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TECHNICAL ASSOCIATION
OF THE EUROPEAN NATURAL GAS INDUSTRY

Survey methane emissions for gas transmission and distribution in Europe

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1. SUMMARY

In this study the total methane emission from Natural Gas transmission and distribution networks was estimated.

The impact of Greenhouse Gases on climate change has been recognized for some time which has led to measures aimed to reduce global warming. Methane (CH_4) which is a major component of Natural Gas has an impact on climate changes.

As Natural Gas is a major source of energy for the society, it is the role of the gas network operators to deliver continuous and safe service whilst managing responsibly impact on the environment.

MARCOGAZ, the Technical Association of European Gas Companies, considers that it is important for the Gas Industry to understand and quantify its emissions of Natural Gas. It is also important to be transparent about the methodology used to calculate emissions and to demonstrate that best practices are used across the European Gas Industry.

The total amount of methane emitted in Europe[1] via the Natural Gas transmission and distribution network was estimated by MARCOGAZ via different statistical methods.

The total amount of GHG emissions caused by the methane emissions from Natural Gas transmission and distribution grids is estimated to be between **0,5% and 0,9%** of the total of anthropogenic[2] GHG emission (CO_2 equivalents) in Europe (EU28)[3].

Compared to the total mass [tons] of Natural Gas sales in Europe[4], the aggregated European methane emission is calculated to be **0,1%** for transmission and **0,4%** for distribution grids.

Because of the limited number of datasets this result is a first preliminary qualitative characterization of the total methane emissions arising from Natural Gas distribution and transportation networks in Europe.

MARCOGAZ continues through its Working Group Methane Emissions to investigate better methods to measure and estimate methane emissions in the gas supply chain.

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[1] Romania and Russia are not included in the MARCOGAZ dataset

[2] Anthropogenic emissions: emissions originating in human activity

[3] Annual European Union greenhouse gas inventory, 1990–2012 and inventory report 2014, Submission to the UNFCCC Secretariat, page 10 - 11

[4] This calculation included the countries : Austria, Belgium, Czech Republic, Denmark, France, Finland, Germany, Greece, Italy, Ireland, the Netherlands, Norway, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Switzerland, United Kingdom

2. INTRODUCTION

In the past five years an increasing number of reports from reputable institutions have highlighted the environmental impact of global warming and the accelerating effect that the continued release of Greenhouse Gases to atmosphere is having on this phenomenon.
This changing attitude of governments, regulatory bodies and the general public has resulted in increasing attention being paid to the methane releases from the gas networks across Europe.

Significant literature has been published which proposes various methods of estimation. This is further complicated by the differences in the different Countries.

MARCOGAZ developed and published (2005) a methodology using all existing knowledge available within the group of European gas infrastructure operators.

As Countries have differences in their operating regimes, the common methodology would allow a common approach to the estimation of methane emissions available.

There are still gaps in the methodology where data are not currently available. Therefore, MARCOGAZ started a review in 2014 of the method to see if a more detailed approach with uncertainty assessment will be possible on basis of existing methods used throughout the World.

In 2007 a first assessment was made to derive a range for emission factors for gas transmission and distribution. In 2014 and 2015 this assessment was repeated to look at developments of the emission factor, but also to give an estimate of the total methane emissions from Natural Gas Industry.

The emissions of methane from gas chain can be divided into four major categories: fugitive emissions, emissions from pneumatic devices, vented emissions and incomplete combustion emissions.

Methane emissions from underground gas storages and LNG terminals are not considered in this study because no data was provided at the moment.

3. LIST OF DEFINITIONS

In order to obtain comparable objective emission calculations or estimations, the use of identical definitions is necessary. For this reason, a number of definitions are given hereunder.

3.1. Emissions: sources of methane

- *Fugitive emissions*: All leaks from flanges, pipe equipments, valves, joints, seals and seal gas systems etc. that are more or less continuous sources.

- *Pneumatic emissions*: All emissions caused by gas operated valves, continuous as well as intermittent emissions.

