TEXTE
143/2023

Update of methane emission factors for natural gas supply

Comparison of previous greenhouse gas reporting methods with new findings from emission measurements in Germany

by:

Christian Böttcher

German Environment Agency, Department for Emissions Situation (Fachgebiet V 1.6 Emissionssituation)

Publisher:

German Environment Agency

TEXTE 143/2023

Update of methane emission factors for natural gas supply

Comparison of previous greenhouse gas reporting methods with new findings from emission measurements in Germany

by

Christian Böttcher
German Environment Agency, Department for Emissions Situation (Fachgebiet V 1.6 Emissionssituation)

On behalf of the German Environment Agency

Imprint

Publisher
Umweltbundesamt
Wörlitzer Platz 1
06844 Dessau-Roßlau
Tel: +49 340-2103-0
Fax: +49 340-2103-2285
buergerservice@uba.de
Internet: www.umweltbundesamt.de

Report completed in:
August 2022

Edited by:
Section V 1.6 Emissions Situation
Christian Böttcher

Publications as pdfs:
http://www.umweltbundesamt.de/publikationen

ISSN 1862-4804

Dessau-Roßlau, October 2023

Abstract: Update on emission factors for methane for natural gas supply

The European Green Deal, the Methane Pledge based on the United Nations Climate Change Conference in November 2021, the German Climate Protection Act, and other national and international efforts intend to reduce global methane emissions. Against this background, it is necessary to reflect the efforts of industry and politics in the national inventories. Extensive measurement programs of transmission system gas operators, distribution system operators, and other institutions have been carried out since 2019.

Results obtained have been included in the German inventory and are explained in this report.

Table of Contents

List of Figures

List of Tables

List of Abbreviations

Abbreviation	Explanation
AR	Activity rate
BAFA	Federal Office of Economics and Export Control
BPB	Federal Agency for Civic Education
CH_4	Methane
CO_2	Carbon dioxide
CRF	Common Reporting Format
DBFZ	German Biomass Research Center Non-Profit GmbH
DBI	German Fuel Institute
DIN EN	German Institute for Standardization, EN for European Standard
DSO	Distribution system operator
DVGW	German Association of the Gas and Water Industry e.V.
EF	Emission factor
EM	Emission
EU	European Union
GaWaS	Gas and water statistics
GWI	Gas Heat Institute (Gas-Wärme-Institut) Essen
HFS	High-flow sampling
HP	High pressure
IEF	Implicit emission factor
IGU	International Gas Union
IMEO	International Methane Emissions Observatory
IPCC	Intergovernmental Panel on Climate Chance
ISI	Institute for Systems and Innovation Research of the Fraunhofer Society
LBEG	State Office for Mining, Energy and Geology (Lower Saxony)
LDAR	Leak detection and repair
LP	Low pressure
M/R Station	Gas metering and regulating station
ME DSO	Methane-Emissions of Distribution System Operators
ME TSO	Methane-Emissions of Transmission System Operators
MOP	maximum operating pressure
MP	Medium pressure
NAL	Network connection pipeline
NEP	Network development plan
NIR	National inventory report
NMVOC	Non-methane volatile organic compounds
OGE	Open Grid Europe

Abbreviation	Explanation
SUS	Damage and accident statistics
TSO	Transmission System Operators
UBA	German Federal Environmental Agency
UNEP	United Nations Environment Programme
UNFCCC	United Nations Framework Convention on Climate Change
VL	Supply line
ZSE	Central system emissions

Summary

Germany is obliged to report greenhouse gas emissions annually due to various international regulations. This report considers methane emissions from the supply of natural gas according to IPCC Category 1.B.2.b. After extensive measurement programs, the emission factors in this area have changed significantly. According to the IPCC Reporting Guidelines, emission inventories must be complete, transparent, consistent, comparable and accurate. This results in the obligation to show and to compare the changes made. This is the subject of this report.

This switch of the reporting methodology will be used for the first time in the 2023 submission to be comparable with the reports according to the EU regulation on the reduction of methane emissions in the energy sector.

A comparison for 2020 shows that emissions based on the methodology used in the 2022 submission are 118 kilotons higher than those based on the new methodology in the 2023 submission. For the transmission system operators, the newly determined emissions are 55 percent below those of the previous calculation method, for the distribution system operators it is 77 percent. One of the main reasons for the sharp reduction in emissions is the calculation basis. So far, most of the factors have been based on measurements from the 1990s. Some of these were supported with only a few measurement data or even derived from factors abroad. In recent decades, numerous efforts have been made to reduce emissions, which are now being recognized by the data presented here.

1 Introduction

Methane (CH_4) is the second most important greenhouse gas after carbon dioxide and a major precursor in the formation of ground-level ozone. Reducing methane emissions helps protect the climate, human health and ecosystems (Appelhans et al., 2022).

There are increasing national and international efforts to significantly reduce methane emissions. However, missing or inadequate quantification of methane emissions is often cited. To address this issue at the European level, on December 15, 2021 (EC 2021), the European Commission adopted a proposal for future reporting of methane emissions from the energy sector. As part of the EU's methane strategy, meaningful reporting to the EU, as well as to international institutions such as the UNFCCC, will be required to better monitor the achievement of methane reduction targets. In addition, the U.S. and EU launched the Global Methane Pledge[1] in September 2021, with more than 100 countries committing to a 30 percent methane reduction by 2030 compared to 2020 emissions.

The Transmission System Operators (TSO) and the German Technical and Scientific Association for Gas and Water (DVGW) have carried out extensive measurement programs on behalf of their members in the distribution network area and have made their data available to the German Federal Environment Agency. These will be included in emissions reporting in 2023. This will result in significantly lower emissions in category 1.B.2.b. The purpose of this background paper is to explain the rationale for using the lower emission data and to explain the interpolations between the previous approaches and the new data.

[1] https://www.globalmethanepledge.org

2 IPCC and UNFCCC frameworks

Under the United Nations Framework Convention on Climate Change (UNFCCC) and the Paris Agreement, Germany is required to compile, publish and regularly update national greenhouse gas emission inventories. Additional reporting requirements are derived from the appropriate protocols. Basically, emission inventories have to meet the quality criteria of completeness, transparency, consistency, comparability and accuracy. This results in an obligation to continuously improve emission inventories and to carry out verification measures.

The IPCC Guidelines form the basis for the calculation of the inventories (Eggleston et al., 2006). Currently (as of August 2022), the 2006 guidelines must be used for reports. Germany has voluntarily committed to include aspects of the 2019 IPCC Refinement (Boettcher et al., 2019) in its reporting. These include natural gas vehicles and user emissions (see Table 1).

To meet the calculation requirements, the German Federal Environmental Agency uses the Central Emissions System (ZSE) database. Time series for emission sources and sinks are calculated here. Essentially, this is done using the formula specified by the IPCC (Rypdal et al., 2006) (Chapter 1.2)

$$Activity\ Rate\ (AR) * \ Emission\ Factor\ (EF) = \ Emissions\ (EM)$$

In a few cases, other calculation methods are used, which are described in detail in the National Inventory Report (NIR) published annually.

Although the UNFCCC reporting guidelines differ slightly from the IPCC guidelines (Volume 2, Chapter 4) in terms of structure, the subcategories for the category natural gas can essentially be assigned according to the following scheme:

Table 1: Subdivision of the reporting category "Fugitive Emissions from Natural Gas" according to UNFCCC CRF tables and IPCC Guidelines 2006 as well as indexing in the ZSE of the German Federal Environment Agency

Name according to CRF and IPCC	CRF Code (UNFCCC)	IPCC Guidelines 2006	UBA – ZSE
Exploration	1.B.2.b.i	1.B.2.b.iii.1	Exploration drilling (see Chapter 5.1)
Production	1.B.2.b.ii	1.B.2.b.iii.2	Production of natural gas (see Chapter 5.2)
Processing	1.B.2.b.iii	1.B.2.b.iii.3	Treatment of sour gas (see Chapter 5.2)
Transmission and storage	1.B.2.b.iv	1.B.2.b.iii.4	Shut-off device/gate valve (see Chapter 3) Natural gas compressor station (see Chapter 3) Cavern storage (see Chapter 5.3) Pore storage (see Chapter 5.3) Gas pressure control systems (see Chapter 3) Pipelines (see Chapter 3) Pigging (see Chapter 3)
Distribution	1.B.2.b.v	1.B.2.b.iii.5	Surface storage (see Chapter 5.4) Natural gas compressor station (see Chapter 4) M/R Station (see Chapter 4) Pipelines (see Chapter 4) Pigging (see Chapter 4) Natural gas vehicle tank emissions (see Chapter 5.5)

Name according to CRF and IPCC	CRF Code (UNFCCC)	IPCC Guidelines 2006	UBA – ZSE
Other	1.B.2.b.vi	1.B.2.b.iii.6	End-user emissions (see Chapter5.6)
Venting	1.B.2.c.i	1.B.2.b.i	No separate designation of methane emissions. Will be reported under "Transmission" or "Distribution".
Flaring	1.B.2.c.ii	1.B.2.b.ii	No separate designation of methane emissions. Will be reported under "Production" or "Processing".

Source: (Eggleston et al., 2006) and (UNFCCC 2022)

The tables and guidelines generally refer to "natural gas". Thus, according to IPCC Chapter 4, the category is defined as follows: "*Intentional or unintentional release of greenhouse gases may occur during the extraction, processing and delivery of* ***fossil fuels*** *to the point of final use. These are known as fugitive emissions*." (Carras et al., 2006) (Chapter 4.1) Already in the CRF tables, in Table 1.B.2, footnote 4, it was added that biogas also falls into this category. In the 2019 IPCC Refinement, the definition is expanded to include the phrase: "*Certain fugitive emissions from biomass are included here as well, such as fugitives of biogas from natural gas systems (e.g. distribution pipelines), and fugitives during fuel transformation for charcoal.*" (Boettcher et al., 2019).

Germany does not yet distinguish between biogenic and fossil methane for the purpose of determining methane emissions. Due to the low share of biomethane in the gas network and the lack of requirements in the guidelines, this is not planned in the medium term.

The territorial principle applies to the preparation of national emission inventories. Only the emissions that occur on German soil are reported. Therefore, emissions that occur through upstream chains abroad are not taken into account here. This information can be found in the respective National Inventory reports or documents on the UNFCCC page[2].

Other emission sources associated with methane emissions along the gas chain, such as biomethane production in biogas plants or methane leakage from incomplete combustion, are also not covered in this report, as they are assigned to other source groups according to IPCC guidelines.

[2] https://unfccc.int/ghg-inventories-annex-i-parties/2022

3 Derivation of the emission factors for the TSO

3.1 Initial situation

The emission factors used for the 2022 report are mainly derived from studies that refer to very old measurement data or to data collected outside German territory (Gottwald, 2012) (Chapter 3.2) and (Schütz, 2014).

Table 2: Emission factors used for 2022 reporting

Plant	Value	Unit
Shut-off device/gate valve	33.000	Kg/No
Natural gas compressor station	22.000	Kg/MW
M/R Station	548	Kg/No
Pipeline	158,9	Kg/km
Pigging	41,3	Kg/km
Pore and cavern storage	0.03	Kg/1000m³

References to the factors can be found in the following text section

As these factors have been held constant for years, technological improvements — such as the use of mobile compressors — are not reflected. On the contrary, due to the constant expansion of the infrastructure, emissions in this area have actually increased throughout Germany. In addition, for statistical reasons, electric compressors were calculated using the same emission factors. At the same time, they have significantly lower emissions than natural gas-powered compressors.

The emission factors for the shut-off devices (gate valves) and natural gas compressors are from a study by the DBI 2014 (Schütz, 2014) and are based on evaluations of the Wuppertal Study 2005 (Lechtenböhmer et al. 2005). This study mainly performed and evaluated measurements at Russian facilities.

The emission factor for the gas pressure regulating (measuring) stations comes from the DBI 2016 evaluation of the GaWaS (Zoellner & Große, 2015), which in turn refers to the study of (Reichert et al., 2000). All reported plants with an operating pressure greater than 16 bar were included. The resulting factor of 849 m^3 natural gas/plant*a [3] is slightly lower than the value of 924 m^3 natural gas/plant*a (Reichert et al. 2000) previously used in the Fraunhofer ISI study (Chapter 2.4).

For the pipelines, the emission factor from the Fraunhofer ISI study from the year 2000 (Reichert et al., 2000) was used. The origin of the factor comes from the 1989 Battelle study (Schneider-Fresenius et al., 1989), which in turn refers to a 1989 internal Ruhrgas AG report. Unfortunately, this report is no longer available. According to the Battelle study, fittings, flanges, expanders, condensate bowl drainage, blowout and purge volumes, and line damage are all included in the emission factor. Blowout and purging volumes result from repairs, line rearrangements, and the integration of new power supplies between two slides. It can be assumed that the maintenance and cleaning processes by pigging have not been considered. The DBI was therefore commissioned by the UBA to estimate these (see text box below).

[3] 849 m^3 natural gas/plant * Density 0.717 methane kg/m^3 * Methane content in natural gas of 90% yields 548 kg/plant

Pigging

The derivation of the emission factors described here and the data used are from the 2019 DBI assessment (Große, 2019 - unpublished).

For cleaning and inspection purposes, pigs travel with the gas stream from a transmitter station to a receiver station. Emissions are generated during loading and unloading. In addition, the locks can also have leaks. The pig locks found in Germany are included in the Gas-Water Statistics (GaWaS) of the German Technical and Scientific Association for Gas and Water (DVGW). Even though not all operators report to GaWaS, the degree of completeness is estimated to be over 90%. For the TSO, the number of permanent and temporary locks for the 2016-2018 survey period is between 683 and 689.

The assessment of methane emissions distinguishes between venting from loading and unloading and leakage. The exhaust emissions per operation were determined using the operating pressure of the line and the geometric volume of the lock. This results in approximately 660 m^3CH_4/process for pig locks in the transport network. The frequency of processes per year was estimated from expert interviews to be 0.3 processes per year per lock. When the methane emissions per process are multiplied by the frequency of the processes per year and the number of locks, this results in approximately 0.01 $ktCH_4$/a.

In the absence of a national value, an EF of 2,628 $kgCH_4$/(lock·a) was derived using the Swedish EF of 300 gCH_4/(lock·h) and a discharge time of 8760 h/year. Multiplied by the number of permanently installed locks in Germany, this results in an emission amount of 1.36 $ktCH_4$/a in the transport network.

To include this value in the time series of the UBA database, the emissions were divided by the pipeline length. Averaged over the years, this results in a value of 41.3 kg/km.

For the 2022 emissions report, the following emissions were reported for CRF category 1.B.2.b.iv "Transmission and Storage":

Table 3: Reported methane emissions for 2020 in the 2022 report in the category 1.B.2.b.iv "Transmission and Storage"

Plant	Value	Unit
Shut-off device/gate valve	37,189,900	Kg
Natural gas compressor station	27,179,460	Kg
Cavern storage*	452,580	Kg
Pore storage*	258,450	kg
Gas pressure control systems	518,408	kg
Pipework	5,372,250	Kg
Pigging	1,396,785	Kg
Overall	**72,367,833**	**kg**

*Emissions from cavern and pore storage are to be attributed to the storage companies and not to the TSO. The IPCC rules and the UNFCCC reporting guidelines summarize both in the CRF tables under "Transmission and Storage".

3.2 Measurement Program

In the period from September to November 2020, as part of the ME TSO (Methane-Emissions of Transmission System Operators) (TSO 2021) project, about five percent of the potential leakage points of the total set of long-distance network operators were completed by the measurement service provider "The Sniffers" using bottom-up measurements. The total measurement period was eight weeks.

The data set provided by the TSO includes 43,144 individual measurements. According to their own data, this represents five percent of all potential leakage points in the entire set. This was determined according to DIN EN 15446, and the most conspicuous areas were verified by High Flow Sampling (HFS). For measurements without a measured value, the lower limit of determination was specified (Fischer et al., 2021).

Measurement methods

The DIN EN 15446 method measures the concentration of methane in the vicinity of the suspected leak using a methane-sensitive detector based on one of the following principles: catalytic oxidation, flame ionization, infrared absorption or photoionization. This concentration is determined using the formula given in DIN 15446, Appendix C (DIN 2008).

$$ER = A\,(SV)^{B}$$

Where ER is the emission rate in kg/h, SV is the screening value in ppm, and A and B are correlation parameters as entered in Tables C.1 and C.2 as the standard.

High Flow Sampling (HFS) involves enclosing the leak site with a gas-impermeable fabric and then pumping the accumulated gas into a detection device. This allows a qualitative determination of the emission rate.

Both methods are well established in emission determination. HFS is much more complex and time consuming, but it gives much more accurate readings. It was also the basis for determining the correlation parameters in DIN EN 15446 (Fischer et al., 2021).

Five compressor stations were measured, one each from GUD, Bayernets and Gascade and two from OGE. In addition, 131 valve stations (20x Bayernets, 24x Gascade, 21x Gasunie, 11x Nowega, 35x OGE, 15x Ontras, 7x Thyssengas).

During the evaluation of the measured points, clusters were formed, and the following picture emerged (Table 4).

