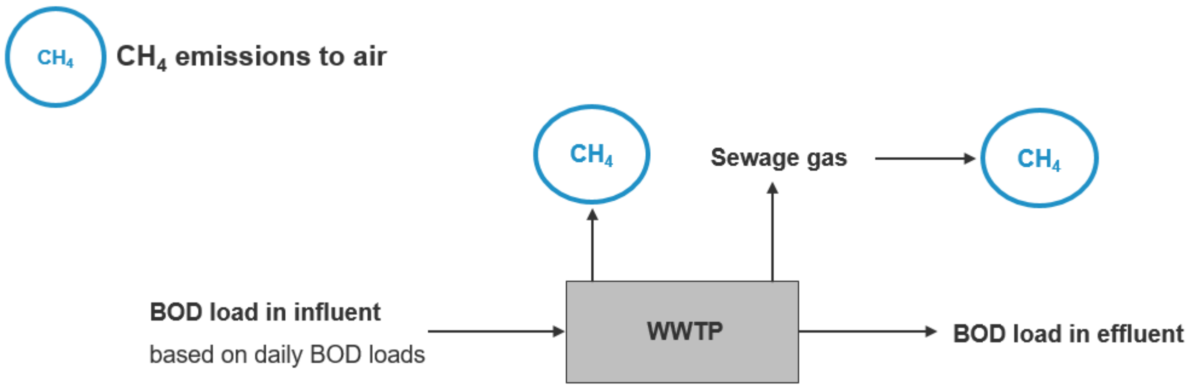

Figure 2: Simplified model for assessing nitrous oxide emissions according to the IPCC 2006 Guidelines

Total organically degradable material:

$$TOW = P * BOD * 0.001 * I * 365 \tag{4}$$

Emission factor for CH_4 depending on collection and treatment pathway:

$$EF_{PLANTS,j} = B_{PLANTS} * MCF_{PLANTS} \tag{5}$$

Methane emissions from different collection and treatment pathways:

$$CH_{4,\ PLANTS} = \sum (U_i * T_{i,j} * EF_j) * TOW \qquad (6)$$

Parameters:

TOW	Total organics in wastewater [kg BOD / year]
P	Population size [# person]
BOD	Per capita load of organically degradable material [g BOD / pers. / day]
I	Correction factor for additional industrial BOD [-]
$EF_{PLANTS,\ j}$	Emission factor for methane emissions from WWTP [kg CH_4 / kg BOD]
B_{PLANTS}	Maximum CH_4 production capacity [kg CH_4 / kg BOD]
MCF_{PLANTS}	Methane correction factor (depending on treatment pathway) [-]
$CH_{4,\ PLANTS}$	Methane emissions from wastewater treatment [kg CH_4 / year]
U_i	Fraction of population in group i in income year [%]
$T_{j,j}$	Degree of utilisation of treatment pathway or system j for each income group I [-]
EF_j	Emission factor for treatment pathway j [kg CH_4 / kg BOD]

3. Application of Guidelines to Switzerland's NIR

In the following section, a check is made to see if the application for Switzerland's National Inventory Report is in line with the Guidelines or whether any different assumptions or methods correspond to the current state of knowledge. It is in line with the Guidelines to implement country-specific methods or data if these are stated and documented correctly.

3.1 Application of Guidelines for N_2O emissions

The IPCC GL were correctly applied. The protein consumption is based on national statistics and is adjusted yearly. The application of additional factors is explained and is reproducible. $F_{NON\text{-}CON}$ is set to 1.1, as waste is not allowed to be discharged into wastewater, and the default value of 1.25 is used for $F_{IND\text{-}CON}$. Data on the amount of sewage sludge and its nitrogen content was available for the earlier years (Külling 2002) and was extrapolated from statistics for subsequent years (FOEN 2000 - 2016).

Summary: The assessment of N_2O emissions is in line with the IPCC GL.

3.2 Application of Guidelines for CH_4 emissions

Switzerland's NIR applies a Tier 3 country-specific method. Only the pathway of collecting wastewater in covered sewers and treatment in advanced and well-managed WWTPs is considered. All collected wastewater is treated in advanced WWTPs independently of income group. The emissions from uncollected wastewater are neglected, since the methane emissions are very small due to the low mean temperatures in the uncollected areas and the high connection rate to the wastewater treatment system (FOEN Indicator WS076 2018). The emission factor is based on the maximum CH_4 production capacity and the CH_4 correction factor for well-managed plants. AD and EF are multiplied as in Equation 6.

In Switzerland, sewage gas handling and usage is also assessed. Different pathways for sewage gas were implemented and assessed (Equation 7). The AD of the energy flows from sewage gas usage is based on the national statistics on renewable energies and expert judgments given to FOEN and provided by them. These emission factors are also based on expert judgements.

Methane emissions from sewage gas usage:

$$CH_{4,\ SEWAGE\ GAS} = \sum P_{j,\ SEWAGE\ GAS} * EF_{j,\ SEWAGE\ GAS} \tag{7}$$

Parameters:

$CH_{4,\ SEWAGE\ GAS}$	Methane emissions from sewage gas usage [kg CH_4 / year]
$P_{j,\ SEWAGE\ GAS}$	Activity data for sewage gas usage [TJ / year]
$EF_{j,\ SEWAGE\ GAS}$	Methane emission factor for sewage gas usage [kg CH_4 / TJ]

The methodology for methane emissions from wastewater is correctly applied and the underlying assumptions are reasonable and justified. The focus on two pathways for wastewater treatment is explained. Omitting the emissions from uncollected wastewater is reasonable and in line with the IPCC Guidelines.