- *Vented emissions*:
    - *Maintenance vents:* Methane emissions from normal or planned operating conditions where significant volumes of Natural Gas are released to atmosphere from the gas network. This includes release through vent stacks; blow off valves, pressure release and flushing of installation (distribution, transmission …), and emissions due to normal maintenance inspection and control. Distribution emissions from service lines and pipelines are also included.
    - *Incident vents:* Methane emissions from unplanned events. This will normally be from failures of the system due to third party activity and external factors normally outside of the control of the gas company.
    - *Operation vents:* i.e. starting and stopping of the compressors.

- *Incomplete combustion emissions:* Unburned methane in the exhaust gases from gas turbines, gas engines and combustion facilities and flares.

3.2. Gas system

- *Transmission system*: High-pressure gas transport over long distance including pipelines, compressor stations, metering and regulating stations and a variety of above-ground facilities to support the overall system. Underground gas storage and LNG are excluded. Transport from production companies to the distribution companies and to the industries. Operating pressure is normally equal or greater than 16 bar.

- *Distribution system*: Medium to low pressure transport including distribution pipelines, service lines and a variety of above-ground facilities to support the overall system. Local transport from transmission system to customer meters. Pressure normally ranges less than 5 bar. But new polyethylene systems up to 10 bar are now developed in some EU countries. Medium pressure: 0,200 – 5 bar. Low pressure: less than 200 mbar.

  Note: The part of the system under 16 bar and above 5 bar can be considered in transmission or distribution, depending on the system boundaries adopted by each company and/or on the techniques used (steel, polyethylene…).

- *Underground storage*; Gas storage in gas fields, aquifers or salt and other domes including gas compressor station, treatment plants and a variety of above-ground facilities to support the overall system.

- *LNG terminal*: Storage and gasification of Liquefied Natural Gas – LNG - including unloading of the ships and a variety of above-ground facilities to support the overall system.

3.3. Factors

- *Activity factor:* The activity factors are the population of emitting equipment's such as length of pipelines, installed compressor capacity, the number of venting activities, accidental perforation, etc.

- *Emission factor:* The emission factor describes typical methane emissions of a component or part of the gas system (e.g. valve, pipeline section).

3.4. Geographical boundaries

The estimations for methane in this report for distribution and transmissions companies in Europe are based on the list of Counties given in paragraph 7.4 appendix IV.
For comparison against the anthropogenic Greenhouse Gas emission of the EU28 the *Annual European Union greenhouse gas inventory, 1990–2012 and inventory report 2014, Submission to the UNFCCC, page 11* was used [see §6 - reference 3].

4. RESULTS

4.1. Data collection

MARCOGAZ started a survey among its Members in October 2014 with the question to fill in the form of the MARCOGAZ method (see Appendix I – page 23). The form was returned by 6 Members of the MARCOGAZ transmission pipeline operators and 4 Members for distribution system operators. Although the group who has responded is relative small it will be possible to make an estimation of the total methane emissions in Europe coming from distribution and transmission of Natural Gas.

4.2. Description of the method

The evaluation of total emissions is based on the following equation:

$$\boldsymbol{Methane\ emission} = \sum(\boldsymbol{AF}\ \times \boldsymbol{EF})$$

Where:

AF = activity factor
EF = emission factor

The **activity factors** are the population of emitting equipment's such as length of pipelines, number and type of valves, number and type of pneumatic devices, and the frequency of emitting events such as number of operating vents. The activity factors, because of the high number and types of emitting equipments in the gas chain, must be often estimated with a statistical approach based on a random sample of gas chain, introducing a factor of uncertainty.

The **emission factors** are defined as the quantity of methane emitted from each emitting source and for each emitting event. Some emissions are known, such as the gas released for operating reasons or for maintenance, some others can be evaluated on the basis of the characteristics of components and their emission factors, the emission from the operation of a pneumatic device. Other emission factors are difficult to measure such as those deriving from fugitive emissions. For fugitive emissions several measurements methods exist.