Table 4: Number of measuring points

Cluster	Number of measuring points	Share of total measurement
Compressor seal	7	0,02%
Flange	17,568	40,72%
Open end	89	0,21%
Pump seal	17	0,04%
Relief valve outlet	1	0,00%

Cluster	Number of measuring points	Share of total measurement
Stem control valve	730	1,69%
Stem valve	6,888	15,97%
Connection	17,844	41,36%

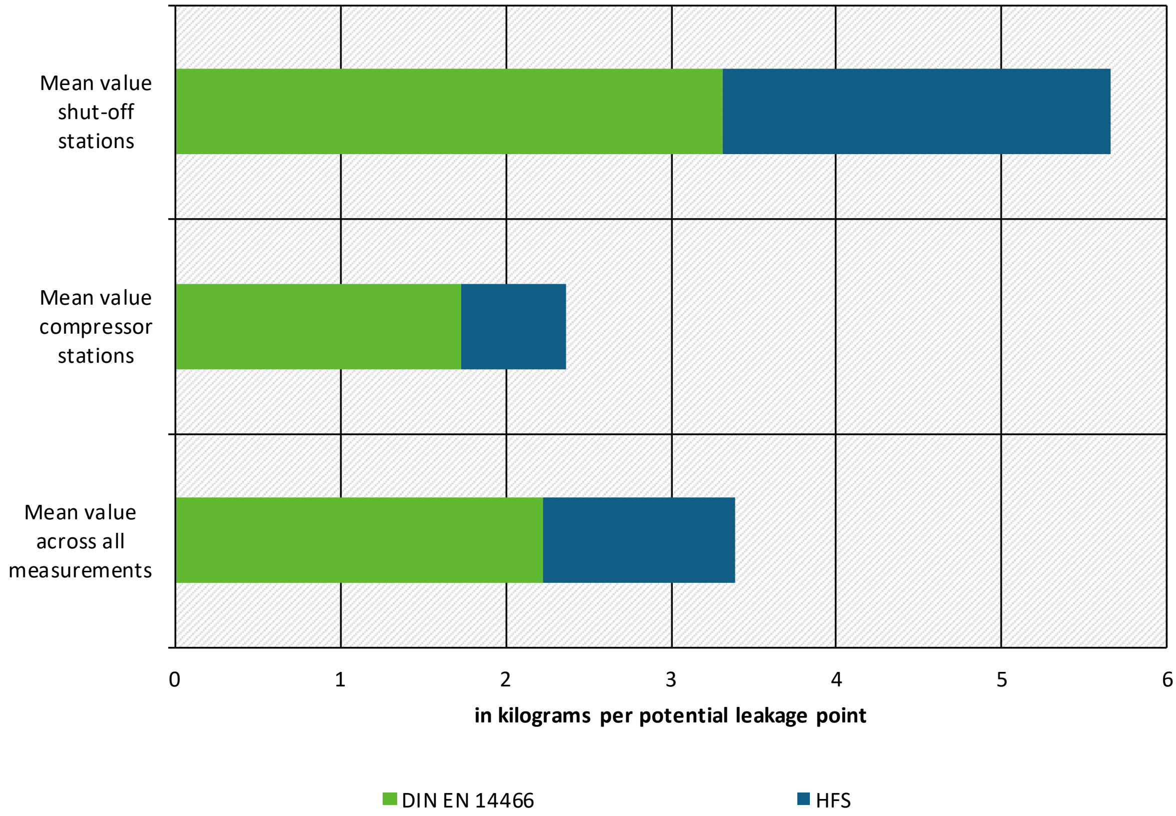
For the DIN EN 15446 measurement method only, the total emissions are 96,412 kg. For the combined measurement method, the total emissions are 56,686 kg (Table 5). This method always used the value from HFS. If none was available, the value from the DIN EN 15446 method was used.

Table 5: Measurements according to DIN EN 15446 and HFS

Cluster	Number of measurements	Share of the measured assets	Total emissions determined only according to DIN EN 15466 (kg)	Share of emissions in the total set according to DIN EN 15466 (kg)	Emissions according to combined measurement method DIN EN 15446 and HFS (kg)	Share of emissions in the total set by combined method
Compressor seal	7	0.02%	0.2	0.00%	0.2	0.0%
Flange	17568	40.72%	9098	9.44%	4366.3	7.7%
Open end	89	0.21%	7081	7.34%	7081.0	12.5%
Pump seal	17	0.04%	4	0.00%	3.6	0.0%
Relief valve outlet	1	0.00%	63	0.07%	63.1	0.1%
Stem control valve	730	1.69%	2876	2.98%	524.3	0.9%
Stem valve	6888	15.97%	47851	49.63%	17210.1	30.4%
Connection	17844	41.36%	29439	30.53%	27437.2	48.4%
Sum	**43144**	**100.00%**	**96412**	**100.00%**	**56686**	**100.00%**

This shows that the more accurate HFS method leads to lower emission values. This becomes even clearer when comparing the emissions of the plants (Figure 1). The HFS method cannot be used at all measurement points because of the time required to perform it. Thus, the combined method of the TSO represents the conservative approach and is suitable for calculating emissions compared to the UNFCCC.

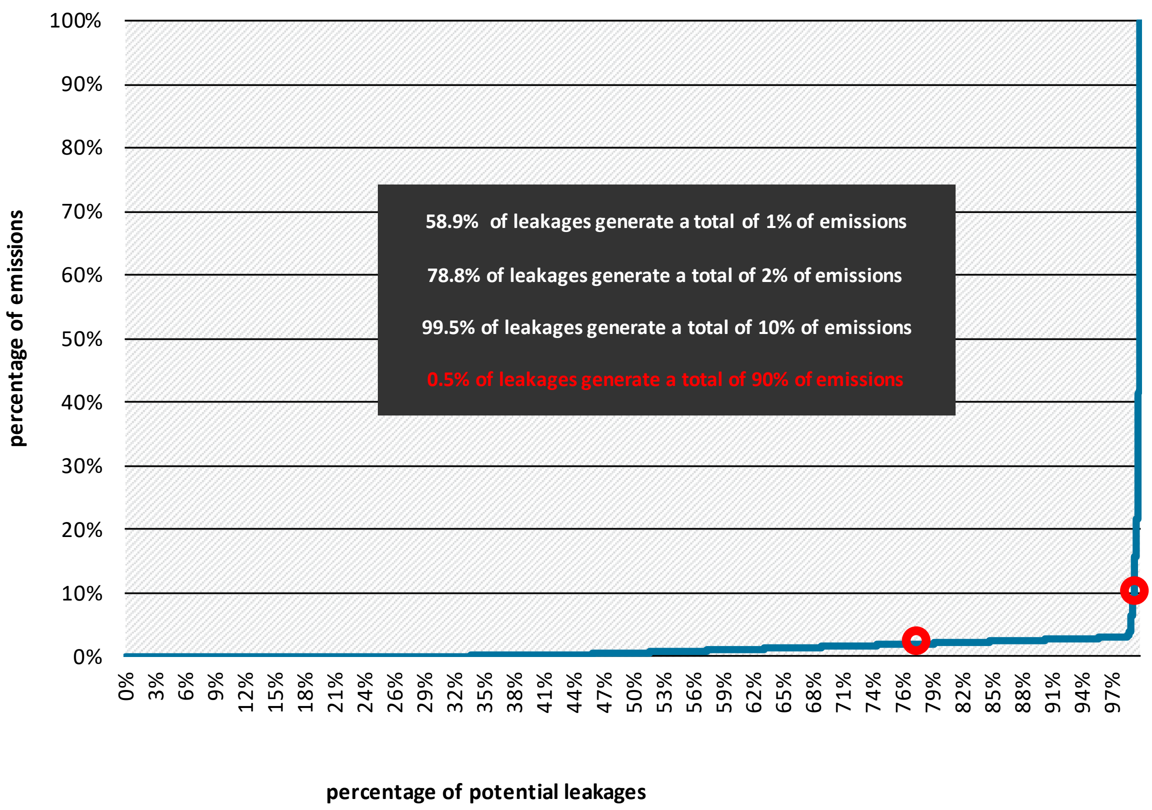
Figure 1: Comparison of the two measurement methods by means of plant-specific emissions



Source: Own representation based on TSO measurement data, German Federal Environment Agency

The accumulation of all emission values clearly shows that 0.5% of all leaks are responsible for 90% of emissions (Figure 2).

Figure 2: Potential leakage points as a percentage of emissions



Source: own representation based on the data set transmitted by the TSO, German Federal Environment Agency

This finding clearly shows that extensive LDAR campaigns are not only necessary for reporting, but also give operators an overview of where they need to focus their search for leaks.

The data was applied by the TSO to its total assets and provided to the UBA. In addition, these were transmitted to IMEO (Kupers et al., 2021).

3.3 Evaluation of the results

In order to be able to classify the data, it is advisable to use similar measurement programs in neighboring countries. In the Swedish NIR (Jonsson et al. 2022) reference is made to a similarly extensive measurement program from Swedegas (Table 6).

Table 6: Measurements by Swedegas in Sweden

Cluster	Emission factor	Unit	Number of plants
M/R station	797	kg/a	43
Storage	1752	kg/a	1
M/R+Compressor	1945	kg/a	1
Compressor	876	kg/a	1
Valve station	263	kg/a	26
Pig station	2628	kg/a	9

Cluster	Emission factor	Unit	Number of plants
Ramification station	263	kg/a	39

The data in the Swedish NIR 2021 Table 3.34 are in g/h – this was multiplied by 8.76 to determine kg/a

Since not all plants are comparable to the German ones and not all plant types have been measured in Germany yet, an implicit emission factor is determined in accordance with IPCC Guidelines 2006 (Winiwarter et al., 2006) (Page 6.13) in order to be able to compare the countries. Multiplying the number of plants by the calculated emission factors and adding them together gives a total emission of 79.6 metric tons of methane. Relative to the 620 km of pipeline network, this gives an IEF of 128 kg/km.

If we take the total emissions of the German TSO of 16.4 kt (Table 11), add the emissions of the storage facilities (from NIR 2022 (Günther & Gniffke, 2022) (Chapter 3.3.2.2.4): 0.7 kt according to the old calculation method), 17.1 kt of methane is obtained. If you put this in relation to the pipeline network of 35,476 km, you get an IEF of 482 kg/km.

In the Netherlands, according to NIR 2022 (Ruyssenaars et al., 2022), an extensive LDAR program has been in place since 2016, where all compressors are regularly measured. Accordingly, the transmission system operator N.V. Nederlandse Gasunie accounts for 4.6 kt of methane in the Netherlands. Based on its own information, this operator has 12,000 km of pipeline network. This corresponds to an IEF of 385 kg/km (NV 2017).

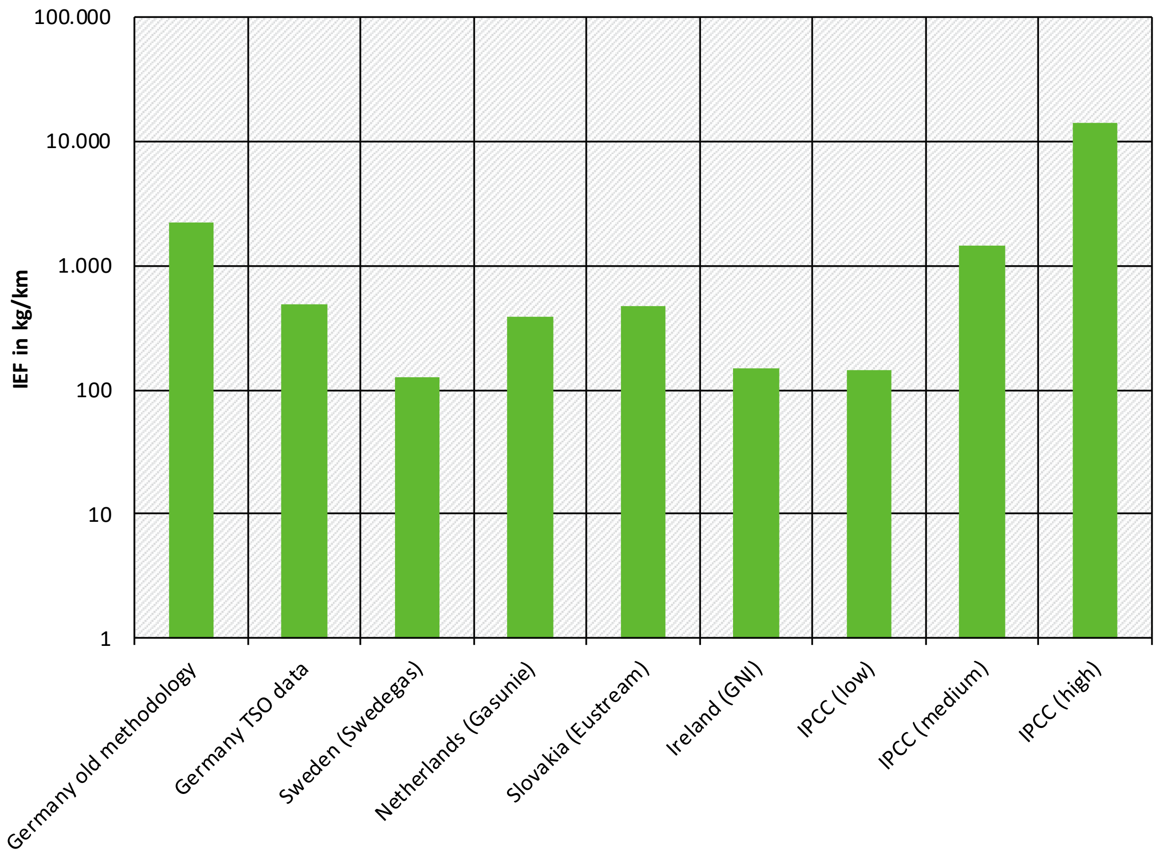
Slovakia reports in the NIR 2022 (Szemesová et al. 2022) (Page 129) that emission data are determined according to the Tier 4 Approach according to OGMP 2.0. The data is collected by the sole operator Eustream through measurements and calculations. If we take the reported 1.06 kt methane emissions from the CRF tables in relation to the line length of Slovakia of 2,270 km (ENTSOG and NET4GAS 2012) an implicit emission factor of 466 kg/km is obtained.

Ireland also reports receiving operator specific data from Gas Networks Ireland in its 2022 NIR (Duffy et al., 2022) (page 118). The reported value of 367.65 t in relation to the pipeline length of 2477 km (GNI 2019) (Table 12.2) gives an implied emission factor of 148.4 kg/km.

The scale shows that the countries are comparable (see Figure 3). The IEF for the old German calculation method is 2212 kg/km and lies between the average and the highest emission factor from the IPCC Guidelines 2006, Table 4.2.8 (Boettcher et al., 2019).

Figure 3: Comparison of the IEF

Logarithmic representation; reference to the year 2020



IPCC data (Volume 2, Chapter 4 – Table 4.2.8) converted from m³/a to kg/a with density of 0.717 kg/m³]

Source: Own representation, German Federal Environment Agency

3.4 Derivation of new emission factors

3.4.1 Derivation of emission factors from the 2020 monitoring program

The TSO have determined an emission of 6,430 tons for compressor stations. Dividing this by the installed compressor capacity of 2068.2 MW gives an emission factor of 3,109 kg/MW.

In the case of the valve nodes, the emissions are 4,966 tons. The number of nodes is 11,075, which gives an emission factor of 448 kg/No. However, it must be noted that the definition of the valve nodes is different than for the previous valve stations. In chapter 3.4.2 this will be discussed in more detail.

Although emissions from the pipes were not included in the measurement program, the emission factor was slightly reduced from 2010 onwards. Mobile compressors have been in use since 2010. They pump the gas into other piping systems in blocked sections, so that the maintenance emissions (esp. venting) are significantly lower than before. According to the OGE's own information (OGE 2022) 95% of methane emissions can be prevented in this way.

The emission factors of the M/R Station were kept constant.

Thus, the following emission factors result:

Table 7: New emission factors for the reporting year 2020

Plant	Newly derived factor	Previously used factor
Pipelines Pigging	104 kg/km 41 kg/km	159 kg/km 41 kg/km
Compressor	3.109 kg/MW	22,000 kg/MW
Valve nodes Valve station	448 kg/No	 33,000 kg/No
M/R Station	548 kg/No	548 kg/No

The data was requested in a discussion between the TSO and UBA (Boettcher et al., 2021).

3.4.2 Interpolation in the years 1990 and 2020

The TSO have set a goal of reducing their emissions by 50% compared to the base year 2015 (Fischer el al. 2021). For the year 2015, emissions of approximately 22 million kilograms have been determined based on individual measurements and projections. This value is also taken into account for the interpolation.

Since there is currently no newer data available for the storage operators, the old methodology (see Chapter 5.3) will be used for the time being.

For the M/R Station, data from GaWaS were previously interpolated between the 1990 and 2012 support years and then extrapolated forward. However, during the evaluation of the GaWaS by the DBI, it was pointed out (Boettcher et al., 2015) that some operators have dual designation of their facilities as both regulating stations and M/R Station. The previous values therefore had a high degree of uncertainty. Since operator reports are now available for 2020, the 1990 GaWaS or SUS value of 604 systems and the TSO value of 832 are now interpolated. The emission factor is continued as described in Table 19.

The performance of natural gas compressors was previously covered by the Network Development Plan (NEP) (von Ohlen, 2021b) and allocated to the distribution and transmission networks using a split factor. This factor comes from the DBI's 2014 evaluation (Zoellner et al., 2014 – unpublished) of GaWaS (see Table 13). Due to strong fluctuations, the value of 0.59 was set for all years. In the early years, however, there were hardly any compressors in the distribution network. It was not until the 2000s that these were increasingly used, for example at natural gas filling stations and biogas feed-in plants. For example, according to Müller BBM, the number of natural gas filling stations increased from around 40 in 1997 to as many as 900 in 2011 (Bender & Langer, 2012) (Chapter 4.3). Therefore, it can be assumed that there were false entries in the GaWaS during this time. As can be seen from Table 13, the factor has changed significantly in the years after 2016. However, it can also be seen that the entries in the TSO performance vary greatly.