According to a Tier 3 method, it is reasonable to assess emissions from sewage gas treatment and usage. However, the Guidelines advise making a distinction between flaring and energy recovery systems (IPCC Guidelines 2006). The applied country-specific methodology proposes five categories for sewage gas: Furnaces, Combined Heat and Power (CHP) installations, torches, leakages and upgrading. In the NIR, emissions from all categories are allocated to Sector 5: Waste (Chapter 6 Wastewater). However, it is clearly stated in the IPCC guidelines that the emissions from sewage gas usage in furnaces and CHP installations should be allocated to Sector 1: Energy.

Summary: The Calculation of CH_4 emissions from wastewater on WWTP is carried out correctly according to the IPCC Guidelines with country-specific parameters.

Proposed changes: The sewage gas classifications should be edited and allocated to their respective sectors. Furnace and CHP installations are not part of Sector 5: Waste, and any emissions correspond to the energy production in Sector 1.

4. Activity data

The activity data provides the basis for calculating emissions. The IPCC Guidelines report default activity data, which can be adapted to a specific country.

4.1 Activity data of N_2O emissions

Protein consumption

The protein consumption is the main indicator of nitrogen loads. Therefore, the estimated protein consumption, according to the IPCC Guidelines, was cross-compared with three independent data sources for nitrogen loads to Swiss WWTP:

- Nitrogen loads in Switzerland in the year 2005 – published by FOEN (FOEN 2010)
- Estimation of nitrogen loads in Switzerland in 2020 – published by FOEN (FOEN 2013)
- Nitrogen loads based on operational data from Swiss WWTP operators, collected in datasets by SWA and FOEN and evaluated by eawag (SWA and FOEN 2011 / 2017)

The SWA dataset comprises the loads and sizes of a representative selection (around 70% of the person equivalents connected) of Switzerland's WWTPs. The FOEN dataset includes all WWTPs in Switzerland and enables the extrapolation of the SWA dataset to a country-wide level. A total influent load of 46,490 t N/year in 2010 resulted from the analysis. Together with the two reports and considering the different references years, it was concluded that the current application of the IPCC GL results in significantly higher nitrogen loads in the NIR. The overestimation of nitrogen loads to the WWTPs leads to an overestimation of N_2O emissions.

In Equation 2, two additional factors ($F_{IND-COM}$ and $F_{NON-CON}$) account for industrial protein while additional loads from garbage account for other nitrogen sources. According to the load estimates noted above, it seems appropriate for industrial protein to be already included in the statistics. Furthermore, it is not allowed to dispose garbage in wastewater in Switzerland. Both factors therefore seem too large for the Swiss situation. It is therefore proposed that both factors $F_{IND-COM}$ and $F_{NON-CON}$ be set to 1.0, which is in the range provided by the IPCC GL. The application of the adjusted factors is shown in Table 1 and results in comparable nitrogen loads.

Table 1 Comparison of nitrogen accounting

Nitrogen load to WWTP	$N_{INFLUENT}$ load [t/year]	$N_{EFFLUENT}$ load [t/year]
N load in 2005 from report (FOEN 2010)	43,200	26,000
N load in 2020 from report (FOEN 2013)	47,900	25,390
N load in 2010 from datasets (SWA and FOEN 2011 / 2017)	46,490	23,830
N load in 2015: Eq. 2 - calculation according to IPCC GL	65,780	47,550
N load in 2015: Eq. 2 - calculation with $F_{IND-COM}$ and $F_{NON-CON}$ set to 1.0	47,840	-

Sewage sludge

The AD on sewage sludge is based on a study of Külling et al. for the years 1990 to 1999 (Külling 2002) and subsequently on the official waste statistics of FOEN, which indicate the total production and per capita values (FOEN 2000 - 2016). Since 2006, the amount of sewage sludge was not updated in the waste statistics and was therefore not adjusted in the calculations for the NIR. 2011 was the last year in which a per capita value was stated. The nitrogen content of the sewage sludge was examined in the same study of Külling et al. There is no updated information on this topic in the literature.

Summary: There is good data coverage on protein consumption, population size, connection rate and sewage sludge (in the years 1990 – 1999). However, the data has not been cross-checked with independent sources, which suggests an adaption of the default values.

Proposed changes: The additional factors $F_{IND\text{-}COM}$ and $F_{NON\text{-}CON}$ should be set to 1.0, as the current values overestimate the situation in Switzerland. The proposed changes affect the assessment of direct emissions from WWTP and indirect emissions from the discharges. However, if these changes are implemented, it is necessary to state in the NIR that industrial wastewaters are included in the protein consumption and not via additional factors.

Even though no recent studies or literature on the sludge amount and nitrogen content are available, it is clearer for the sludge production to be assessed with a per capita production. The inclusion of population change allows a more realistic assessment of sludge production in the NIR. A per capita sludge production of 26 kg per person and year based on the 2011 waste statistics should be applied from 2010 onwards (FOEN 2000 - 2016). If the sludge amount is adapted in the assessment, it must also be corrected in the other categories of Sector 5: Waste and Sector 1: Energy.

4.2 Activity data of CH_4 emissions

Organics load in wastewater (TOW)

The calculation of TOW loads via daily BOD production per person is reasonable and correctly executed. The values match an expert judgment and the literature values.

It is correctly explained that the uncollected wastewaters are treated in alternative systems. Only remote and sparsely populated regions are permitted to treat their wastewaters in such systems (FOEN 2018). The high connection rate, 97% in 2013, to the sewer system also shows this (FOEN Indicator WS076 2018). The mean temperatures in these regions only rarely exceed 15°C so that methane production is limited by the low temperatures. CH_4 emissions from these systems can be neglected.

Sewage gas production and usage

The AD of sewage gas is divided into several categories: Furnace, CHP installations, upgrading, torches and leakages. The first three categories are available from national statistics of the Federal Office for Energy (FOE 2017). The other two categories (torches and leakages) are not assessed in the statistics. These are extrapolated by expert judgements, which are provided by FOEN, for the total sewage gas production. The total gas production includes five categories: Furnace, CHP installations, upgrading, torches and leakages

However, the execution of the calculation currently differs from the stated methodology. As seen in Table 2, the categories (4) torches and (5) leakages are calculated from only a few categories, rather than from the total sewage gas production. In this review, the conversion of the gas production, reported in the statistics, to the total gas production is revised and corrected according to Table 2.