4.3. General

Main goal of the analysis was to find emission factors for the total emissions of methane arising from the European Natural Gas transmission and distribution grid. With these factors it is possible to derive an estimate of the total emissions in Europe from all pipelines assuming that the companies who delivered their data are representative for this purpose[5]. It is remarked that the data received came from major gas transmission companies in Europe having a good knowledge of their methane emissions.

Analysis of variance and linear polynomial fitting were used to calculate the polynomial coefficients and their uncertainty from which the total methane emission could be derived (See [Reference 1] - page 22). Because of limited number of the datasets and the quality (accuracy, completeness) of the datasets the total methane emissions were derived from a first order polynomial in which the total methane emission was calculated directly from the total pipeline length.

[5] The data set for transmission covered 30% to 70% of the total transmission pipeline length. 70% for the average calculation and 30% for the most representative datasets. For distribution the dataset covered 30% - 60% of the total distribution pipeline length. 60% in case for the average calculations and 30% in case of the representative datasets.

In this analysis 4 scenarios were distinguished, i.e.:

- **Average emission factor** in which the emission factor is derived as the average factor from polynomial fitting including uncertainty of the coefficients.
- **Median emission factor** in which the emission factors is calculated as the median emission factor of the sample population.
- **Worst case emission factor** where the largest emission factors from the sample population is used for the estimation of the methane emission.
- **Most representative emission factor**, in which the most representative values are used. These are from the companies who delivered complete datasets.

4.4. Transmission data sets

4.4.1. Evaluation of the quality of the data set

In 2004-2005, eight European gas transmission companies, depicted as company A → J, provided data related to Natural Gas emissions from their infrastructure, for the years 2002-2005.

In 2014 and 2015 twelve gas transmission companies provided the same data, related to the years 2009-2014.

From the data sets it was concluded that most of the companies did not deliver all the data according to the MARCOGAZ format. Sometimes data was reported as one group instead of reporting the detail in different subgroups. Some of the companies consider the whole gas infrastructure and a lot of them consider only vented emission instead of all emissions categories, according to European MARCOGAZ methodology. For the new submission (2009-2013) the situation is becoming better although some companies are still not reporting all the data according to the MARCOGAZ methodology. This is illustrated in the following tables:

Legend:

■ data provided

Methane emission source	A	B	C	D	E	F	G	H	I	J	K	L	M
pipe maintenance	■		■	■	■	■	■			■			
pipe pneumatic valves				■				■					
pipe fugitive			■	■		■				■			
pipe incidents			■	■	■								
pipe flares													
CS vents starts	■		■	■	■	■	■			■			
CS vents stops	■		■	■	■	■	■						
CS vents flare													
CS incidents			■		■			■					
CS combustion gas engines			■		■	■				■			
CS combustion gas turbines	■		■	■	■	■	■	■		■			
CS fugitive ESD valves			■	■		■	■			■			
CS fugitive gas engines						■				■			
CS fugitive gas turbines	■		■	■		■		■		■			
CS pneumatic components	■			■		■	■			■			
CS maintenance			■	■	■		■			■			
RR fugitive	■			■		■		■		■			
RR pneumatic	■			■	■	■		■					
RR maintenance				■	■		■						
RR combustion	■			■		■	■	■		■			

Table 1: Transmission data per company period 2002-2005

Methane emission source	A	B	C	D	E	F	G	H	I	J	K	L	M
pipe maintenance	X	X	X	X	X		X		X		X		X
pipe pneumatic valves				X				X				X	
pipe fugitive				X	X			X			X	X	X
pipe incidents			X	X					X		X		
pipe flares													X
CS vents starts	X	X	X	X	X			X				X	
CS vents stops	X		X	X	X							X	
CS vents flare													
CS incidents			X										
CS combustion gas engines					X								
CS combustion gas turbines	X			X	X			X					
CS fugitive ESD valves				X				X					
CS fugitive gas engines													
CS fugitive gas turbines	X			X	X			X			X	X	
CS pneumatic components	X	X		X	X			X					
CS maintenance		X	X	X	X		X					X	X
RR fugitive	X			X	X			X			X	X	X
RR pneumatic	X	X		X	X			X				X	
RR maintenance		X			X			X	X				
RR combustion	X			X				X	X				X