The implementation report on the NEP Gas 2020-30 of the TSO shows a total of 2,810 MW of compressor capacity, which were installed at the remote network operators as of the reporting date 31.12.2019 (von Ohlen, 2021a). However, this value is not absolute in the report, as some operators provide only approximate information. According to the DBI 2021 evaluations, this also includes double counts as some operators use and specify the same compressors. Adjusted to DBI 2020, the result is a capacity of 2,217 MW (Große, 2020 – unpublished).

This value, as well as that of the NEP 2020, differs from the entries of the GaWaS. Due to the large fluctuations in the database, the value of 2068.2 MW for 2020 reported directly to UBA by the TSOs is now used and interpolated between the 1997 values from the DVGW SUS and the Fraunhofer ISI (Reichert et al., 2000) evaluations.

The emission factor is left at the original value until 2000 and then interpolated between the newly determined values (see Table 19).

The number of valves in the TSO reports differs by an order of magnitude from those in the ZSE reports. The ZSE value is calculated on the assumption that there is a valve station every 30 km. But this is not generally true. There are significantly more, especially in the old network (built before 1970). The TSO has specified the number of shut-off elements in its OGMP notification. Although there is no direct correlation between the gate station and the shut-off element (or valve), newer stations always have about 5-10 valves installed (track valves, bypass valves, blow-out valves, etc.) (Boettcher et al., 2022). To ensure consistency between the previously used methodology and the new data, the value of the TSO of 11,075 was divided by 10. According to the old methodology, 1127 were calculated. The difference is less than 2%. So we can assume a good approximation. The emission factor determined in Table 7 must now be increased by a factor of 10 for consistency.

According to the IPCC guidelines, not taking this into account would mean a methodological break in the activity rates, since a different reference value is used only for the year 2020. Since this is not permissible, the adjusted value for the shut-off devices is selected.

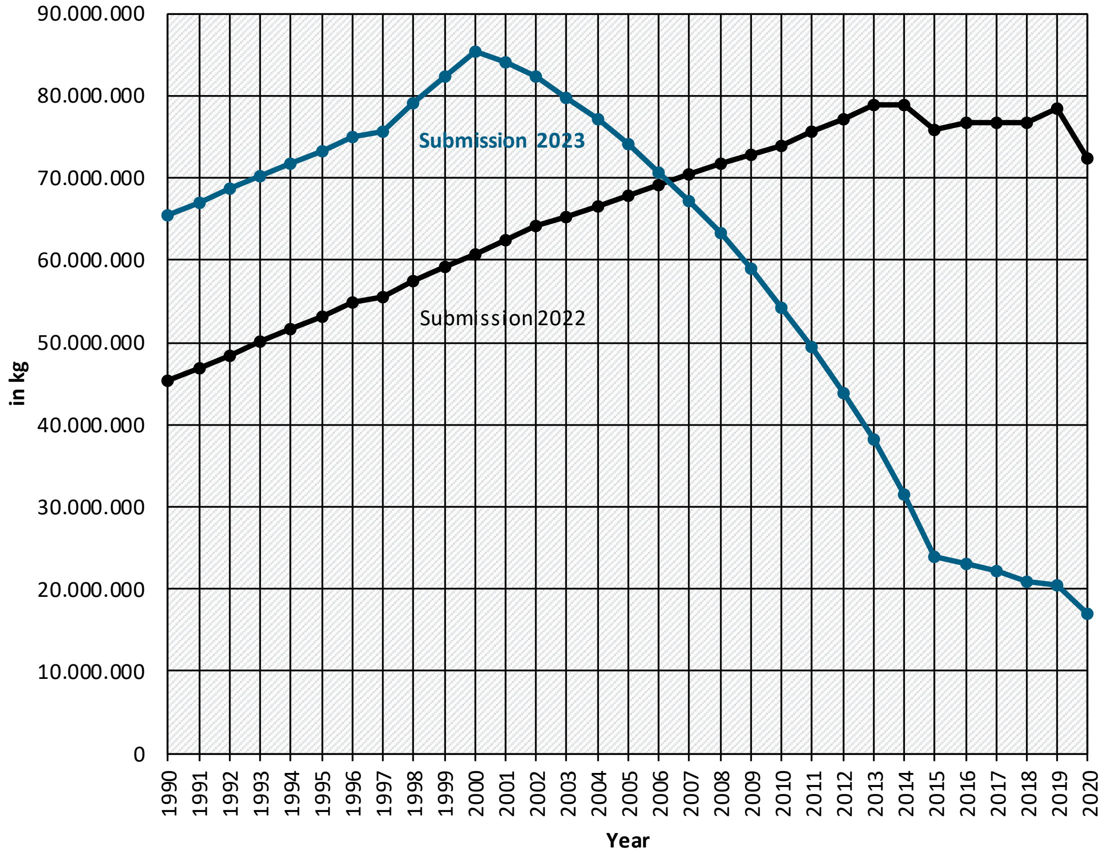
Table 8: Emissions determined for the 2023 report for the reporting year 2020 in category 1.B.2.b.iv "Transport"

Source	Unit	1990	2000	2010	2020
Natural gas compressors	kg	34,800,000	42,173,250	29,406,391	6,430,034
Capacity	kg	1,280,000	1,302,000	1,278,000	711,030
Pipelines	kg	3,606,395	5,118,805	5,641,427	3,516,136
Pigging	kg	937,663	1,330,889	1,466,771	1,396,785
M/R Station	kg	330,992	333,549	336,107	338,664
Shut-off devices	kg	24,609,308	35,066,651	16,202,228	4,626,259
Total	**kg**	**65,564,358**	**85,325,144**	**54,330,923**	**17,018,907**

As of the date of this report (August 2022), the data for the 2023 report has not yet been coordinated by the Department and has not yet been reviewed and finalized through various reviews, Therefore, there may be discrepancies between the official data and the report to the UNFCCC dated April 15, 2023.

Figure 4: Comparison of 2022 and 2023 submissions

Reference to the year 2020 – Data in the 2023 submission is preliminary, as interdepartmental coordination had not been completed at the time of reporting.



Source: Own representation, German Federal Environment Agency

3.4.3 Comparison of emissions

The TSO have a value for the year 2020 of 16.384.000 according to OGMP reported to IMEO. This was determined mostly with the Level 2 approach (see Chapter 3.5). In order to ensure a transition between the method from ZSE, based on time series, and the plant-specific method according to OGMP, the new reporting has to be adapted once to the old reporting to allow interpolation on time-series level. The last reporting year under the Framework Convention on Climate Change was chosen for this purpose.

Table 9: Emissions determined for the 2023 report for the reporting year 2020 in category 1.B.2.b.iv "Transport"

Source designation in the ZSE	Emissions according to the previous methodology	Emissions according to a new methodology	Unit	Deviation
Shut-off device/gate valve	37,189,900	4,626,259	Kg	-88%
Natural gas compressor station	27,179,460	6,430,034	Kg	-76%
Cavern storage	452,580	452,580	Kg	0%
Pore storage	258,450	258,450	kg	0%
Gas pressure control systems	518,408	338.664	kg	-35%

Source designation in the ZSE	Emissions according to the previous methodology	Emissions according to a new methodology	Unit	Deviation
Pipework	5,372,250	3,516,135	Kg	-35%
Pigging	1,396,785	1,396,785	Kg	0%
Overall	**72,367,833**	**17,018,907**	**kg**	-76%

As of the date of this report, the data for the 2023 report was still in the process of being coordinated between departments and had not yet been verified and finalized through various reviews. Therefore, there may be discrepancies between the official data and the report to the UNFCCC dated April 15, 2023.

For 2020, emissions with the newly derived emission factors are almost 0.45% lower than the OGMP data provided by the TSO (Table 10). This is mainly due to rounding of activity rates. For the base year 2015 chosen by the TSO, the emissions are about eight percent higher than the emissions reported by the TSO to IMEO. The linear interpolations in particular have a significant influence here. However, the emissions reported to IMEO for 2015 are also subject to higher uncertainties as there was no comprehensive measurement program in place at that time and some emissions were estimated.

3.5 Future reporting

The OGMP initiative is currently (as of August 2022) voluntary and not all companies are members. For the seven members, their asset data was aggregated and compared to the total assets of all TSOs.

Table 10: Share of the total set of OGMP members for 2020

Description	Pipelines (km)	Compressor (MW)	Valve nodes	M/R systems
Assets OGMP Members	29,108.9	2,018.2	10,713	534
Total assets of the TSO	33,808.5	2,068.2	11,075	832
Share of the total assets of all TSO	86.1%	97.6%	96.7%	64.2%

The data was requested in a discussion between the TSO and UBA (Boettcher et al., 2021).

The remainder falls to non-members. The missing emissions can then be extrapolated from the emissions of the individual assets.

For future reporting, the TSO will submit a template to the UBA that includes operational and volatile emissions as well as methane emissions from incomplete combustion. The data of the companies that only report according to OGMP Level 1 are divided by the emission sources using the emission factors and the asset data. Overall, the majority of the TSO reports according to the higher aggregation level (level 2). This data is aggregated for emissions reporting (Table 11). However, the UBA has the data at the operator level, so that inquiries can be made in a targeted manner.

Table 11: Emissions of the OGMP members and extrapolation to all TSO

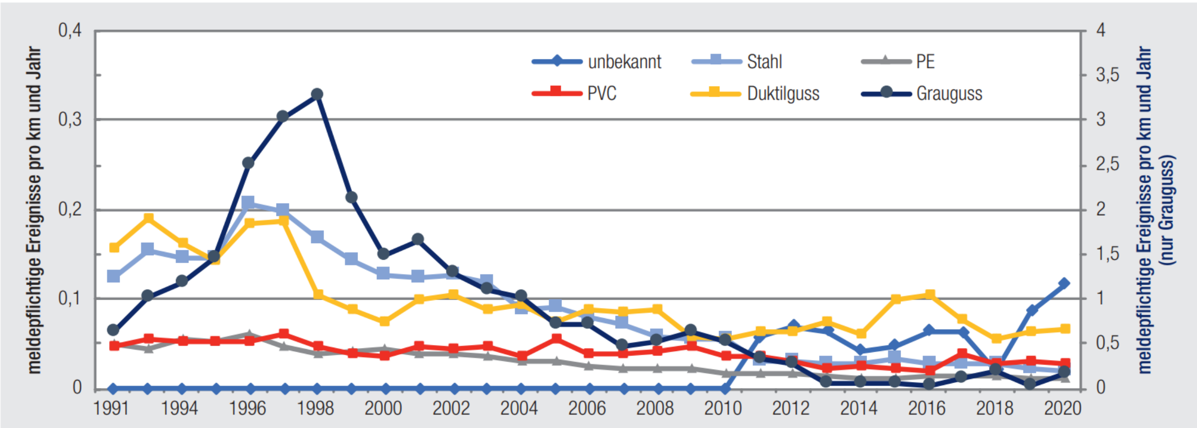
Year 2020	Total of OGMP members	Extrapolation to all TSO
Transmission grid	4,295 t	4,988 t
TSO – Reduction & regulating stations / Measurement stations / Valve stations / Consumer supply stations for metering and regulating	4,547 t	4,966 t
Compressor stations	6,274 t	6,430 t
Sum	**15,117 t**	**16,384 t**

4 Derivation of the emission factors for the DSO

4.1 Initial situation

The emission factors for pipelines used in the 2022 report are primarily derived from the Fraunhofer ISI study of 2000 (Reichert et al. 2000) (Chapter 2.3.2), but were adjusted in the study (Gottwald, 2012) for the years 2003 to 2008 using the following formula and damage event assessments (Figure 5). The Fraunhofer ISI study is based on a measurement program conducted by Gelsenkirchen University of Applied Sciences and Ruhrgas AG in the mid-1990s. For this purpose, the number of leakage points per kilometer of the SUS of the DVGW was used and emission factors were calculated from the measurement program with an average leakage rate of 140 l/h. The evaluation of the SUS up to 2010 and the GaWaS from 2011 onwards shows that a high number of leakage points occurred, especially in the late 1990s (see Figure 5). The calculations are therefore very conservative, especially from the 2000s onwards.

Figure 5: Development of reportable events between 1991 and 2020 on all gas pipelines by material groups



Source: (Lange et al., 2021) (Page 75).

Translation : « meldepflichtige Ereignisse pro km und Jahr » = « events subject to reporting per km and year » ; « meldepflichtige Ereignisse pro km und Jahr (nur Grauguss) » = « events subject to reporting per km and year (only gray cast iron) » ; unbekannt = unknown ; Stahl = steel ; Duktilguss = ductile cast iron ; Grauguss = gray cast iron

The emission factors were determined according to ISI using the following formula (Reichert et al. 2000) (Page 8).

$$E = 8{,}76 * R * N * F * \frac{1}{2}(J + j)$$

Considering the following:

E = emissions in m^3/year

8.76 = the conversion from l/h to m^3/year

J = the monitoring period

N = number of leaks per kilometer of monitored pipeline

j = repair period of leaks in years

F = proportion of methane in natural gas

R = average quantity discharged per leak in l/h

The distribution of pressure levels was done according to the approach of the BGW (Bundesverband der deutschen Gas- und Wasserwirtschaft – predecessor of today's BDEW). Accordingly, lines below 100 mbar were defined as the low-pressure range, lines between 100 and 1000 mbar as the medium-pressure range, and lines above 1000 mbar operating pressure as the high-pressure range. These pressure levels have been divided at the state level into material types such as cast iron, steel, plastic, and others. In addition, house connection lines were shown separately and statistics on the types of gas meters were indicated. These data were determined by means of an operator survey and represented over ninety percent of the inventory (footnotes of Tables 11 to 20 in the 117th gas statistics) (BDEW 1996). After the merger with BDEW in 2007, these statistics were only partially continued. The material breakdown is no longer reported. Therefore, the material key from GaWaS was used for reporting, even if it referred to other pressure levels.

Table 12: Emission factors used for 2022 reporting

Source designation in the ZSE	Value	Unit
Surface storage	5	Kg/1000m³
Natural gas compressor station	22.000	Kg/MW
M/R Station	256	Kg/No
HP – Plastic piping, other materials	0,3	kg/km
HP – Piping made of steel and ductile cast iron	62	kg/km
MP – Plastic piping, other materials	28	kg/km
MP – Piping made of steel and ductile cast iron	207	kg/km
LP – Grey cast iron pipe	445	kg/km
Plastic LP piping, other materials	51	kg/km
Steel and ductile cast LP piping	372	kg/km
Pigging	0,66	Kg/km
Natural gas vehicle tank emissions	0,3	Kg/No

References to the listed emission factors can be found in the following section of the text.

For the calculation of greenhouse gas emissions, the house connection lines, as listed in the ISI study, were (Reichert et al. 2000) (Chapter 2.3.3) not included. The BGW gas statistics could not reflect the breakdown by material. In addition, in the 2000s, the gas suppliers already partially integrated the supply lines into the local network (internal file note dated 03.01.2007). For example, according to the 138th BDEW gas statistics in 2016 (BDEW 2018), 166 operators reported their data, including house connection lines. This approach has been proven plausible by comparing the cable lengths with the monitoring report (see Table 15).

In the absence of a representative emission factor for natural gas compressors in the distribution system (e.g. for biogas feed-in plants and natural gas filling stations), the factor was taken from the transmission grid[4]. Since the data on the compressor capacity used in Germany differed significantly between the different data sources (NEP, GaWaS, direct reports), a splitting factor derived from GaWaS based on 2014 was split between the TSO and DSO with the total compressor capacity installed in Germany. During the year, up to 47% of the total compressor output was allocated to the DSO and 53% to the TSO. From today's perspective, this division has led to a significant overvaluation of the distribution network. This is the conclusion of the DBI (Große, 2020 – unpublished), which created the subsequent division:

Table 13: Installed compressor capacity in Germany according to GaWaS and distribution according to DSO and TSO

Year	DSO (MW)	DSO Share of total output as a percentage	TSO (MW)	TSO Share of total output as a percentage
2013	1573	56,66	1203	43,34
2014	1636	47,15	1834	52,85
2015	1485	54,84	1223	45,16
2016	485	15,44	2656	84,56
2017	483	26,73	1324	73,27
2018	482	24,32	1500	75,68
2019	483	18,93	2069	81,07
2020	478	20,51	1853	79,49

Compressor capacity in Germany according to GaWaS – DBI Große 2020 evaluations

It was not possible until 2015 to definitively clarify why the split in GaWaS was almost 50/50 between TSO and DSO. The years from 2016 onwards show an almost constant picture, so the values shown here can be considered reliable. TSO's fluctuations are not plausible, according to personal interviews with OGE and Gascade (Boettcher, Lang, et al., 2022), which together operate more than 83% of the installed services. This leads to the conclusion that there is incomplete coverage here.

The emission factor for surface storage was found in the Fraunhofer ISI 2000 study (Boettcher, Lang, et al., 2022) (Chapter 2.4; Table 2.6). It is currently being determined how much working gas is still available in Germany. A study by Müller-BBM estimated 60 million m^3 for 2012 (Bender & Langer, 2012). In a 2013 DBI study, amount was only 9 million m^3 (Große, 2018 – unpublished). Based on press releases and individual operator surveys, the UBA assumes that only half of the 2012 storage capacity will be used by 2020. However, this value is still significantly higher than that of the DBI study.