Table 2 Mass balance for sewage gas in 2016: The middle column indicates the status quo, while the right column shows the proposed corrections.

Category number	Description	Current mass balance sewage gas	Review: Mass balance sewage gas
-	*In Statistics:*		
(1)	Furnace [TJ/y]	370.8	370.8
(2)	CHP installations [TJ/y]	1,278.0	1,278.0
(3)	Upgrading [TJ/y]	526.36	526.36
-	Sewage gas in statistics [TJ/y]	(1) + (2) + (3) = 2,175.2	(1) + (2) + (3) = 2,175.2
-	Sewage gas prod. in statistics [%]	100%	100% - 2% - 0.75% = 97.25%
-	Total production [TJ/y]	2,175.2	2,175.2 / 97.25% = 2,236.7
(4)	Torches [TJ/y]	(1) + (2) * 2% = 33.0	(2,236.7) * 2% = 44.7
(5)	Leakages [TJ/y]	(1) + (2) * 0.75% = 12.4	(2,236.7) * 0.75% = 16.8
-	Total sewage gas in assessment [TJ/y]	(1) + (2) + (3) + (4) + (5) = 2,220.5	(1) + (2) + (3) + (4) + (5) = 2,236.7

Summary: The TOW loads match the default value from the IPCC Guidelines and a cross-check with the literature. However, the sewage gas is not accounted correctly. The missing categories are based on only part of the sewage gas production.

Proposed changes: The correct application is to refer the two categories of torches and leakages to the total sewage gas production (all five categories.).

5. Emission factors

The multiplication of the AD and EF results in emissions. The given EF mostly refer to a general case and are therefore often adapted to a country's specific application. In the following section, the emission factors given by the IPCC Guidelines and country-specific factors for Switzerland are reviewed.

5.1 N_2O emission factors

Switzerland applies the default emission factors EF_{PLANTS} and $EF_{EFFLUENT}$ (IPCC Guidelines 2006). These are *best practice*. A literature review and the data evaluation from the running measurement campaign performed by eawag showed that the current value of EF_{PLANTS} proposed by the IPCC GL is too low and underestimates the emissions significantly, as seen in Daelman et al. and Kosonen et al. (Daelman et al. 2015, Kosonen et al. 2016) .

The default emission factors are also applied in Germany (FEA Germany 2017). However, Austria's Environmental Agency requested measurement campaigns on different WWTP over varying time spans (EA Austria 2015). The result was a much higher emission factor of 43 g N_2O / person / a (an increase by a factor of 13 compared to IPCC GL). This shows how essential monitoring campaigns and an assessment of the EF_{N2O} are. In future, the necessary input for the revision of the emission factors will be generated from a measurement campaign run by eawag in collaboration with FOEN. The preliminary results are stated in Chapter 8.1.2 and suggest a higher EF. The final results are expected in 2020.

The default EF for N_2O emissions from the wastewater effluent was reviewed by the expert judgement of M. Lehmann. He stated that the varying conditions made a generalisation difficult but he would nevertheless estimate an EF in the same range (Lehmann and Gruber 2018).

Summary: As only a preliminary emission factor for Switzerland can currently be proposed, it is *best practice* to use the default IPCC GL value.

5.2 CH_4 emission factors

The CH_4 Emission factor (EF_{CH4}) is based on the maximum CH_4 production capacity and the methane correction factor. It is *good practice* to use the default value. The methane correction factor depends on the treatment system and its management. The Swiss treatment systems contain (mostly) aerobic processes and are well managed. Therefore, a default value of 0.05 [-] is applied and explained in detail.

The EF values for sewage gas usage are based on an expert judgment, correspond to *best practice* and are reasonable.

Summary: The emission factors are reproducible and understandable.

6. Emissions

The emissions according to Switzerland's NIR and with the proposed changes are shown in the following section and the comparison with other countries is discussed.

6.1 N_2O emissions

The emissions from Switzerland's NIR and those including the recommended changes for the year 2016 are shown in Figure 1. The changes neglect the additional factors for industry nitrogen and unconsumed protein in the influent nitrogen and couple the sludge amount to the population size. It is proposed to change the emission factors according to the conclusions of the ongoing measurement campaigns by eawag and these are therefore not implemented in this comparison. The monitoring campaigns and their necessity are described in Chapters 5.1 and 8.1.2.