Table 2: Transmission data per company period 2009 - 2013

There is some concern that the limited number of completed data responses from the MARCOGAZ Members, could result in a more qualitative than quantitative result. This may not be completely representative for the Gas Industry as a whole and could be open to challenge. Although the datasets were not complete, data was grouped in the following subcategories:

Activity factor i.e.:

System length (kilometer of pipeline)
Compressor station total thermal input of the compressors and engines
Compressor station total gas consumed by turbines and gas engines
Number of pressure regulating and reduction station
Number of city gate stations

Total emissions for:

Total CH_4 emission transmission system (CH_4 total)
Total CH_4 emissions compressor stations (CS)
Total CH_4 emissions pressure regulating and reduction stations (RR)
Total CH_4 emissions city gate stations (CG)
Total CH_4 emission other stations (rest)

Reduction and regulation stations also include metering.

4.4.2. Further Analysis

To investigate significant correlation between activity factors and emission factors a correlation matrix was calculated.

Although some of the correlations between activity factors and total or partial methane emissions are high it has to be recognized that some of the correlations in the matrix cannot be used for linear polynomial fit purposes. This because of the incompleteness of the data sets (some correlations are calculated from only 3 data points).
Subject of the data analysis study was to investigate whether it is possible to derive the total company emissions using a combination of partial system activity factors and their accompanying methane emissions according to the formula:

$$\boldsymbol{Company\ total\ emission} = \sum_{i}^{n} (\boldsymbol{EF_i} \times \boldsymbol{AF_{i)}})$$

Where:

EF = emission factor
AF = activity factor
i = CS, RR, CG, pipeline, rest

Further evaluation has to be done to investigate the possibility to predict the total methane emission from the partial activity factors, according to the formula:

$$\boldsymbol{Company\ total\ emission} = \sum_{i=1}^{n} (\boldsymbol{\beta_i} \times \boldsymbol{AF_i})$$

Where:

AF = activity factor
i = CS, RR, CG, pipeline, rest
β_i = polynomial coefficient of i

Both studies gave statistically poor results.

Because for all reporting companies the total system length and the total methane emissions were available it was decided to evaluate the emission factors as given in §4.3. This was also supported by a correlation coefficient of 0,74. MARCOGAZ collects system data of the total length of the transmission pipeline grid of almost all European countries ([Reference 2 – page 22). This data was used to estimate a total methane emission from transmission for Europe using the emission factors derived from the dataset.