The factor for natural gas vehicle tanks was determined in the Müller-BBM 2011 (Bender & Langer, 2012) study and also rated as fairly good by the IPCC 2019. Since this has also been included in the IPCC Guidelines (Boettcher et al., 2019) (page 4.81), a renewed investigation is not planned (compare the derivation in Chapter 5.5). However, it is currently being considered whether emissions from natural gas vehicles should be reported under the IPCC category

[4] To this end, a research project will be launched at the DVGW in 2022 – see Chapter 8.4

"other" instead of "distribution" (see Table 1). However, the reallocation has a small impact on the amount of emissions.

The emission factor for the M/R Station is derived (in a similar manner to the plants in the transport network) from GaWaS evaluations and two DBI studies (Zoellner & Große, 2015). All reported plants with an operating pressure of less than 16 bar were included. For plants with a MOP of less than 5 bar, the value is 225 kg of natural gas per plant; for plants with a MOP between 5 and 16 bar, the value is 472 kg of natural gas per plant. Averaged over the number of plants, this results in a value of 396 m^3 of natural gas/plant*a.

The emission factor for pigging is the same as the methodology in the Chapter 3.1 text box. For the DSO, the number of permanent and temporary locks for the study period 2016-2018 is 138 to 140. The blowout emissions per operation were determined using the operating pressure of the line and the geometric volume of the lock. This resulted in around 340 m^3CH_4/process for pigged pipelines in the distribution network. If the methane emissions per process are multiplied by the number of processes per year and the number of locks, the result is approximately 0.1 kt CH_4/a (Große, 2019 – unpublished).

For the entry and exit processes, an emission quantity of 0.33 ktCH_4/a was determined in the distribution network, analogous to Chapter 3.1 (Große, 2019 – unpublished). To include this value in the time series of the UBA database, the emissions were divided by the line length. Averaged over the years, this results in a value of 0.66 kg/km.

4.2 Measurement Program

The DVGW measurement program included 126 measurements on underground pipelines. 28 distribution system operators participated nationwide. In addition to the supply lines, mains connection lines made of various materials (steel, plastic, ductile cast iron) of different years of construction were also examined. In addition, measurements were taken on 159 gas pressure regulating and metering systems at ten distribution system operators at various pressure levels and years of construction. The measurement program also aimed to develop a measurement organization concept and protocols to standardize future measurement.

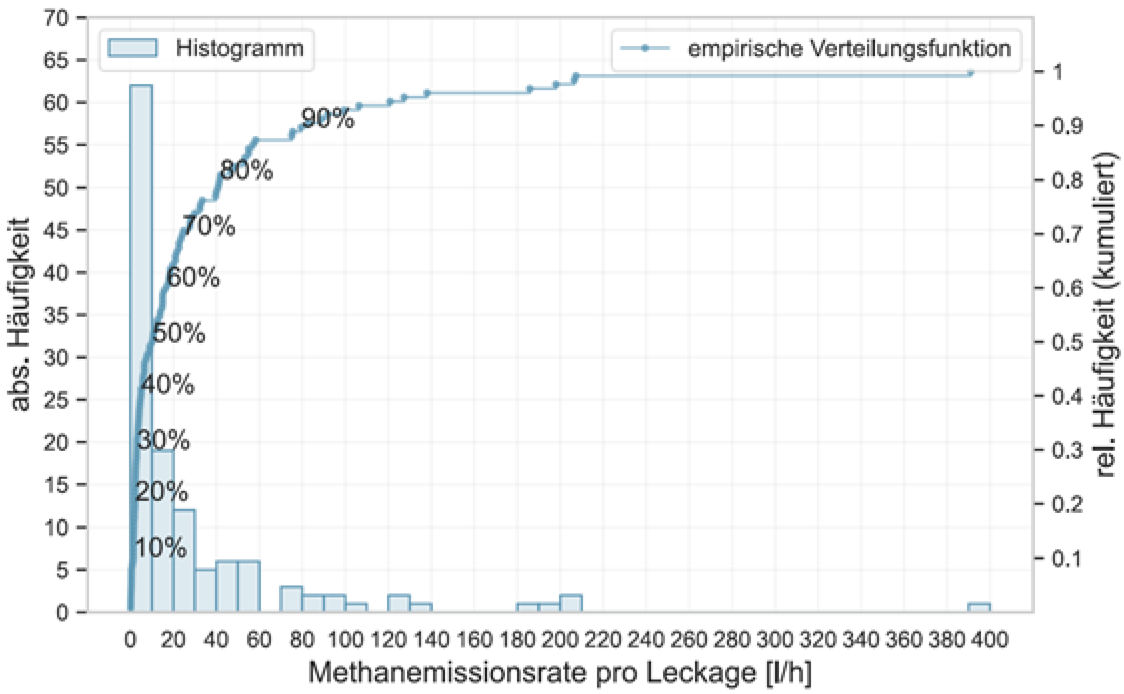
In addition to leaks, permeation, blowout, and malfunctions were considered, which was not done in previous studies.

Together with the DBI, the DVGW has published a comprehensive report on the measurement program entitled "Determination of Methane Emissions of the Gas Distribution System (ME DSO)" (Große et al., 2022).

4.3 Evaluation of the results

The focus was on determining the average leakage rate. The factor of the Fraunhofer ISI study is 140 l/h per leakage. The DVGW measurements show a significantly lower value of 30 l/h (Figure 6). While the Fraunhofer-ISI study (Reichert et al., 2000) (Chapter 2.3.1) was able to derive a correlation between operating pressure and material, the investigations of the ME-DSO project showed no cross-correlation (Große et al., 2022). However, the Fraunhofer study is based on only 18 measured values for lines (Reichert et al. 2000) (Page 9), so the claim of correlation is not sufficiently substantiated.

Figure 6: Histogram of the reported methane emission rates at line leaks (incl. 126)

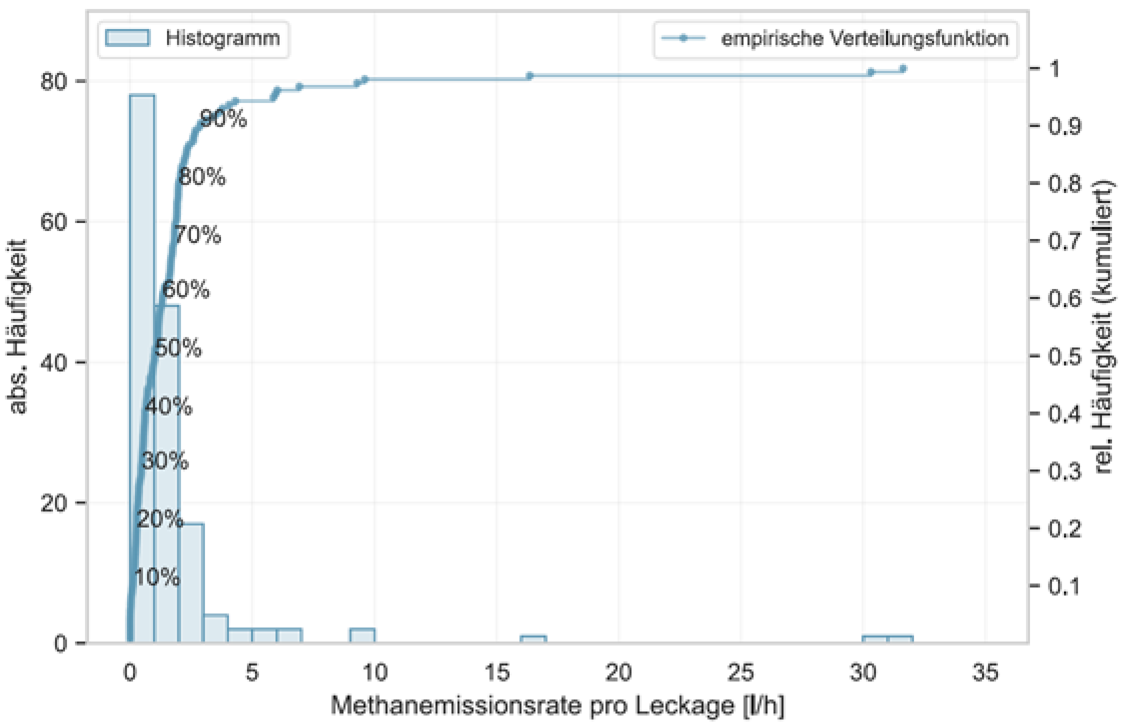


Source: (Große et al., 2022) (Page 39)
Translation : « abs. Häufigkeit » = « abs. Frequency » ; « rel. Häufigkeit (kumuliert) » = « rel. Frequency (cumulative) » ; Histogramm = histogram ; empirische Verteilungsfunktion = empirical distribution function ; « Methanemissionsrate pro Leckage » = « methane emission rate per leakage »

In addition, the ME DSO report (Große et al., 2022) included an extensive uncertainty analysis performed in accordance with the methods commonly used for reporting (Tier 1 (error propagation) and Tier 2 (Monte Carlo simulation) approaches).

In addition to the pipelines, measurements were carried out on 159 M/R Station with a total of 662 blowers (Figure 7). The average emission rate was 1.8 l/h per plant, well below the values of about 105 l/h (plants above 16 bar) and about 26 l/h (plants below 16 bar) derived from five measurements. Again, a comprehensive uncertainty analysis was performed (Reichert et al. 2000) (page 9).

Figure 7: Histogram of the reported methane emission rates at M/R Station (total. 159)



Source: (Große et al., 2022) (Page 46)
Translation : « abs. Häufigkeit » = « abs. Frequency » ; « rel. Häufigkeit (kumuliert) » = « rel. Frequency (cumulative) » ; Histogramm = histogram ; empirische Verteilungsfunktion = empirical distribution function ; « Methanemissionsrate pro Leckage » = « methane emission rate per leakage »

Comparisons with other countries are not easily made on the basis of the CRF tables because the reference variables (activity rate) cannot be converted. You can only compare countries if the method or approach is the same. Therefore, only countries with a Tier 3 approach are listed here.

France reports 212,780 km of line length in the distribution grid in NIR 2022 (Bongrand et al., 2022) on page 280 for 2020. According to NIR page 285, the emissions are determined using a Tier 3 approach. The emissions amount to 10.87 kt of methane (Citepa, 2022). This results in an implicit emission factor of 51.1 kg/km.

Liechtenstein is included in the CRF tables (OE 2022) with 26,875 kg methane emissions, also determined using a Tier 3 approach. The NIR (Schäppi et al. 2022) (Section 3.3.2.2) refers to a 1994 (Battelle 1994) Battelle Institute study as the source of the emission factors. However, this is also based on the derivations from the old German study from 1989 (Schneider-Fresenius et al. 1989). Thus, the implicit emission factor of 61.1 kg/km[5] is more comparable to the German IEF according to the old methodology.

The Netherlands refers to the NIR (Ruyssenaars et al., 2022) (Chapter 3.3.2.2.) for a Tier 3 method to determine methane emissions. The CRF tables (RIVM 2022) give a length of 125,280

[5] Line length determined from the sum of the line lengths for 2019 given in Table 3-36 on page 139, since there appears to be a clerical error for 2020 (439.5 km total).

km for 2020. Combined with the reported 5.43 kt of methane emissions, this gives an implicit emission factor of 43.3 kg/km.

Latvia also reports according to the Tier 3 method and has a length of 5,337 km in the NIR (Skrebele et al., 2022) (Chapter 3.3.2.1 Table 3.56) for 2020. The CRF tables (MEPRDP 2022) report 494,439 kg of methane emissions, resulting in an implicit emission factor of 92.6 kg/km.

In its NIR, the UK refers to (Brown et al., 2022) based on a Tier 2 approach, based on the amount of natural gas sold. Therefore, comparisons between the approaches are limited. The United Kingdom has a pipeline network of 280,000 km (Dodds & McDowall, 2013) (Chapter 2.1). The CRF tables (REE 2022) report 127.11 kt of methane. This results in an IEF of 454 kg/km. One reason for the very high value could be the age of the network (Dodds & McDowall, 2013) (Chapter 2.2). Another is that user emissions were also included in this category (see Chapter 5.6). It is noteworthy that the ratio of emissions from transportation to the distribution network is 1:42. Therefore, it is likely that lines that fall under the transportation network in Germany will be included under distribution in the UK.

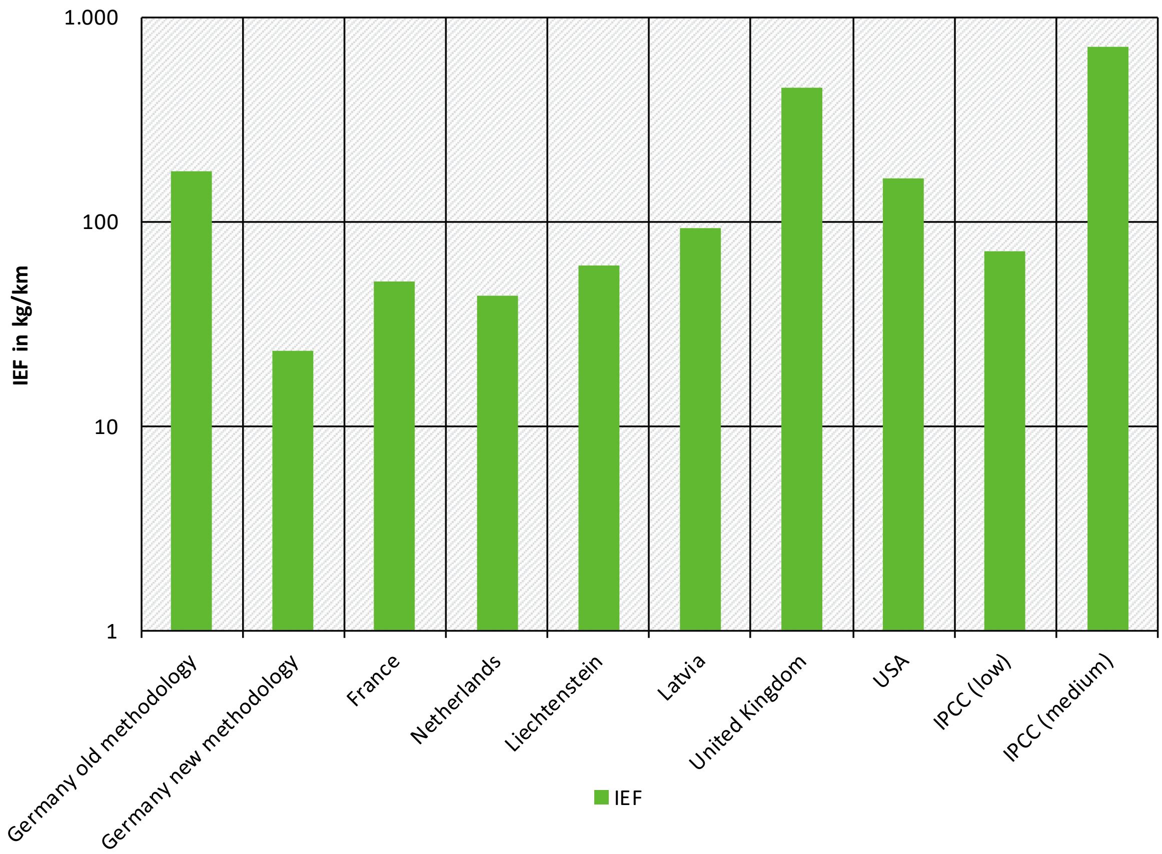
The U.S. has a state-specific method for determining emissions that is similar to the Tier 3 method. The NIR (Desai & Camobreco, 2022) (page 3-91) states that the length of the pipeline network is 1,316,800 miles, or 2,119,184 km [6]. Emissions are reported as 554.29 kt of methane, resulting in an implied emission factor of 261.6 kg/km. However, post-meter emissions are also included in the emissions (compare Chapter 5.6). If these are subtracted using the data in Table 3-67 (page 3-91), 347.5 kt of methane and an IEF of 164 kg/km are obtained.

Germany's implicit emission factor is 23.6 kg/km [7], the lowest in the country comparison (Figure 8).

[6] 1 US Mile = 1,609 km

[7] Emissions of Table 19 11.9 million kg divided by route length Table 15 of 503,543 km

Figure 8: Comparison of the IEF



Logarithmic representation; reference to the year 2020 data of the IPCC (Volume 2, Chapter 4 – Table 4.2.8) converted from m³/a to kg/a with density of 0.717 kg/m³]

Source: Own representation, German Federal Environment Agency]

In a study conducted by a research team from the University of Utrecht, the Technical University of Denmark and the environmental organization Environmental Defense Fund (EDF) in the Atmospheric Measurement Techniques Discussion (Maazallahi et al., 2022), the suction method used in the ME DSO is compared with the so-called "Mobile Method" and "Tracer Method." In particular, in the A1 and A2 security regions [8], the Mobile Method scores were almost twice as high as the other two methods. Often it was because there were shafts or cavities in these regions. These could fill up with gas over time, and the extraction method had its limitations because the gas had to be extracted first. These areas were usually only calculated, not measured, because the leaks had to be repaired quickly for safety reasons. Blow-out processes (ME DSO report 6.1.2.), odor reports (ME DSO report chapter 3.2.2.2.2) and third-party damage (ME DSO Report 6.1.2.2.1) were used to determine the leakage quantities. According to the report, a very high emission rate was used, to be conservative. However, direct comparability in these regions is not conclusive due to the small number of samples.