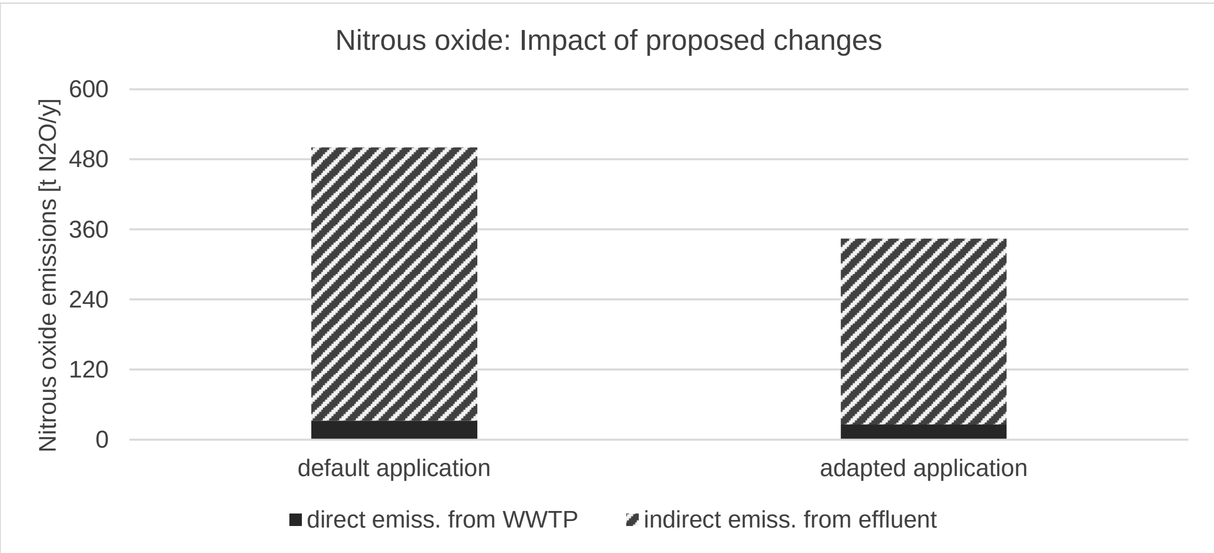

Figure 3: Assessment of nitrous oxide emissions in the year 2016 - The data from Switzerland's NIR are displayed on the left and the implementation of the proposed changes on the right

The IPCC GL assumes that indirect emissions from the effluent are much higher than direct emissions, so that only direct emissions are of interest for advanced centralized wastewater treatment plants. However, the comparison with Austria's NIR showed a flipped ratio if higher EF values for direct emissions are applied (EA Austria 2017). The same trend of a flipped ratio is expected for Switzerland, which again points to the fact that direct emissions are greatly underestimated.

6.2 CH_4 emissions

Methane emissions from the WWTP are dominant compared to sewage gas handling and treatment, as can be seen in Figure 2. The proposed changes adapt the mass balance of sewage gas production and usage. They do not alter the results significantly but ensure consistent calculations.

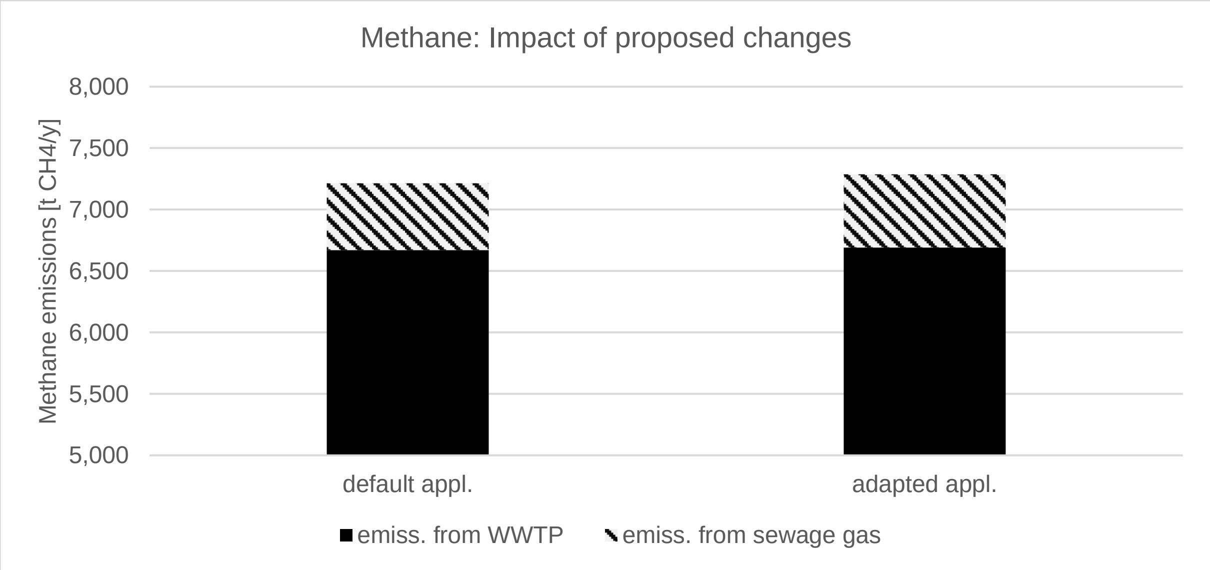

Figure 4: Assessment of methane emissions in the year 2016 - The data from Switzerland's NIR are displayed on the left and the implementation of the proposed changes on the right

Different country-specific methodologies can be found in the Austrian and German NIRs (EA Austria 2017, FEA Germany 2017). The main difference between these and Switzerland's assessment is that methane emissions from advanced WWTP are neglected. However, Germany and Austria also include the wastewater not treated at centralized advanced plants in the assessment and calculate the emissions accordingly. This share of wastewater is treated under anaerobic conditions. Both differences to Switzerland lead to the reporting of significantly lower methane emissions.

However, it is correctly stated in Switzerland's NIR that the wastewater not connected to centralized WWTP is treated at low temperatures, so that methane production is minimal and can be neglected (FOEN 2017, 2018). It is therefore proposed to retain the current approach for Switzerland.

7. Documentation

This review of the documentation examines whether the relevant data and information provided by FOEN are accessible and the assumptions are explained.

7.1 N_2O documentation

The documentation is complete and allows the calculations to be reproduced.

If the proposed changes are implemented, the update of the additional factors ($F_{NON-CON}$ and $F_{IND-CON}$) must be explained and mentioned as it corresponds to a deviation from the default value. Furthermore, it must be stated explicitly that industrial wastewater is included in the protein consumption and not accounted for by an external factor ($F_{IND-CON}$).

Summary: The documentation is detailed and reproducible. Further changes to the default methodology must be stated clearly.

7.2 CH_4 documentation

The documentation in the “EMIS-Kommentar” is very specific and accurate for the assessment of methane emissions from WWTP (FOEN 2018).