In the B and C ranges, the "Mobile method" and the extraction method were of a similar order of magnitude, but the tracer method had significantly lower emission rates.

[8] Based on the risk of explosion, gas leaks are classified into four types: A1, A2, B and C. This classification is based on the distance of gas leaks from buildings and cavities (e.g. shafts) and is supported by DVGW Code of Practice 465-3 (Appendix A) with deadlines for repair. A1 means immediate repair, A2 within one week (DVGW 2019).

While the " Mobile Method " provides a quick way to quantify emissions in a given region, it has significant uncertainties when it comes to directly locating leaks or when leaks are away from walkable areas.

An evaluation of the methods is not provided at this point. However, whether this is the reason for the relatively low implicit emission factor (Figure 8) cannot be conclusively determined due to the lack of data on the measured values of individual countries. In order to avoid an underestimation in the inventory, the uncertainties in the CSE are increased to take into account the study results.

4.4 Derivation of new emission factors

4.4.1 Derivation of emission factors from the 2020 monitoring program

The DVGW ME DSO measurement program included pipelines and gas pressure regulating (measuring) stations (M/R Station) (Große et al., 2022). For the M/R Station, an emission factor of 26 kg/plant is given in the report (page 62). This is an order of magnitude lower than the previous factor of 256 kg/plant.

Emission factors for supply lines (VL) and network access lines (NAL) were calculated for lines based on GaWaS data. However, GaWaS interprets the pressure levels differently than the previous procedure of the German Federal Environment Agency, which is based on the gas statistics of BDEW (Table 16 in 140. Gas statistics) (BDEW 2020). While low pressure up to 0.1 bar, medium pressure up to 1 bar and high pressure above 1 bar were used here, the GaWaS maps four pressure ranges (less than 1 bar, 1 to 5 bar, 5 to 16 bar and from 16 bar). The research report on the measurement program made the following comparison based on UBA factor conversions:

Table 14: Comparison of the emission factors of the Federal Environmental Agency with the factors determined in the ME DSO project

Category	Emissions according to ME DSO	Calculated EF according to ME DSO factor	Calculated EF according to UBA (Submission 2022)
VL	5.000.750	14	112
NAL	1.752.752	11	112

(Große et al., 2022) Page 62

The UBA factors were determined by weighting line pressure and material types. The breakdown of pressure levels from the GaWaS was used and then multiplied by the proportion of materials used. Due to the lack of cross-correlation between material and pressure level, as well as the different definition of pressure levels between UBA and GaWaS, this can only be considered an approximation. In addition, the UBA is based on other activity rates. These are taken from BDEW statistics, while the cable lengths used in the ME DSO report are taken from the monitoring report of the Federal Network Agency (BNetzA und BKartA 2022) and extrapolated to all network operators using our own assumptions.

Table 15: Comparison of the German Federal Environment Agency's cable lengths with the values determined in the ME DSO project

Cable lengths in km

Source	2017	2018	2019	2020
Length according to monitoring report (only share of network operators)	497.429	498.081	512.000	522.000
Extrapolated length according to ME DSO (extrapolated to all network operators)	512.438	517.543	526.884	536.479
UBA data based on BDEW gas statistics	483.456	486.991	489.100	503.543

ME DSO, page 25 (Große et al., 2022); Data from NIR 2022 Chapter 3.3.2.2.5

There is also a discrepancy in the data in this area.

As the aim is to harmonize reporting under the UNFCCC with that under IMEO, the German Federal Environment Agency's reporting will adopt the methodology of the ME DSO study from 2023 onwards.

4.4.2 Interpolation in the years 1990 and 2020

As explained in Chapter 4.4.1, the definitions of pressure levels and activity rates are quite different. However, in order to include the results of the measurement program in the emission reports, the measured values must be converted to the previously used format.

The emissions of 6,753,502 kg determined in the study for the VL and NAL (see Table 14) are first applied to the line lengths (line 1) in the ZSE (Table 16 – line 3). The emissions of the VL are multiplied by the proportion of the total line length of line 2 (line 3). The emissions of the NAL from the ME DSO report are assigned to 45% of the LP and 55% of the MP range (calculated from the proportion of the line length of both ranges) and according to the ratio of the material (line 4). Subsequently, the emission values calculated in line 3 are added to those in line 4 (line 5) and the ratio to the total emissions of 6,753,502 kg is determined. These ratios are now multiplied by the previous emission factors from Table 12 (line 7).

Table 16: Emissions determined for the 2023 report for the reporting year 2020 in category 1.B.2.b.iv "Distribution"

	Step	Steel (LP)	Plastic (LP)	Grey Cast Iron (LP)	Steel (MP)	Plastic (MP)	Steel (HP)	Plastic (HP)
1	Cable length in the ZSE (km)	66.748	105.214	81	72.314	136.686	42.385	80.115
2	Share of total pipeline length	13%	21%	0%	14%	27%	8%	16%

	Step	Steel (LP)	Plastic (LP)	Grey Cast Iron (LP)	Steel (MP)	Plastic (MP)	Steel (HP)	Plastic (HP)
3	Emissions from ME DSO divided by the proportion of supply line length (VL) in (kg)	662,883	1,044,894	804	718,160	1,357,446	420,931	795,632
4	Emissions from ME DSO divided by the proportion of the network access line length NAL in (kg)	307,033	483,972	373	332,636	628,739	-	-
5	Total emissions VL + NAL	969,916	1,525,865	1,177	1,055,797	1,986,185	420,931	795,632
6	Share (line 5) of total emissions	14%	23%	0%	16%	29%	6%	12%
7	Calculated emission factor (kg/km) From line 6 multiplied by factors from Table 12	53.4	11.5	0.1	32.2	8.2	3.9	0.04

The emission factors obtained in this way do not necessarily reflect reality due to the many assumptions. They are only used to determine the emission development since the last measurement program according to the methodology used in the UBA.

For the M/R Station, it was assumed in the 2022 submission that, purely statistically, there is a plant in the pipeline network on average every eight kilometers. This assumption was made by UBA experts in the absence of appropriate existing public statistics. However, in 2020, this will result in only 47,827 installations being applied to the previous emission factor in the CSE. According to GaWaS, there are 51,468 plants (Große et al., 2022) (Page 62). This value is now used for the recalculation with the emission factor of 26 kg/plant (See chapter 4.4.1).

The compressor performance was based on a split factor from the 2014 GaWaS for the calculation of emissions in the 2022 submission to the ZSE. This does not reflect reality, as explained in chapter 3.4.2. The values from 2016 from Table 13 are used for recalculation and the average value up to 2006 is used for interpolation. The first amendment to the German Renewable Energy Sources Act (EEG) in 2004, which increased the amount of subsidies (BMJ 2004), led to a rapid expansion of biogas plants. According to DBFZ, this is evidenced by the number of plants (DBFZ 2012). The years up to 1995 were set to zero. Between 1995 and 2006, a linear trend was set, reflecting the expansion of natural gas filling stations. According to "gib-gas.de " (Wöber, 2022) there were a total of 2000 natural gas-powered vehicles on 1 January 1998. This data was obtained by the Federal Motor Vehicle Authority. The internet portal gas.info also published this value. There is no data available before this time. Since it can be assumed that vehicles already existed and were fueled by that date, the conservative approach was to start the linear trend in 1996 (Table 17).

Table 17: Activity rates for natural gas compressors derived from the 2023 report for the reporting year 2020 in category 1.B.2.b.iv "Distribution"

Description	1990	1995	2000	2005	2010	2015	2020
Compressor capacity in MW	0	0	220	441	485	485	478

The emissions from the pigging stations are measured with the emission factor of 0.66 kg/km from Table 12, however, the length of the distribution network specified in the gas statistics minus the house connection lines is used for the line length, since the latter are not pigged.

The approach to surface storage remains unchanged (see chapter 5.4), as well as the determination of the emissions of natural gas vehicles (Chapter 5.5).

This is how the distribution of emissions in Table 18 in the "Distribution" category is determined. The emissions of the natural gas vehicles that have been taken into account so far are reallocated (see chapter 5.5)

Table 18: Emissions determined for the 2023 report for the reporting year 2020 in category 1.B.2.b.iv "Distribution"

Source	Unit	1990	2000	2010	2020
Surface storage	kg	1,278,000	340,000	306,667	150,000
Pipelines	kg	206,805,034	116,639,290	63,542,077	8,388,950
Pigging	kg	1,466,771	163,057	239,744	252,527
M/R Station	kg	5,174,784	7,905,792	5,805,675	1,338,168
Compressor	kg	16,202,228	683,980	1,507,865	1,486,102
Total	kg	**230,926,817**	**125,732,119**	**71,402,028**	**11,615,747**

As of the date of this report (August 2022), the data for the 2023 report has not yet been coordinated by the Department and has not yet been reviewed and finalized through various reviews, Therefore, there may be discrepancies between the official data and the report to the UNFCCC dated April 15, 2023.

4.4.3 Comparison of emissions

As with the TSO (chapter 3.4.3), in order to allow a transition between the method from ZSE, based on time series, and the system-specific method according to the ME DSO report, an interpolation at the time-series level must be carried out once. The last reporting year under the Framework Convention on Climate Change was chosen for this purpose.

Table 19: Emissions determined for the 2023 report for the reporting year 2020 in category 1.B.2.b.iv "Distribution"

Source designation in the ZSE	Emissions according to the previous methodology	Emissions according to a new methodology	Unit	Deviation
Surface storage	150,000	150,000	Kg	0%

Source designation in the ZSE	Emissions according to the previous methodology	Emissions according to a new methodology	Unit	Deviation
Natural gas compressors	24,102,540	1,486,102	Kg	-94%
M/R Station	12,243,744	1,338,168	Kg	-89%
Pipework	51,680,326	8,388,950	kg	-84%
Pigging	361,762	252,527	kg	-30%
Overall	**88,568,614**	**11,615,747**	**kg**	**-87%**

As of the date of this report (August 2022), the data for the 2023 report has not yet been coordinated by the Department and has not yet been reviewed and finalized through various reviews, Therefore, there may be discrepancies between the official data and the report to the UNFCCC dated April 15, 2023.

According to (Große et al., 2022) (Page 62) the pipelines and the M/R Station emitted a total of 8,079,062 kg of methane in 2020. With the adapted method in the ZSE, the result is 9,727,118 kg. This represents a deviation of around 20% percent. This is mainly due to the underlying activity rate (pipeline length) as calculated in Table 15 and the pressure stages (cf. chapter 4.4.1). For example, the pipeline lengths in the ZSE sometimes also include network connection pipelines, so that some of these values may have been counted twice (see chapter 4.1). Furthermore, rounding and assumptions in Table 16also play a role.

It is to be expected that the emissions of the natural gas compressors will continue to be far too high despite the reduced emission factor. Investigations are already underway at the DVGW on this (Chapter 8.4).

4.5 Future reporting

Due to the lack of correlation between the previous calculation approach and the new findings from the ME DSO measurement program, the calculation in the UBA has to be changed. Previous activity rates were extrapolated from BDEW gas statistics. In the future, GaWaS data will be used. These have a different classification of material types and pressure levels, but are consistent with the results of the ME DSO program and the factors derived from it.

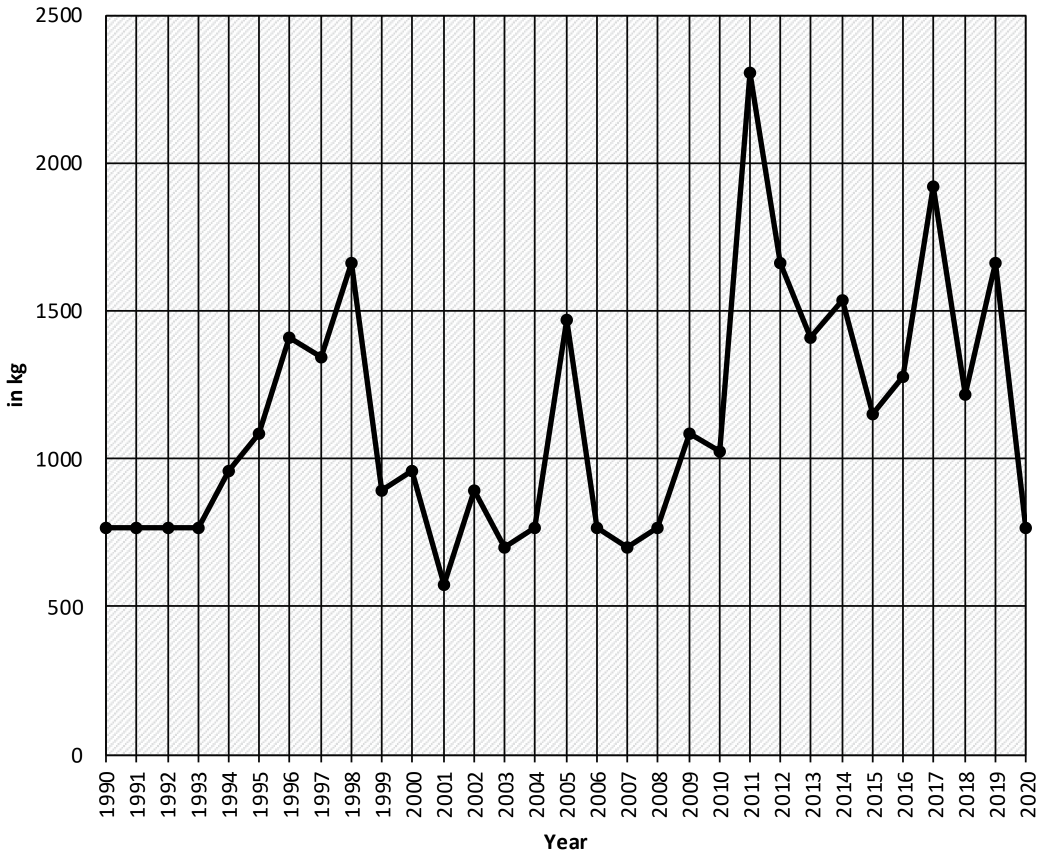
OGMP reporting cannot be estimated at this time (August 2022) because very few distribution system operators are members.

5 Derivation of emission factors for other sources

5.1 Exploratory drilling

Exploratory drilling is not a significant source in Germany. According to the BVEG (Boettcher & Grundmeier, 2011), there are almost no diffuse emissions from drilling operations, as measurements are regularly taken at the boreholes (methane sensors in the shelter around the borehole, ultrasound measurements, annular space manometers) and old, unused boreholes are filled in and usually covered with concrete. In the absence of measurement results for individual boreholes, emissions for boreholes were conservatively estimated using the default factor from the IPCC GPG 2000 (Hiraishi et al., 2000) for carbon dioxide and methane calculated using the Tier 1 approach. The sum of the emission factors for "drilling", "testing", and "maintenance" was used for a conservative estimate.

Figure 9: Methane emissions from exploratory drilling



Source: data from the 2022 submission to the UNFCCC (as of 15.04.22) "Source: own representation, German Federal Environment Agency".]

Due to the lack of country-specific data, an external expert opinion was (Bender & Langer, 2009) commissioned. In the source group analysis, it concluded that the default factors were applicable to Germany. A comparison with other countries was not possible due to the lack of comparability and non-convertible units.

Given the very small share of emissions in the national total, there are no plans to re-evaluate this approach in the medium term.

5.2 Oil and gas production and sulfur extraction

Methane emissions from oil and gas production have been published annually by the BVEG since 1998. In addition, specific emission factors are derived based on the production quantity (BVEG 2022) (Page 21)

This data is calculated by the operators in an activity-focused manner using BVEG "Guidelines – Environmental data (BVEG 2017). These activities include, for example, natural gas and petroleum production, natural gas desulfurization and production, as well as drilling and winch propulsion and diffuse emissions.

Since 2011, in addition to the annual report, the UBA also receives an operator-specific overview so that questions can be answered directly for local and operator-specific events.

For the year 2020, the BVEG reported the following methane emissions:

Table 20: Activities and methane emissions from the upstream sector of the E&P industry

Year 2020	Quantity (activity rate)	Methane emissions	Implicit emission factor
Natural gas production	5 155 390 671 m^3	265,000 kg	51.4kg/10^6m^3
Sulphur extraction from natural gas production	353 293 t	98,000 kg	277.4kg/103t
Oil production	1 906 681 t	85,000 kg	44.6kg/103t

In the medium term, the reporting on this will not change. A distinction between conventional and unconventional transport, as envisaged in the IPCC refinement, is not meaningful (Bertram et al., 2014).

5.3 Underground natural gas storage

The last review of the emission factors was carried out by an expert opinion of Müller-BBM 2012 (Bender & Langer, 2012). The original factors were identified in the Battelle study in 1989 (Schneider-Fresenius et al. 1989) (Chapter 4.3). A distinction is made between underground and surface emissions. The underground area includes storage-related emissions, the surface area plant-related emissions (pumps, compressors, control valves, etc.).

The study by Müller BMM, and also telephone inquiries at the State Office for Mining, Energy and Geology in Lower Saxony (LBEG) assume that due to technical progress, the emission behavior of the storage systems will be lower than determined in the original study. Damage events are a major source of high emissions. However, these have not appeared on a larger scale in recent years.

The emission factors used in the inventory are below the forecast value estimated by Müller BBM.

Table 21: Emission factors of underground storage of natural gas from 2022 in kgCH_4/1,000 m^3

Description	Battelle (1989)	Müller BBM (calculated for 2012)	Müller BBM (Forecast for 2020)	UBA (Expert assessment)
Total underground storage	0.05 - 0.18	0.07	0.05	0.03

Unit of kg per 1000 m³ based on a density of 0.7171 kg/m³ and a methane content of 90% in natural gas.

5.4 Natural gas overground storage

The determination of the emission factor is based on the study by Müller-BBM 2012 (Bender & Langer, 2012). It assumes that in low-pressure gas vessels, gas escapes through the annular gap seal and accumulates over the bell or disk. The gas sensors installed there detect a concentration of one percent of the lower explosive limit (5 vol. %), which corresponds to a methane concentration of 0.01 * 0.05 = 500 ppm. The study assumes a typical turnover rate of 0.3 per day. With a total installed volume of 1.5 million m^3 in 2011, methane emissions of $500 * 10^{-6}$ (concentration) * 1.5 * 10^6 (volume) * 0.3 (envelopes) results in a total of approximately 225 m^3 of methane per day. With a density of about 0.72 kg/m^3, the total emission is about 60 tons of CH_4 per year (365 days).

The study estimates a volume of 1.6 million m^3 for ball and pipe storage systems. It assumes that the pressure vessels are absolutely leak-proof, but with maintenance and cleaning every ten years, at a residual pressure of two bar, it comes to about 220 tons of CH_4/year. The volume, residual pressure, and methane content of the gas (assumed to be 95%) are multiplied by the test intervals. The density of methane is assumed to be 0.72 kg/m^3.

In total, the methane emissions from the sum of the low-pressure gas tanks and the spherical storage tanks can be estimated at 280 t CH_4 per year. Based on the total working gas volume of 50-60 million m^3 installed in 2011, this results in an emission factor of approximately 5 kg CH_4/1,000 m^3 working gas volume.

This approach to emission estimation was also adopted by the IPCC and included as a method in the Refinement 2019 (Boettcher et al., 2019) (Chapter 4.2).

5.5 Natural gas vehicles

The determination of the emission factor is based on the study by Müller-BBM 2012 (Bender & Langer, 2012).

In Germany, there is a growing trend to purchase natural gas vehicles. These are refueled at CNG (Compressed Natural Gas, CNG) filling stations. As a rule, CNG filling stations are connected to the public gas network. There, the gas is pressed into intermediate storage tanks by means of a compressor. These consist of 28 or 42 compressed gas cylinders of eighty liters each. The storage pressure is a maximum of 300 bar. According to the study, the usable storage volume will be 230 or 350 m^3.

To estimate the emissions, the study focuses on the individual potential sources.

Table 22: Emission factors of natural gas vehicles

Description	Emissions per year in tons
Release of dead volumes during the refueling process	6.0
Pressure tests of high-pressure accumulators	1.5
Emptying of vehicle tanks for pressure testing or during decommissioning	23.1
Sum	**30.6**

Unit of kg per 1000 m³ based on a density of 0.7171 kg/m³ and a methane content of 90% in natural gas.

These emissions are related to vehicle stock in 2012 and a factor of 0.33 kg/vehicle per year is determined.

This approach to emission estimation was also adopted by the IPCC and included as a method in the Refinement 2019 (Boettcher et al., 2019) (Chapter 4.2).

5.6 End-user emissions

Germany used the emission factors from the Fraunhofer ISI 2000 study (Reichert et al., 2000) for reporting up to 2022 (Chapter 2.4; Table 2.6). Here, 2.0 m^3 of natural gas /appliance is assumed for the household appliances. For industry, a value of 0.00041 m^3 of natural gas /m^3 of consumption is given.

The factor for industry of 0.00041 m^3 natural gas /m^3 consumption includes the methane emissions of industrial users determined from accounting losses (Reichert et al. 2000) (Table 5.4). According to the IPCC refinement (Boettcher et al., 2019) table 4.2.4k, the $_{\text{gas consumption}}$ is 0.4t/10^6 m^3 (equivalent to 0.00062 m^3 of natural gas /m^3). However, Germany has already reported methane emissions from industrial users of 34.20 kt under 1.A.1 and 6.03 kt under 1.A.2. This makes a total of 40.2 kt. In addition, VERICO (Betzenbichler et al., 2016) could not find any country in the NIR evaluations that reported these emissions under 1.B.2.b. The primary literature on the ISI report (Bramkamp et al., 1994) includes all natural gas consumption by industrial users and does not differentiate between statistical, diffuse, and combustion losses. This shows that the 12.3 kt of emissions reported under 1.B.2.b.vi are already included in 1.A, and there will be double counting here. Therefore, in the 2023 reporting, this calculation of the amount of emissions will no longer be performed under 1.B.2.b.vi.

According to DVGW worksheet G 600 (Schuhmann, 2018), domestic installations with a leakage volume of 0-1 l/h can be used without restriction. If the leak test indicates a higher leakage value, the system must be repaired immediately. The converted maximum emissions are therefore between 0 and 8.76 $m^3_{\text{natural gas}}$/a or 6.3 $kg_{\text{natural gas}}$/a. To be conservative, this value is set to 1990 for reporting in 2023. For this, the 8.76 $m^3_{\text{natural gas}}$/a is multiplied by 0.9 to account for the methane content only. The resulting value of 7.9 m^3_{CH4}/a, however, is significantly higher than the previously used of 1.8 m^3_{CH4}/a.

The Fraunhofer ISI study (Reichert et al., 2000) (Chapter 2.4; Table 2.6) also accepts, in addition to the end devices, house installations with 6.4 $m^3_{\text{natural gas}}$. If we add the values for the house installation and the terminal equipment, assuming that there is only one device per connection, we get 8.4 $m^3_{\text{natural gas}}$/a. This is close to the value in the DVGW regulations. This explains the increased factor of 7.9 m^3_{CH4}/a.

The IPCC Guidelines 2006 only consider the natural gas chain up to the local distribution network. Emissions from the gas meter (so-called post-meter emissions) are listed in the 1996 Guidelines (IPCC 1996) (Chapter 1.8.5) and are again included in the IPCC refinement (Boettcher et al., 2019) (Chapter 4.2). The factor of 2 m^3/a used by Germany so far is at the lower end of the expected emission factor of 2 to 20 m^3/a according to the IPCC Guidelines 2006 (Eggleston et al., 2006) (Table 4.2.8). This factor is based on statements in an International Gas Union publication (Beukeme, 2000). It is not clear from the report how this figure was arrived at. Only on page 42 is it stated that it is an expert estimate.

Previously, it was assumed that the so-called start-stop emissions of the terminals were also considered incomplete combustion under 1.A.4. For 2020, 2,790 metric tons of methane were identified here. A previously unpublished study by GWI on behalf of DVGW (Brandes, 2022) examined emissions from natural gas terminals. The diffuse emissions were found to be 2,019 tons of methane per year, and the start-stop emissions were found to be 39,064 tons of methane per year. So while the diffuse emissions have been overestimated in the previous reporting rounds, the start-stop emissions have been underestimated.

To avoid underestimation, the 2023 report also includes start-stop emissions from the GWI study in 1.B.2.b.vi.

Very few countries include end-user emissions in their inventory. According to VERICO (Betzenbichler et al., 2016), the German approach can only be compared with the UK. The UK uses data from gas fittings and losses during operating cycles and ignition times to estimate emissions. For example, the following sources are taken into account for the emissions (Table 23) (Brown et al., 2022) (Page 237ff and Annex 3.1.5). Although the UK also includes start-stop emissions, their value is only about 2.5 kt (Table 23).

Table 23: UK End-User Emissions

[Data from NIR 2022 of the United Kingdom, Annex 3].

Source	Annual emissions in kilotons
Domestic cooking and gas fires	0.79
Domestic boilers and water heating	0.76
Service sector (all sources)	0.93
Sum	**2.49**

The reason why the UK data are significantly lower than the GWI and also below the expected range of the 2006 IPCC Guidelines (Table 4.2.8) could not be resolved conclusively.

Table 24: End-user emissions in Germany

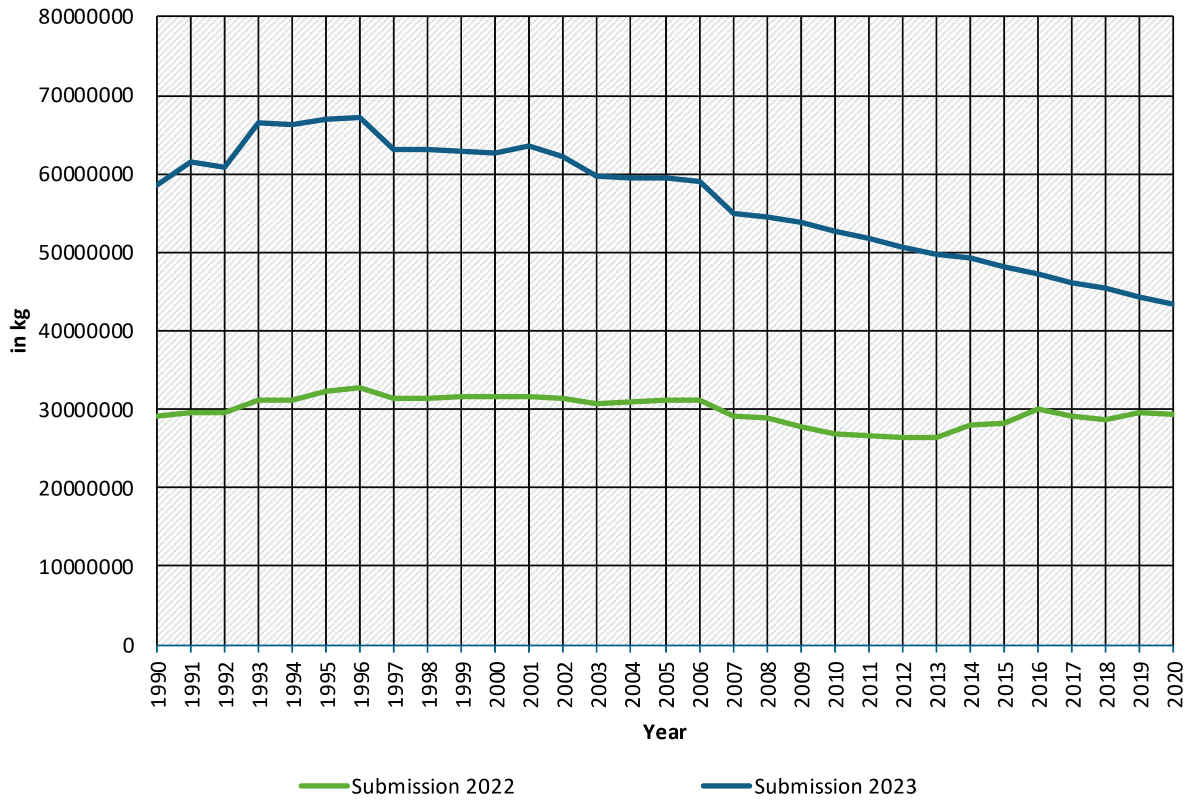
[Data from CRF 2022 as well as personal communication from Mr. Burmeister, GWI]

Source	Annual emissions in kilotons
Diffuse emissions according to previous reporting (1.B.2.b.vi)	17.0
Start-stop emissions and methane loss according to previous reporting (1.A.4 – gaseous fuels)	2.8
Sum	**19.8**
Diffuse emissions according to GWI/DVGW investigations	2.0
Start-stop emissions and methane loss according to GWI/DVGW investigations	39.1
Sum	**41.1**

To establish a timeline, the 41.1 kilotons of methane are put in relation to the 13.1 million gas meters. This results in an emission factor of 3.1 kg_{CH4}/gas meter.

Interpolating between the estimated emission factor of 7.9 m^3_{CH4}/gas meter for 1990 (=5.7 kg_{CH4}/gas meter) and the emission factor of 3.1 kg_{CH4}/gas meter for 2021, emission trend is as follows. (Figure 10)

Figure 10: Emission development of end users according to submission 2022 and 2023



Source: data from the 2022 submission to the UNFCCC (as of 15.04.22) "Source: own representation, German Federal Environment Agency".]

It is planned to change the reference variable (bellows gas meter) to a consumption-dependent reference variable in the short term and to verify the number of cycles in the medium term. This provides a more realistic picture of emissions trends. In addition, a discussion with the United Kingdom is planned in the near future to discuss their emissions assumptions, which are an order of magnitude lower (see Table 23).

GWI's research also included industrial customers. However, their share of reported emissions in Table 24 is 3.7%. A check will be made to ensure that this is not a case of double counting with the methane emissions taken into account under 1.A.1 and 1.A.2 above.

5.7 Orphan boreholes

To date, orphan boreholes (also called abandoned boreholes) have not been included in greenhouse gas reporting and will not be required to be reported in the foreseeable future. In the IPCC refinement (Boettcher et al., 2019), emission factors were presented for the first time that allow an emission quantity to be estimated using the Tier 1 approach (Table 25).

Table 25: Emission factors of orphan boreholes according to IPCC Refinement 2019

Location and condition of the borehole	Emission factor	Unit
Locked on land	20	g/No
Open on land	88.000	g/No
All (locked and open) on land	12.000	g/No
Locked at sea	0,35	g/No
Open at sea	1.800	g/No
All (locked and open) at sea	240	g/No

Unit in g per borehole – converted from IPCC refinement factors Chapter 4, Volume 2 – Table 4.2.4E

According to the BGR (Boettcher & Ladage, 2016), there are approximately 40,000 abandoned boreholes in Germany, most of which are located in the northern German lowlands. These are usually locked, as is mandatory in Germany. Using the specified factor given in Table 25 for closed boreholes on land results in an emission quantity of 800 kg. If you take a conservative approach and factor in all the boreholes on land, you arrive at 480 tons. Germany's total methane emissions in 2020 were 2,036 kilotons (FEA 2022). Although the emissions from the orphan boreholes would be less than one part per thousand according to both approaches, the German Federal Environment Agency is nonetheless striving to quantify these emissions more precisely in the near future by means of a research project (to be announced in the EVU plan (Energy Project of the German Federal Environment Agency) – as of Spring 2022).

6 Derivation of CO_2 and NMVOC split factors

In the project to determine the quality of natural gas at various points in the German natural gas network (Lubenau & Schuetz, 2014), measurements of the gas composition were carried out at 32 locations throughout Germany. The measurement points were selected to cover all major imported gases as well as domestic production. In addition, a mixture distributed in Germany was analyzed. This resulted in a split factor for both inherent CO_2 and various VOCs (volatile organic compounds), which are presented here as a sum.

Table 26: Natural gas procurement Germany 2014 and CH_4, CO_2, and NMVOC content of natural gas

Regard	Import share	CH4 Percentages	CO2 Percentages	Percentage of NMVOC
Denmark	3.86	87.99	2.55	8.5
Netherlands	17.74	83.20	0.91	3.6
Norway	34.75	91.69	1.43	5.5
Russia	35.42	96.63	0.20	2.5
Self-financed	8.23	87.27	0.83	3.2

Weighting the reference regions and the methane or NMVOC and carbon dioxide concentrations yields an average methane content of 91.43 percent[9], an average CO_2 content of 0.90 percent and a value of 3.8 percent for NMVOC. Multiplying the methane and carbon dioxide content gives a split factor of 0.82 percent, which is then applied to each methane emission factor for transport, distribution, and end-user emissions. This results in a value of 3.5 percent for NMVOC.

The split factors for the years 1990 to 2015 were determined according to the same principle (Table 27).

Table 27: NMVOC and CO_2 content of natural gas

Share	1990	2000	2010
NMVOC share	2.57%	2.97%	3.43%
CO_2-Share	0.63%	0.75%	0.82%

For data protection reasons, the BAFA no longer lists countries of origin for natural gas imports (BAFA 2022) so the factors calculated in Table 26 are used for further calculations.

More recent sources often refer to surveys or estimates and sometimes deviate significantly from each other (see Table 28). For example, the German Federal Agency for Civic Education (BPB) expects a share of Russian imports of 55% (BpB 2022) while the German federal government expects only 38% at the beginning of 2022 (Presse- und Informationsamt der Bundesregierung, 2022).

[9] Note: Due to the high reference share of Russian and Norwegian natural gas, the average methane share in 2014 was 91.43 percent. In the early years, the share of Dutch gas was significantly higher, so the average methane share in Germany was only just over 89 percent on an annual basis. In the previous chapters, a factor of 90 percent was calculated in a simplified manner. This variability is also reflected in the uncertainty of the emissions report.

Table 28: Natural gas supply to Germany in 2021 (percentages) by German Federal Government and BPB

Source	other	Netherlands	Norway	Russia
Federal	4.6	22.4	34.8	38.2
BPB	1.6	13	31	55

The share of Norwegian and Russian imports (with medium and low CO_2 content) remains high in both estimates, which means that the CO_2 split factor is a very good approximation. In the case of NMVOCs, however, there may be a slight underestimation as the value for Russian gas is quite low.