The source of AD for sewage gas is explained in the documentation. However, the calculations of the total sewage gas production and its separation into the categories of furnace, CHP installations, torches, leakages and upgrading are not stated in the commentary report (FOEN 2018). The calculation files (5_Kläranalagen__EMIS-Bericht-ohne-Mesap-Formeln-20180308.xls) are more specific about the AD and EF of the sewage gas and allow the reproduction and disclosure of errors. In the “EMIS-Kommentar”, an equation with the EF of sewage gas and a normalized population is stated but never applied in the calculation files.

Summary: The documentation of AD and EF of methane from wastewater treatment is accurate and complete.

Proposed changes: The assumptions and calculations of the sewage gas emissions should be included in the “EMIS-Kommentar” and explained properly.

8. Proposal of revised methodology

In this section, additional methods are proposed which describe the production and emission pathways of GHG more accurately. The aim was to develop methods based on the IPCC GL but refined for Switzerland. These are therefore labelled as *country-specific* according to the guidelines. Nevertheless, one goal was to design methodologies which are transferrable to other countries. The methods are based on literature reviews, expert judgements and running monitoring campaigns, so the finalisation of the proposals is pending until these campaigns have been concluded.

8.1 Country-specific nitrous oxide methodology

The proposed methodology for N_2O assessment is based on the protein consumption as the main indicator of nitrogen flows. These are the same indicator and activity data as in the IPCC GL. However, the mass balance of nitrogen on a WWTP is constructed differently in order to include the nitrogen removal via nitrification and denitrification.

8.1.1 Activity data on nitrogen loads and mass balance

The calculation of the nitrogen load in the wastewater treatment is similar to the IPCC GL. The additional factors for industrial and non-consumed protein are omitted, as these are not representative for the case of Switzerland, shown in Section 4.1. The calculation is shown in Equation 8.

It is proposed that no differentiation be made between plants with or without nitrification or denitrification. N_2O emissions are only expected from plants with nitrification and denitrification treatment steps. However, as carbon-only removal plants could be nitrifying in the summer, no simple assessment of the plants could be made and it is most practical not to distinguish between the types of plants.

The generalized mass balance for nitrogen on a WWTP includes nitrogen removal as a pathway which is not integrated in the IPCC GL approach. A simplified but correct way is to determine this value via the nitrogen removal rate based on data from the operators. The effluent load is assessed without specifying sludge amounts and nitrogen content in sludge: it is shown in Figure 3 and Equation 9.

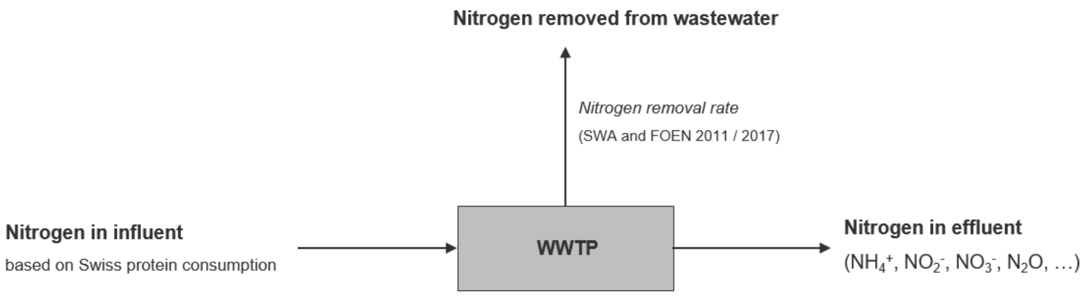

Figure 5: Simplified nitrogen balance on WWTP for climate reporting

The proposed nitrogen removal rate (Equation 9) is based on a 1993 report on WWTP in CH (FOEN 1996) and on two datasets from SWA and FOEN (SWA and FOEN 2011 / 2017). The assessment of the WWTP dataset by SWA, which contains the influent and effluent quality of about two thirds of the plants for the year 2010, resulted in an average nitrogen removal rate for Switzerland. The available influent and effluent data were evaluated and resulted in an average nitrogen removal rate of 48.7% over all plants in 2010 (SWA and FOEN 2011 / 2017).

The literature values for 1993 and the dataset for 2010 for the nitrogen removal rate were used to inter- and extrapolate a time series (FOEN 1996, SWA and FOEN 2011 / 2017). The expert stated that the relevant processes are gradually being implemented at plants and no change in legislation had taken place. Both factors result in a slow change of the removal rate and a linear function can be applied according to the expert. The full data series can be found in the file “Expert Review - additional data” under number 1. Additional information can be found in the notes from the expert discussion with Hansruedi Siegrist (Siegrist and Luck 2018).

Data series on the nitrogen removal rate for Switzerland:
(1993* and 2010* are set points – the other years are linearly extrapolated)

1990	1993*	2000	2005	2010*	2015	2020	2025	2030
25.3%	28.9%	37%	42.9%	48.7%	54.6%	60.4%	66.3%	72.1%

Influent nitrogen load for the calculation of onsite N_2O production:

$$N_{INFLUENT} = T_{PLANT} * Protein * F_{NPR} \qquad (8)$$

Effluent nitrogen load based on the average removal rate – substituting Equation 2 from the IPCC 2006 Guidelines:

$$N_{EFFLUENT} = N_{INFLUENT} * (1 - r_{NITROGEN\ REMOVAL\ RATE}) \qquad (9)$$

Parameters:

$N_{INFLUENT}$	Influent nitrogen Nload [kg N / year]
T_{PLANT}	Connection rate to WWTP [-]
Protein	Protein consumption [kg protein / year]
F_{NPR}	Nitrogen in protein [%]
$N_{EFFLUENT}$	Effluent nitrogen load [kg N / year]
$r_{NITROGEN\ REMOVAL\ RATE}$	Average nitrogen removal rate - data series is displayed above [-]

8.1.2 Emission factor for nitrous oxide in the wastewater sector

Three pathways for N_2O emissions from wastewater treatment are considered, as shown in Figure 6. The nitrous oxide produced onsite is either emitted through stripping into the air or remains in the wastewater stream and can subsequently be emitted to the air from the effluent. The third pathway is the production of nitrous oxide outside the plant from nitrogen in the effluent. The calculation of the emissions is shown in Equations 11, 12 and 13; the subscripts firstly indicate the production and secondly the emission location.