7 Summary and comparison of 2022 and 2023 submissions

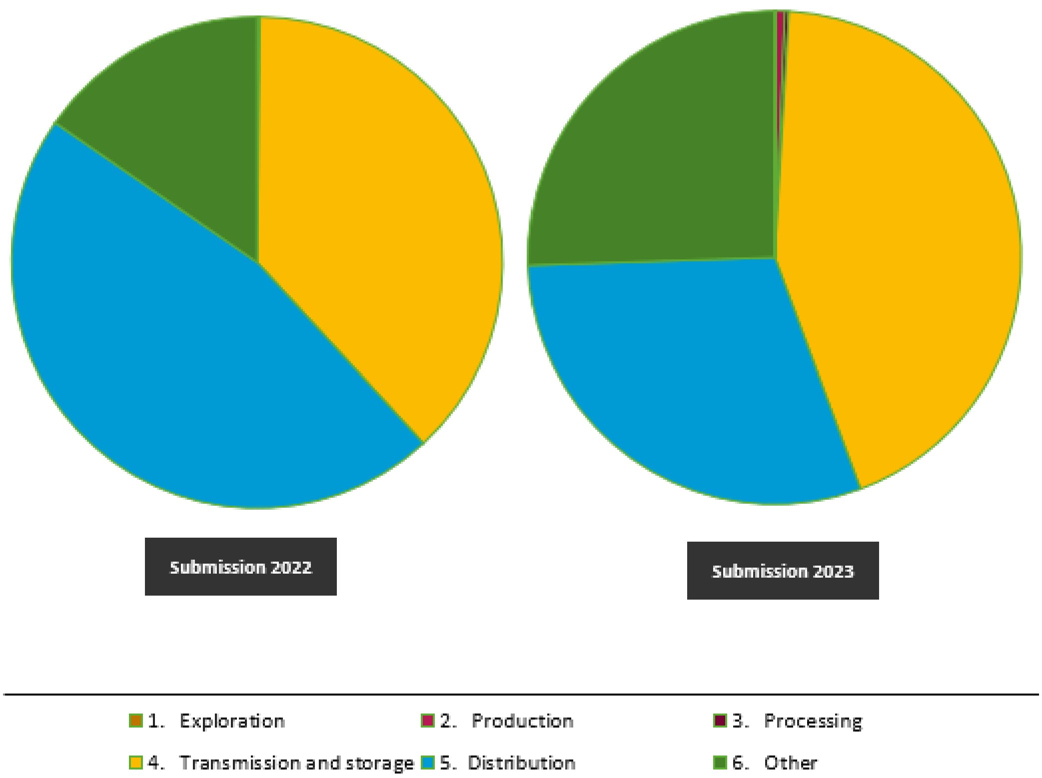
Significant changes have been made as a result of extensive measurement programs and re-evaluation of previously used emission calculation methods. Almost all areas of the IPCC Category 1.B.2.b "Fugitive Emissions of Natural Gas" are affected (Table 29). In a number of places it has become clear that there is still a need for further investigation. Overall, however, it can be said that by adjusting the emission factors, some of which are more than 20 years old, the gas industry's efforts to reduce emissions can be reflected in the inventory. The new data will also be used to evaluate future reports to the IMEO and to verify compliance with self-imposed and politically mandated emission reduction targets. It also takes into account the European Commission's request to make Member States' emission inventories more comparable.

Table 29: Methods used for CRF category 1.B.2.b for reporting 2023

Subcategory	Change	Chapter
Exploration	Update	Chapter 5.1
Production	Update	Chapter 5.2
Preparation		Chapter 5.2
Transport		
Shut-off device/gate valve	New measurements	Chapter 3
Natural gas compressor	New measurements	Chapter 3
Station	Update	Chapter 5.3
Cavern storage	Update	Chapter 5.3
Pore storage	New measurements	Chapter 3
Gas pressure control systems	New measurements	Chapter 3
Pipework	Update	Chapter 3
Pigging		
Distribution		
Surface storage	Update	Chapter 5.4
Natural gas compressor	New measurements	Chapter 4
Station	New measurements	Chapter 4
M/R Station	Update	Chapter 4
Pipework	Update	Chapter 4
Pigging		
Other		
End-user emissions	New measurements	Chapter5.6
Natural gas vehicle tank emissions	Update, but so far under "Distribution reported"	Chapter 5.5
	New – as no data has yet been reported with "not estimated" for the time being	Chapter 5.7
Old boreholes		

The changes listed in Table 29 result in a different picture for emissions reporting, not only for the level of emissions, but also for the distribution in the subcategories as a whole (Figure 11). While the recalculation of compressor capacity in the TSO area in particular shows an increase in emissions for the early years, methane emissions have decreased significantly in all areas since the turn of the millennium.

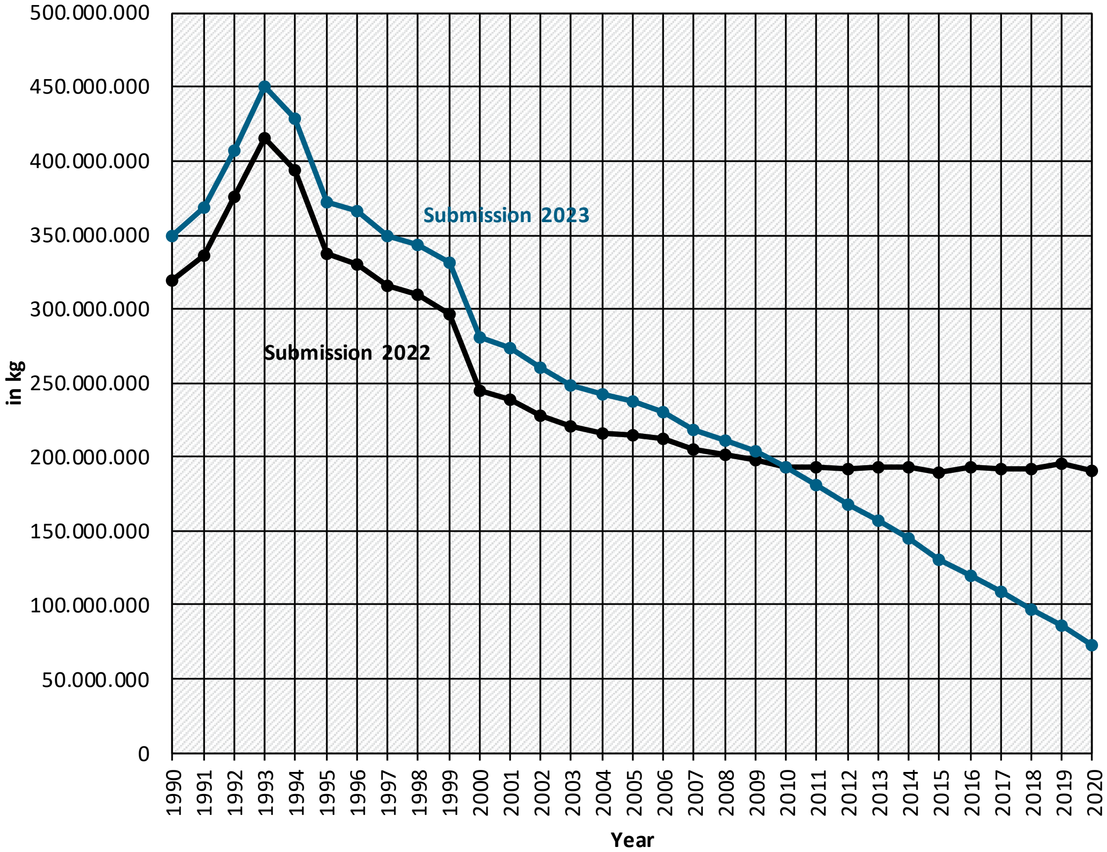
Figure 11: Comparison of old and new reporting – breakdown of methane emissions for 2020



As of the date of this report, the data for the 2023 report was still in the process of being coordinated between departments and had not yet been verified and finalized through various reviews. Therefore, there may be discrepancies with the official data reported to the UNFCCC as of April 15, 2023.

Despite extensive expansion of the pipeline network, emissions have been significantly reduced (Figure 12). In addition to the installation of lines with significantly lower emissions, factors such as shorter monitoring periods for systems and the use of new technologies, such as mobile compressors also play an important role.

Figure 12: Comparison of old and new reporting – Methane emissions from 1990 to 2020



As of the date of this report, the data for the 2023 report was still in the process of being coordinated between departments and had not yet been verified and finalized through various reviews. Therefore, there may be discrepancies between the official data and the report to the UNFCCC dated April 15, 2023.

For the year 1990, the total emissions increase by 9 percent. By contrast, emissions decreased by 62 percent in the 2020 reporting year (Figure 12).

While methane emissions from the natural gas chain (IPCC category 1.B.2.b) accounted for 9 percent of the total inventory under the old methodology, they account for only 4 percent[10] under the new calculations. While this shows that much has already been done in this area, efforts must continue to lead Germany into a greenhouse gas-neutral future.

[10] As of the date of this report, the data for the 2023 report was still in the process of being coordinated between departments and had not yet been verified and finalized through various reviews. Therefore, there may be discrepancies between the official data and the report to the UNFCCC dated April 15, 2023.

8 Outlook

8.1 Division by "Venting" and "Leaks" according to CRF tables

The CRF tables, including the future CTF tables, require a differentiation between venting and other emissions. This has not yet been done. The data is also not differentiated for the 2023 reporting, as the UBA does not have this division completely accessible. In the IPCC Refinement (Boettcher et al., 2019) divisions are given in Tables 4A.2.1-7. Although a division by these values would technically meet the requirements of the tables, it increases uncertainties. Therefore, "IE" for "included elsewhere" will continue to be used under Ventilation with reference to the subcategories in 1.B.2.b.

8.2 Liquid gas

Germany is currently discussing the construction of liquefied natural gas (LNG) terminals. A floating LNG terminal is currently under construction (as of August 2022) at the Wilhelmshafen site and is expected to be operational from 2023 (Uniper SE 2022). An LNG terminal is also being built in Brunsbüttel. According to media reports, it is expected to be operational in 2023 (NDR 2022). According to the report, two more will be built in the foreseeable future.

There are currently no LNG terminals in Germany, so these emissions are not included in the inventory. Once the terminals are in operation, an estimate of emission levels will be made using the default emission factors given in the IPCC refinement (Boettcher et al., 2019) (Table 4.2.4i). A value of 1.66 tons of methane and 14.687 tons of CO is produced per station$_2$ will be used.

According to the EU Commission's proposal to reduce methane emissions in the energy sector (EC 2021) (page 29, chapter 1, point 2), LNG terminals will also be covered by reporting to IMEO, so that more accurate data for reporting can be expected in the interim.

8.3 Possible double counting for end users

Chapter 5.6 lists new estimates of end-user emissions. These lead to a significant increase in emissions in this area (Table 24). However, it turns out that in some places there is possible double counting, in particular for stationary firing (1.A.1, 1.A.2 and 1.A.4). The emission factors used there will be tested in due course.

8.4 Other measurement programs

According to the DVGW, a research project on compressor emissions has been underway since April 2022, particularly at natural gas filling stations and biogas feed-in plants. Results are not expected before mid-2023 (Boettcher, Dietzsch, & Grosse, 2022). Once available, these values will be reviewed by the UBA and, if approved, used for reporting in 2024.

8.5 Evaluation of measurement methods and use of remote sensing data

In particular, Deutsche Umwelthilfe (Müller-Kraenner & Zerger, 2021) and the Environmental Defense Fund (Maazallahi et al., 2022) have expressed concerns to UBA about the validity of the TSO and DSO measurements.

Due to Germany's federal structure, the UBA cannot procure its own measurements. Given the complexity of the industry, this would also not be an expedient approach. Rather, discussions with measurement service providers, operators, and other authorities such as IMEO, as well as with inventory teams from other countries, should help to compare measurement methods and make recommendations for future measurements.

In the intermediate term, the UBA plans to use the evaluation of satellite data for plausibility checks. The beginnings of this work have been going on for a few years already. However, the spectrometers on the satellites do not measure the methane concentration itself, but rather the light absorption in the electromagnetic spectrum from 300 to 2,500 nanometers. The amount of methane in the atmosphere can then be deduced through complex radiation transfer modeling. There are already companies that have achieved such high resolution with their own satellites that methane emission data for smaller areas of the oil and gas industry, as well as the coal and waste sector (in this case esp. Landfills) can be derived (Appelhans et al., 2022) (Chapter 4.2). The extent to which these findings can be applied to inventory work in Germany is not yet clear.

9 Acknowledgement

I would like to take this opportunity to thank those who have assisted me in the preparation of this document.

In particular, I would like to emphasize the exceptionally good cooperation with the transmission system operators, namely Dr. Bastian Lang (GASCADE) and Dr. Tobias van Almsick (OGE), who never tired of answering all my questions about natural gas transportation. We would also like to thank the DBI, especially Charlotte Große, for the evaluation and preparation of numerous data sets and the support in communicating with the DVGW.

I would also like to thank my two colleagues Yaman Tarakji and Patrick Gniffke for their graphic and layout support.

10 List of sources

Appelhans, J., Boettcher, C., Kessler, K., Mielke, C., Nowack, A., Purr, K., . . . Tambke, J. (2022). *Underestimated greenhouse gas methane: sources, effects, mitigation options.* Retrieved from Dessau-Rosslau: https://www.umweltbundesamt.de/publikationen/unterschaetztes-treibhausgas-methan

BAFA – Federal Office of Economics and Export Control. (2022). Energy – Raw materials – Natural gas statistics. Retrieved from https://www.bafa.de/DE/Energie/Rohstoffe/Erdgasstatistik/erdgas_node.html

Battelle Institute. (1994). *Methane release during natural gas use in Switzerland and comparison with other emitters.* Retrieved from Zurich:

BDEW – Federal Association of the Energy and Water Industry e. V. (1996). *117. Gas statistics, reporting year 1995.* Bonn: WVGW – Economic and publishing company gas and water mbH.

BDEW – Federal Association of the Energy and Water Industry e. V. (2018). *Annual data of gas suppliers: 138. Gas statistics 2016 Federal Republic of Germany.* Bonn: WVGW – Economic and publishing company Gas and Water mbH.

BDEW – Federal Association of the Energy and Water Industry e. V. (2020). *Annual data of gas suppliers: 140. Gas statistics 2018 Federal Republic of Germany.* Bonn: WVWG – Economic and publishing company Gas and Water mbH.

Bender, M., & Langer, D. (2009). *Inventory improvement 2008 – Improvement and addition of the current inventory data: IPCC category (1996) 1.B.2. Diffuse emissions from petroleum and natural gas ; Report no. M76 595/4* (Müller-BBM-GmbH Ed.). Munich.

Bender, M., & Langer, D. (2012). *Determination of emission factors and activity rates in the IPCC area (1996) 1.B.2.b.iii: Diffuse emissions from natural gas storage.* Retrieved from Planegg http://webde/gruppen/bibliothek/OnlineReports/EF000467.pdf

Bertram, A., Boettcher, C., Iyimen-Schwarz, Z., Kirschbaum, B., Osiek, D., Purr, K., & Rechenberg, J. (2014). *Fracking for shale gas extraction: an energy and environmental assessment.* Retrieved from Dessau-Roßlau: https://www.umweltbundesamt.de/sites/default/files/medien/376/publikationen/position_fracking_zur_schiefergasfoerderung.pdf

Betzenbichler, W., Kolmetz, S., Randall, S., Starckx, S., & Lengyel, Z. (2016). *Development of scientific and methodological foundations for the implementation of the recommendations from the international inventory reviews – Improvement of quality management and verification of the German emission inventories* (v. SCE Ed.). Freising.

Beukeme, K. (2000, 6.-9.06.2000). *Report of working committee 8 – environment, safety and health.* Paper presented at the 21st World gas conference.

BMJ – Federal Ministry of Justice. (2004). *Law on the new regulation of renewable energies in the field of electricity.* Cologne: Bundesanzeiger Verlag. Retrieved from https://www.bgbl.de/xaver/bgbl/start.xav?startbk=Bundesanzeiger_BGBl&jumpTo=bgbl104s1918.pdf#__bgbl__%2F%2F*%5B%40attr_id%3D%27bgbl104s1918.pdf%27%5D__1657525557360

BNetzA – Federal Network Agency for Electricity, G., Telecommunications, Post and Railway,, & BKartA – Federal Cartel Office. (2022). *Monitoring Report 2021.* Retrieved from Bonn: https://www.bundesnetzagentur.de/SharedDocs/Mediathek/Monitoringberichte/Monitoringbericht_Energie2021.pdf;jsessionid=5318E185692FB157AA6E4572CCC92D6D?__blob=publicationFile&v=7

Boettcher, C., Dietzsch, F., & Grosse, C. (2022, 09.08.22). [Web conference: Continuation of exchange UBA DVGW DBI].

Boettcher, C., Garg, A., Mbuthi, P. N., Oliver, S. J., Quadrelli, R., Ann Randles, C., . . . Songli, Z. (2019). Chapter 4: fugitive emissions. In L. E. Dawidowski, O. Kolmogortseva, T. Okazaki, I. P. R. e Pinho, S. C. Smyth, & J. Witi (Eds.), *2019 Refinement to the 2006 IPCC guidelines for national greenhouse gas inventories, Volume 2: Energy* [Book section] (Vol. 2 – Energy, pp. 164). Retrieved from https://www.ipcc-nggip.iges.or.jp/public/2019rf/pdf/2_Volume2/19R_V2_4_Ch04_Fugitive_Emissions.pdf

Boettcher, C., & Grundmeier, B. (2011, June 24). [Personal exchange: environmental data and emission-causing activities].

Boettcher, C., & Ladage, S. (2016). [Number of abandoned boreholes].

Boettcher, C., Lang, B., & van Almsick, T. (2021, September 24). [Web-Conference: Exchange TSO and UBA].

Boettcher, C., Lang, B., & van Almsick, T. (2022, June 15). [Web-Conference: Exchange TSO and UBA].