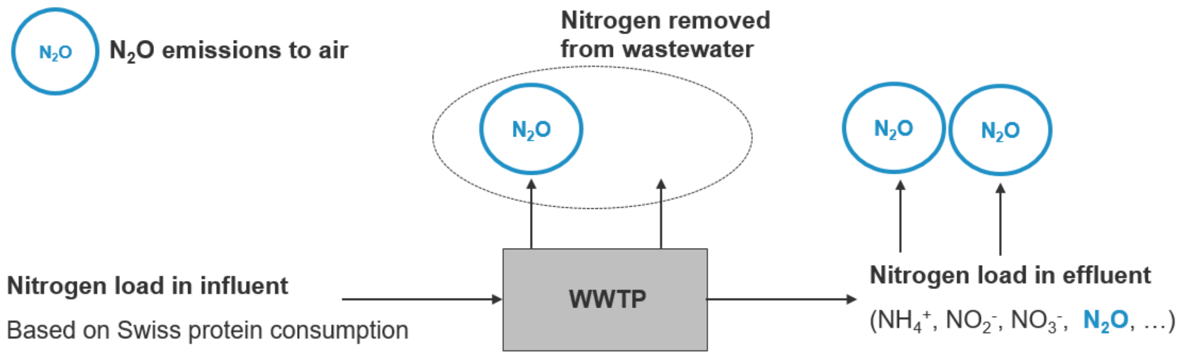

Figure 6: Nitrous oxide emission pathways in the proposed methodology: N_2O emissions from wastewater treatment, emissions from N_2O in the effluent, N_2O production and emissions in the effluent

The $EF_{N2O,\ PLANT}$ for N_2O from WWTP in the IPCC GL (IPCC Guidelines 2006) is based on a paper from the United States (Czepiel et al. 1995) in which field measurements at a plant with only nitrification processes are evaluated. A cross-check with the literature showed that the default value is significantly lower than recent long-term studies suggest (Daelman et al. 2015, Kosonen et al. 2016). The limited availability of the literature data and methodical differences in the strategies do not allow the revision of emission factors based on the available literature.

Long-term monitoring campaigns by eawag are consequently planned and in operation. The goal is to identify an EF [kg N_2O-N / kg $N_{INFLUENT}$] based on monitoring campaigns extending over at least ten years. The selection of WWTP should be representative of the WWTP landscape in Switzerland and allow the extrapolation to a national EF. The preliminary results, as shown in Table 3, indicate much higher emission factors than the default values in the guidelines. Each EF constitutes the aggregation of the monthly means to annual emission factors (containing each month once).

*Table 3 Compilation of measurement campaigns used to identify a preliminary emission factor (the EF identified with a star * are preliminary values from running monitoring campaigns)*

WWTP	Literature	Timespan	EF
Campaigns by eawag/ eth:			
Altenrhein SG	-	Dec. 2015 – Mar. 2017	1.1%
Emmen, REAL LU	-	Mar. 2014 – Sep. 2015	1.1%
Bazenheid SG	-	Jan. 2018 – Jul. 2018	2.5% *
Werdhölzli ZH	-	Aug. 2016 – Jul. 2018	0.5% *
Published campaigns:			
WWTP Kralingseveer	Daelmann, et al., 2013	Oct. 2010 – Dec. 2011	2.8%
WWTP Viikinmäki	Kosonen et al., 2016	Jul. 2012 – Jun. 2013	1.9%

The $EF_{N2O,\ PLANT\text{-}EFFLUENT}$ is assessed from the equilibrium of dissolved to stripped N_2O and refers to the total influent nitrogen load. The emission factor is based on the current measurement campaign at WWTP Bazenheid and data from February 2018 to July 2018.The result is a concentration of 0.03 g N_2O-N/ m^3 in the effluent and an emission factor $EF_{N2O,\ PLANT\text{-}EFFLUENT}$ of 0.0008 kg N_2O-N per kg $N_{EFFLUENT}$. This emission factor is based on one measurement campaign by eawag and could be validated by a second campaign at the end of the project, although no significant changes are expected. It is assumed that the EF is constant and can also be applied in the future. More detailed explanations and the full data series can be found in the additional data under Number 2 (Luck 2018).

No updated information on the emission factor from the discharge ($EF_{N2O,\ EFFLUENT\text{-}WATERBODY}$ = 0.005 kg N_2O-N /kg $N_{EFFLUENT}$) is available. However, it is *best practice* to use the default value of the IPCC GL and this is therefore also proposed here (IPCC Guidelines 2006). The multiplication of AD and EF is displayed in Equations 10 to 12.

Nitrous oxide emissions from WWTP to the atmosphere:

$$N_2O_{PLANT} = N_{INFLUENT} * EF_{N2O,\ PLANT} \tag{10}$$

Nitrous oxide emissions from onsite production and release from effluent:

$$N_2O_{PLANT-EFFLUENT} = N_{INFLUENT} * EF_{N2O,\ PLANT-EFFLUENT} \tag{11}$$

Nitrous oxide emissions from N_2O produced in effluent :

$$N_2O_{EFFLUENT-WATERBODY} = N_{EFFLUENT} * EF_{N2O,\ EFFLUENT-WATERBODY} \tag{12}$$

Parameters:

N_2O_{PLANT}	Nitrous oxide emissions from WWTP [kg N_2O-N / year]
$EF_{N2O;\ PLANT}$	Emission factor for onsite production and emissions [kg N_2O-N / kg N]
$N_2O_{PLANT-EFFLUENT}$	Nitrous oxide emissions to the effluent and subsequently to air [kg N_2O-N / year]
$EF_{N2O;\ PLANT-EFFLUENT}$	Emission factor for onsite production and emissions to effluent [kg N_2O-N / kg N]
$N_2O_{EFFLUENT-WATERBODY}$	Nitrous oxide emissions from effluent [kg N_2O-N / year]
$EF_{N2O;\ EFFLUENT-WATERBODY}$	Emission factor for production and emissions in effluent [kg N_2O-N / kg N]

8.2 Country-specific methane methodology

The wastewater collected in Switzerland is treated under aerobic conditions in well-managed plants. No significant methane emissions from the biological treatment steps are therefore expected. This assumption has been validated by the ongoing monitoring campaign run by eawag at WWTP Uster, where only about 0.001 kg CH_4 per kg $COD_{INFLEUNT}$ is emitted.

However, methane is produced and possibly emitted in the covered sewer system at the WWTP in the grit chamber, where the wastewater is aerated for the first time. In addition, the emission of methane from sludge treatment & storage and from sewage gas handling and usage also have to be considered. The revised methodology for methane emissions therefore includes methane production in the sewer as well as emissions from sewage sludge treatment and usage, as shown in Figure 7.

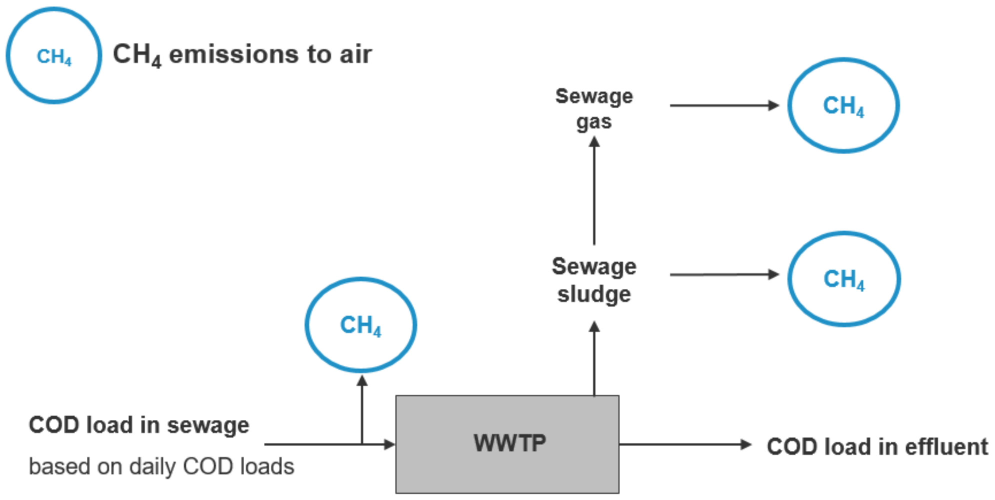

Figure 7: Methane emission pathways in the proposed methodology: CH_4 emissions from the sewer system, CH_4 emissions from sludge treatment and sewage gas usage

8.2.1 Activity data of organic load in sewer and sewage sludge treatment

The main difference is that this method considers the organically degradable material (TOW) per person in the sewer and not in the WWTP because the production of methane takes place in the sewer and not in the WWTP. It is assumed that the load of organic material in the sewer is similar to the influent of the WWTP and the same indicators as in the IPCC GL can be used, as shown in Equation 13.

The organically degradable material is indicated in kg BOD in the currently applied methodology, whereas it is reported in kg COD in the proposed methodology - Equation 13. The units were changed, as the influent and effluent loads in Switzerland are commonly indicated in COD. The two different units of organically degradable material can be converted on the basis of 2.0 kg COD / kg BOD.

The leakages from the treatment and storage of sewage sludge are assessed via the loss of sewage gas. An expert judgement allowed a time series to be developed in which the change from open to covered sludge storage is considered (Siegrist and Luck 2018). The expert stated that open sludge storage could result in emissions of up to 10% of the gas production. The study of M. Cunningham showed similar emissions and confirms the expert statement (Cunningham 2015).

A data series was developed together with an assumption on the number of open and covered plants. It shows the decrease of the total EF as a result of the decrease in the number of WWTP with open sludge storage. The data can be extrapolated to the future, but should be reviewed in the period 2025 – 2030. The full data series is displayed in the additional file under Number 3 (Luck 2018).

Data series on losses from sludge treatment and storage:
(1990 and 2015 are set points based on expert judgements – other years were linearly extrapolated; the time series ends in 2030)

1990	1995	2000	2005	2010	2015	2020	2025	2030
10.0%	9.0%	8.0%	7.0%	6.0%	5.0%	4.0%	3.0%	2.0%

The activity data from sewage gas production is similar to the approach currently in use. The main difference is that the “leakages” category refers not only to leakages from captured sewage gas but includes those from sludge treatment, as discussed in the paragraph above.

The sewage gas usage in the Federal statistics (FOE 2017) only reports part of the total production. The total production is calculated by dividing the reported sewage gas production by the reporting percentage: the formula is shown in Equation 15. This percentage is obtained from the assumptions on “leakages & torches” and listed below. The full dataset is included in the additional data under Number 3 (Luck 2018). An example of this calculation was discussed and executed in Section 4.2 and shown in Table 2.