Boettcher, C., Schuetz, S., Dietzsch, F., & Zoellner, S. (2015, September 30). [Web conference: Conversation on discrepancies between GaWaS, NEP and ZSE].

Bongrand, G., Andre, J.-M., Barrault, S., Bort, R., Cuniasse, B., Dossa, E., . . . Vincent, J. (2022). *Rapport National d'inventaire pour la France au titre de la Convention cadre des Nations Unies sur les Changements Climatiques et du Protocole de Kyoto*. Retrieved from Paris: https://unfccc.int/ghg-inventories-annex-i-parties/2022

BPB – Federal Agency for Civic Education. (2022). Germany's dependence on Russian gas [Electronic article]. Retrieved from https://www.bpb.de/kurz-knapp/hintergrund-aktuell/507243/deutschlands-abhaengigkeit-von-russischem-gas/

Bramkamp, F. B., Kulle, E., Friedrich, J., & Richter, H.-G. (1994). The development of the energy and gas industry in 1994. *GWF Gas + Natural Gas, 139*(9), 16.

Brandes, F. (2022). *Development of methane emissions in gas applications (G 201908)*. DVGW. Bonn. Retrieved from https://www.dvgw.de/themen/forschung-und-innovation/forschungsprojekte/dvgw-forschungsprojekt-megan

Brown, P., Cardenas, L., Choudrie, S., Del Vento, S., Karagianni, E., MacCarthy, J., . . . Wong, J. (2022). *UK greenhouse gas inventory, 1990 to 2020: Annual report for submission under the framework convention on climate change*. Retrieved from Harwell: https://unfccc.int/ghg-inventories-annex-i-parties/2022

BVEG – Federal Association for Natural Gas, E. u. G. e. V. (2017). *Environmental Data Guide*. Unpublished work. Hannover.

BVEG – Federal Association for Natural Gas, E. u. G. e. V. (2022). *Facts and figures: Annual Report 2021*. Retrieved from Hannover: https://www.bveg.de/wp-content/uploads/2022/03/BVEG-Jahresbericht-2021.pdf

Carras, J. N., Franklin, P. M., Hu, Y., Singh, A. K., Tailakov, O. V., Picard, D., . . . Yesserkepova, I. (2006). Chapter 4: fugitive emissions. In *2006 IPCC Guidelines for National Greenhouse Gas Inventories* (Vol. 2 – Energy, pp. 78). Hayama: IPCC – Intergovernmental Panel on Climate Change.

Citepa. (2022). France – 2022 Common Reporting Format (CRF) Table (KP). In *Excel*: Citepa.

DBFZ – German Biomass Research Center Nonprofit GmbH. (2012). Expansion of capacities at biogas plants in 2011 exceeds previous years [Press release]. Retrieved from https://www.dbfz.de/pressemediathek/presse/pressemitteilungen-2012/pressemitteilung-19042012

Desai, M., & Camobreco, V. (2022). *Inventory of U.S. greenhouse gas emissions and sinks: 1990-2020*. Retrieved from Saint louis: https://unfccc.int/ghg-inventories-annex-i-parties/2022

DIN – German Institute for Standardization e. V. (2008). Fugitive and diffuse emissions of general interest for industrial sectors – measurement of fugitive emissions of gases and vapors from leaks of operating equipment and pipelines; German version EN 15446:2008. In (pp. 20). Berlin: Beuth-Verlag GmbH.

Dodds, P. E., & McDowall, W. (2013). The future of the UK gas network. *Energy policy, 60*, 12. doi:10.1016/j.enpol.2013.05.030

Duffy, P., Black, K., Fahey, D., Hyde, B., Kehoe, A., Monaghan, S., . . . Ponzi, J. (2022). *Ireland's national inventory report 2022: Greenhouse gas emissions 1990-2020 reported to the united nations framework convention on climate change*. Retrieved from County Wexford: https://www.epa.ie/publications/monitoring--assessment/climate-change/air-emissions/Ireland-NIR-2022_Merge_v2..pdf

DVGW – German Association of the Gas and Water Industry e. V. (2019). *Technical note – Data sheet DVGW G 465-3 (M): Leakage points on gas pipes in gas pipe networks – Location, classification, handling of leakage points* (D.-D. V. D. G.-U. W. E. V. Ed.). Bonn.

EC – European Commission. *Proposal for a regulation of the European Parliament and of the Council on methane emissions reduction in the energy sector and amending Regulation (EU) 2019/942,* COM/2021/805 final C.F.R. (2021).

Eggleston, S., Buendia, L., Miwa, K., Ngara, T., & Tanabe, K. (2006) 2006 IPCC guidelines for national greenhouse gas inventories. In*: Vol. 1-5*. Hayama: IPCC – Intergovernmental Panel on Climate Change.

ENTSOG – European Network of Transmission System Operators, & Neighbouring Transmission System Operators – NET4GAS. (2012). CEE GRIP – Annex A: Country Profiles. In (pp. 26). Praha: ENTSOG – European Network of Transmission System Operators.

FEA – German Federal Environment Agency. (2022). Germany – 2022 Common Reporting Format (CRF) Table. In *Excel*: FEA – German Federal Environment Agency.

Fennema, H., Hoevers, B. J., Oudejans, R., & Vermeulen, U. (2017). Environmental results. In N.-N. Gasunie (Ed.), *Gasunie in motion: Annual report 2017* (pp. 256). Groningen.

Fischer, B., Kaiser, M., Lang, B., van Almsick, T., Vetter, S., Winzer, N., & Heimlich, F. (2021). Pilot project for the detection of volatile emissions in the gas transport network. *GWF Gas + Energy* (11-12/2021), 8. Retrieved from https://thyssengas.com/files/thyssengas/content/verantwortung/111221_fb_Heimlich.pdf

TSO – Transmission system operator Gas e.V. (2021, 2021). Methane emissions. Retrieved from https://TSO-gas.de/energiezukunft/methanemissionen/

GNI – Gas Networks Ireland. (2019). *Systems performance: report 2019*. Retrieved from Cork: https://www.gasnetworks.ie/docs/corporate/gas-regulation/GNI-Systems-Performance-Report-2019.pdf

Gottwald, M.-S., Hilbich. (2012). *Improvement of greenhouse gas emission reporting in the area of "gas, distribution" through data collection and data provision*. Retrieved from

Große, C. (2018). *Final report: Collection of data records of the transport network operators and quality check of the texts and data in the source group 1.B.2.b*. Unpublished work. DBI Gas and Environmental Technology GmbH.

Große, C. (2019). *Quality check of the texts for the National Inventory Report and data collection in the source group 1.B.2.b: Final report*. Unpublished work. DBI Gas and Environmental Technology.

Große, C. (2020). *Quality check of the technical terms of the English-language National Inventory Report and data collection and evaluation in the source group 1.B.2.b as part of an expert project: Final report*. Unpublished work. DBI Gas and Environmental Technology GmbH.

Große, C., Eisser, M., Lehmann, S., Sammueller, J., & Behnke, M. (2022). *Determination of methane emissions of the gas distribution network (ME DSO): Inventory of the data situation for estimating methane emissions from* *the German gas distribution network, development and implementation of a representative measurement program for collecting the necessary data: Final report*. Retrieved from Bonn:

Günther, D., & Gniffke, P. (2022). *Submission under the United Nations Framework Convention on Climate Change and the Kyoto Protocol 2022: National inventory report for the German Greenhouse Gas Inventory 1990-2020*. Retrieved from Dessau-Roßlau: http://webde/gruppen/bibliothek/Onlinebuecher/EB013570.pdf

Hiraishi, T., Meijer, J., Pullus, T., Simmons, T., Tichy, M., Cahyono Adi, A., . . . Domingos Miguez, J. (2000). Chapter 2: Energy. In M. Gillet, M. Darras, E. Gjerald, D. Kruger, R. Lott, K. Mareckova, M. Phillips, J. Spakman, H. Shenchu, L. Dobbie, R. Falk, M. Gillenwater, R. Hoppaus, G. Reynolds, K. Rypdal, I. Hossain, D. Gomez, M. Miroslav, M. Oi, U. Rajarathnam, S. Tuhkanen, & J. Zhang (Eds.), *IPCC Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories* (pp. 95). Hayama: IPCC – Intergovernmental Panel on Climate Change.

IPCC – Intergovernmental Panel on Climate Change. (1996) Revised 1996 IPCC guidelines for national greenhouse gas inventories. In.

Jonsson, M., Al-Hanbali, H., Szudy, M., Eklund, V., Ortiz, C. J., Skårman, T., . . . Kanth, M. (2022). *National Inventory Report Sweden 2022: Greenhouse gas emission inventories 1990-2020 – Submitted under the United Nations Framework Convention on Climate Change and the Kyoto Protocol*. Retrieved from Stockholm: https://unfccc.int/ghg-inventories-annex-i-parties/2022

Kupers, R., Caltagirone, M., Ferrini, G., Zavala-Araiza, D., Tullos, E., Alonso Esparza Gamez, R., . . . Schwietzke, S. (2021). *An eye on methane: International methane emissions observatory 2021 report*. Retrieved from Nairobi: https://wedocs.unep.org/bitstream/handle/20.500.11822/37283/AEM_IMEO.pdf

Lange, R., Steiner, M., & Schwigon, A. (2021). Gas inventory and event data collection – results from the years 2011 to 2020. *energy / water practice, 72*(12), 12. Retrieved from https://www.dvgw.de/medien/dvgw/sicherheit/energie-wasser-praxis-dvgw-bestands-ereignisdatenerfassung-gas.pdf

Lechtenboehmer, S., Dienst, C., Fischedick, M., Hanke, T., Langrock, T., Assonov, S. S., & Brenninkmeijer, C. (2005). *Greenhouse gas emissions of the Russian natural gas export pipeline system: results and projections of empirical studies in Russia*. Retrieved from Wuppertal: https://epub.wupperinst.org/frontdoor/deliver/index/docId/2153/file/2153_GEPS_de.pdf

Lubenau, U., & Schuetz, S. (2014). *Measurements of the natural gas quality at various points in the grid for the derivation or verification of average emission factors and calorific values of natural gas*. Unpublished work. DBI Gas- und Umwelttechnik GmbH. Leipzig.

Maazallahi, H., Delre, A., Schuetz, C., Fredenslund, A. M., Schwietzke, S., Denier van der Gon, H., & Röckmann, T. (2022). Intercomparison of detection and quantification methods for methane emissions from the natural gas distribution network in Hamburg, Germany. *Atmospheric Measurement Techniques Discussions*, 29. doi:10.5194/amt-2022-134

MEPRDP – Ministry of Environmental Protection and Regional Development of the Republic. (2022). Latvia – 2022 Common Reporting Format (CRF) *Excel*: MEPRDP – Ministry of Environmental Protection and Regional Development of the Republic.

Müller-Kraenner, S., & Zerger, C. (2021). Deutsche Umwelthilfe reveals climate-damaging methane leaks on German natural gas infrastructure. Retrieved from https://www.duh.de/presse/pressemitteilungen/pressemitteilung/deutsche-umwelthilfe-enthuellt-klimaschaedliche-methan-lecks-an-deutscher-erdgas-infrastruktur/

NDR – North German Broadcasting Corporation (Norddeutscher Rundfunk Anstalt des öffentlichen Rechts). (2022). The rush to build LNG terminals [Press release]. Retrieved from https://www.tagesschau.de/wirtschaft/lng-fluessiggas-lng-terminal-erdgas-gasembargo-101.html

OE – Office of Environment. (2022). Liechtenstein – 2022 Common Reporting Format (CRF) Table. In *Excel*: OE – Office of Environment.

OGE – Open Grid Europe GmbH. (2022). Network products: Repair work without loss of natural gas: economical and environmentally friendly with a mobile compressor. Retrieved from https://oge.net/de/fuer-kunden/dienstleistungen/technische-dienstleistungen/netzprodukte/mobile-verdichter

Press and Information Office of the Federal Government. (2022). Government Policy Facts: Improving security of Supply – Gas Supply: Reducing Dependencies [Electronic Article]. Retrieved from https://www.bundesregierung.de/breg-de/themen/gasversorgung-abhaengigkeiten-verringern-441270?view=renderNewsletterHtml

REE – Ricardo Energy & Environment. (2022). United Kingdom – 2022 KP Common Reporting Format (CRF) Table. In *Excel*: REE – Ricardo Energy & Environment.

Reichert, J., Schön, M., & Behnke, L. (2000). *Methane emissions from the extraction, transport and use of natural gas: Investigation for the Federal Ministry for the Environment, Nature Conservation and Nuclear Safety* (AG GI5-46043-3/31). Retrieved from Karlsruhe: Library entry: https://search.ebscohost.com/login.aspx?direct=true&db=cat04356a&AN=fuu.02098079&lang=de&site=eds-live

RIVM – National Institute for Public Health and the Environment. (2022). Netherlands – 2022 Common Reporting Format (CRF) Table. In *Excel*: RIVM – National Institute for Public Health and the Environment.

Ruyssenaars, P. G., van der Net, L., Coenen, P. W. H. G., Rienstra, J. D., Zijlema, P. J., Arets, E. J. M. M., . . . van der Zee, T. (2022). *Greenhouse gas emissions in the Netherlands 1990-2020 National Inventory Report 2022*. Retrieved from Bilthoven: https://unfccc.int/ghg-inventories-annex-i-parties/2022

Rypdal, K., Paciornik, N., Eggleston, S., Goodwin, J., Irving, W., Penman, J., & Woodfield, M. (2006). Chapter 1: Introduction to the 2006 guidelines. In *2006 IPCC guidelines for national greenhouse gas inventories, Volume 1: General guidance and reporting* [Book section] (Vol. Volume 1: General guidance and reporting, pp. 12). Retrieved from https://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/1_Volume1/V1_1_Ch1_Introduction.pdf

Schäppi, B., Weber, F., Ehrler, A., Rihm, B., Beckbissinger, J., Jaeggi, N., . . . Eberle, H. (2022). *Liechtenstein's Greenhouse Gas Inventory 1990-2020: National Inventory Report 2022 – Submission of 14 April 2022 under the United Nations Framework Convention on Climate Change and under the Kyoto Protocol*. Retrieved from Vaduz: https://unfccc.int/ghg-inventories-annex-i-parties/2022

Schneider-Fresenius, W., Hintz, R. A., Hoffmann-Meienbrock, U., Klöpffer, W., & Wittekind, J. (1989). *Determination of the methane release due to material losses in the natural gas supply of the Federal Republic of Germany – Contribution of methane to the greenhouse effect.* Retrieved from Frankfurt am Main:

Schuhmann, K.-U. (2018). Technical Regulations for gas installations – The DVGW-TRGI 2018. *Energy and Water Practice, 2018*(9), 6. Retrieved from: https://www.dvgw.de/medien/dvgw/gas/installation/trgi2018-1809schuhman.pdf

Schütz, M.-S. U. (2014). *GHG reduction potentials in the European gas infrastructure*. Retrieved from

Skrebele, A., Treija, S., Lupkina, L., Cakars, I., Siņics, L., Lazdāne-Mihalko, J., . . . Dansone, B. (2022). *Latvia's national inventory report: Greenhouse gas emissions in Latvia from 1990 to 2020 in common reporting formats (CRF)*. Retrieved from Riga: https://unfccc.int/ghg-inventories-annex-i-parties/2022

Szemesová, J., Labovský, J., Horváth, J., Danielik, V., Tonhauzer, K., Privitzer, T., . . . Škultéty, J. (2022). *National inventory report 2022: Submission under the UNFCCC and under the Kyoto Protocol*. Retrieved from Bratislava: https://unfccc.int/ghg-inventories-annex-i-parties/2022

UNFCCC – United Nations Framework Convention on Climate Change. (2022). Reporting requirements. Retrieved from https://unfccc.int/process-and-meetings/transparency-and-reporting/reporting-and-review-under-the-convention/greenhouse-gas-inventories-annex-i-parties/reporting-requirements

Uniper SE. (2022). Construction of the Wilhelmshaven LNG terminal can begin shortly[Press release]. Retrieved from https://www .uniper.energy/news/en/construction of the lng terminal-wilhelmshaven-can-start-fast#

von Ohlen, N. (2021a). *Gas Grid Development Plan 2020-2030: implementation report*. Retrieved from Berlin: https://TSO-gas.de/wp-content/uploads/2021/09/TSO_gas_umsetzungsbericht_2021_de.pdf

von Ohlen, N. (2021b). Procedure: This is how we draw up a plan for a safe and economical gas supply [Press release]. Retrieved from https://TSO-gas.de/netzentwicklungsplaene/

Winiwarter, W., Mangino, J., Ajavon, A.-L.N., & McCulloch, A. (2006). Chapter 6: Quality assurance / Quality control and verification. In M. Woodfield (Ed.), *Volume 1: General Guidance and Reporting* [Book section] (Vol. 1, pp. 31). Retrieved from https://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/1_Volume1/V1_6_Ch6_QA_QC.pdf

Wöber, B. M. (2022). Sustainably mobile with BioCNG, bioLNG, CNG, LNG. Retrieved from https://www.gibgas.de/

Zoellner, S., & Große, C. (2015). *Comparison of the emission data UBA and DBI*. Unpublished work. UBA – German Federal Environmental Agency and DBI Gas and Environmental Technology GmbH.

Zoellner, S., Schuetz, S., & Mueller-Syring, G. (2014). *Expertise on recalculation of emissions*. Unpublished work.