Data series on percentage of sewage gas reported in national statistics (FOE 2017):
(Leakages from sludge treatment & stocking and burned sewage gas in torches are not included in the statistics, which are therefore divided by this factor to calculate the full sewage gas production)

1990	1995	2000	2005	2010	2015	2020	2025	2030
88.0%	89.0%	90.0%	91.0%	92.0%	93.0%	94.0%	95.0%	96.0%

Total organically degradable material:

$$TOW_{SEWER} = P * T_{SEWER} * COD * 0.001 * I * 365 \quad (13)$$

Sewage gas usage reported in Federal statistics:

$$P_{REP,\ SEWAGE\ GAS} = \sum P_{j,\ SEWAGE\ GAS} \quad (14)$$

Total gas production including unaccounted pathways:

$$P_{TOT,\ SEWAGE\ GAS} = P_{REP,\ SEWAGE\ GAS} / T_{Rep} \quad (15)$$

Parameters:

TOW_{SEWER}	Organically degradable material in sewer [kg COD / year]
P	Population [# person]
T_{SEWER}	Connection rate to sewer system = connection rate to WWTP [-]
I	Correction factor for additional industrial COD discharged into sewers [-]
COD	Per capita load of organically degradable material [g COD / pers. / day]
P_j	Reported usages in Federal statistics [TJ / year]
T_{REP}	Percentage of sewage gas reported [%]

8.2.2 Emission factor for methane in wastewater sector

Studies of the methane production in sewers are rare and not transferable to Switzerland due to different climatic and geographical conditions. The EF for methane production in the sewers is therefore based on laboratory studies (Liu et al. 2015). A mean concentration of methane was assumed on the basis of this compilation of methane concentrations in the raw wastewater. To determine the emission factor, the mean concentration was related to the COD concentration in the sewer, which is listed in textbooks (Gujer 2007).

The resulting emission factor of 0.015 kg CH_4 per kg COD was reviewed with the expert judgement of Hansruedi Siegrist (Siegrist and Luck 2018). He stated that he would expect 5% of COD in the raw wastewater to be transformed to CH_4, which results in a similar EF of 0.0125 kg CH_4 per kg COD.

The emission factors of different sewage gas usage are the default values provided by FOEN. They are based on an expert judgement, adapted to Switzerland and applied as in Equation 17 (FOEN 2018).

Methane emissions from sewer system:

$$CH_{4,\ WASTEWATER} = TOW_{SEWER} * EF_{CH4,\ WASTEWATER} \quad (16)$$

Methane emissions from sewage gas usage:

$$CH_{4,\ SEWAGE\ GAS} = \sum P_{j,\ SEWAGE\ GAS} * EF_{CH4,\ SEWAGE\ GAS,j} \quad (17)$$

Parameters:

$CH_{4,\ WASTEWATER}$	Methane emissions from sewer system / WWTP [kg CH_4 / year]

$EF_{CH4, WASTEWATER}$	Emission factor for methane production in sewer [kg CH_4 / kg COD]
$CH_{4, SEWAGE GAS}$	Methane emissions from sewage gas usages / leakages [kg CH_4 / year]
$P_{j, SEWAGE GAS}$	Sewage gas usage [TJ / year]
$EF_{CH4, SEWAGE GAS}$	Emission factor for methane from sewage gas usage [kg CH_4 / TJ]

8.3 Discussion of proposed methodologies

The new methodology proposed in this review assesses higher N_2O emissions than the currently applied IPCC GL. The preliminary results from the monitoring campaigns in particular indicate higher N_2O emissions from nitrification and denitrification. Emissions from dissolved N_2O in the effluent and later emitted to the air are only assessed in the proposed methodology and therefore increase the difference.

The emissions from $N_{EFFLUENT}$ have decreased as the load of nitrogen in the effluent was reduced due to the nitrogen removal step, which removes more nitrogen than in the currently applied assessment.

The assessment of methane emissions according to the new proposed methodology results in more CH_4 being released to the atmosphere. Coincidently the change in the activity data from BOD to COD and in the emission factor from $EF_{CH4, WWTP}$ to $EF_{CH4, SEWER}$ offset each other, so the emissions are the same in both methods.

However, the calculation of leakages from sludge treatment and storage increases the total CH_4 emissions. In 2016, the total emissions increased by a factor of 1.27 in the proposed method compared to the application of IPCC GL, shown in Figure 8. The difference between the two approaches decreased from 1990 to 2016, as the sewage gas usage increased and the leakages decreased.

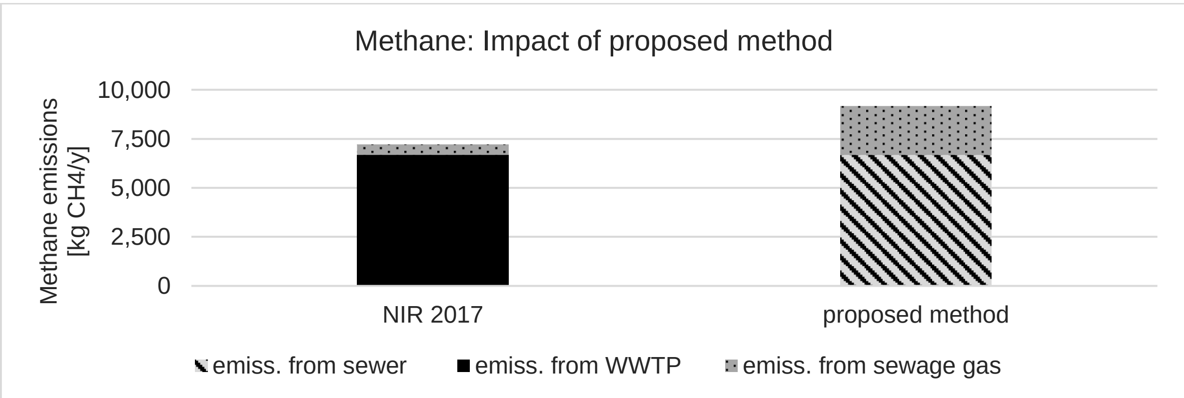

Figure 8: Impact of proposed methodology: Methane emissions based on IPCC GL and the new methodology of 2016

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