4.4.3. Emission factors

4.4.3.1. Scenario 1: Emission factors from polynomial fit

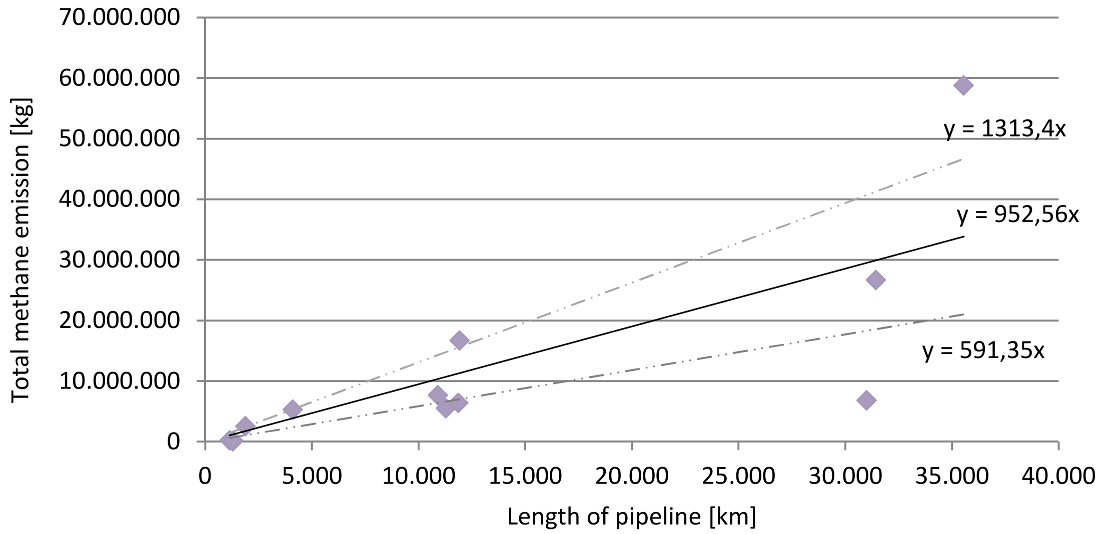

Figure 1: Polynomial fit between pipeline length and emissions

Figure 1 shows the polynomial fit of the methane emission as a function of the transmission pipeline length. The 95% confidence intervals of the polynomials are presented as a dotted line. For a complete summary of the polynomial fit, see Table 10 – page 25.

From the polynomial coefficient the methane emissions for the total pipeline length in Europe was estimated:

type	parameter	total length transmission pipeline [km]	EU methane emission [ton]
polynomial	95% upper control limit	217.685	285.907
	average		207.358
	95% lower control limit		128.728

Table 3: Total methane emissions for transmission pipelines in Europe

A disadvantage of the polynomial approach is that the analysis was done with a non-homogenous dataset. This will give some restrictions to the average polynomial coefficient at this moment.

4.4.3.2. Scenario 2: Median emission factors

In Figure 2 a box and whisker plot is given for the methane emission factors expressed as the total methane emission per company per kilometer of pipeline. A box and whisker plot is a convenient way of graphically depicting groups of numerical data through their quartiles. Box plots may also have lines extending vertically from the boxes (whiskers) indicating variability outside the upper and lower quartiles,

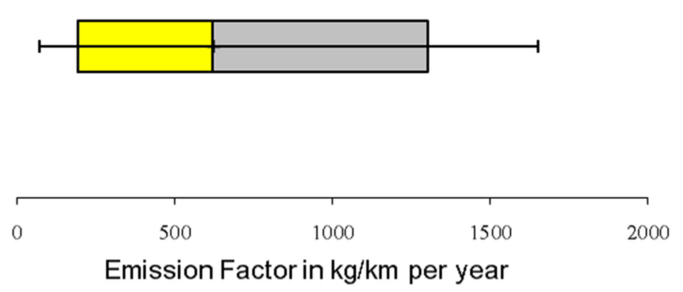

Figure 2: Box and Whisker plot emission factor

With the median value (620 kg/km of pipeline per year) of the box and whisker plot the total methane emission in Europe was calculated. This gives a value of 135.022 ton of methane, what is somewhat lower than the calculated average value calculated in the previous paragraph (*Table 3*).

4.4.3.3. Scenario 3: Worst case emission factor

Taking into account the worst emission factor arising from the dataset (see Table 9) the total emission for approximately 217.685 kilometers of pipeline in Europe will be 360.049 ton of methane per year.

4.4.3.4. Scenario 4: Representative data sets

To find a more realistic emission factors for the methane emissions, a calculation was performed for gas companies providing an almost complete submission in the years 2003-2005 or 2009-2014 (company A, B, D, E, H, J and L). Were companies submitted data for both time periods 2003-2005 and 2009-2014 the emission factors are very close to each other. This can be seen in *Figure 3*. Taking the values of the representative datasets of the last time period available in one graph gives an emission factor of approximately 821 kg methane per kilometer pipeline per year. This can be seen in *Figure 4* and in Table 11 – page 25. *Figure 4* depicts the average polynomial and the 95% confidence intervals of this polynomial.

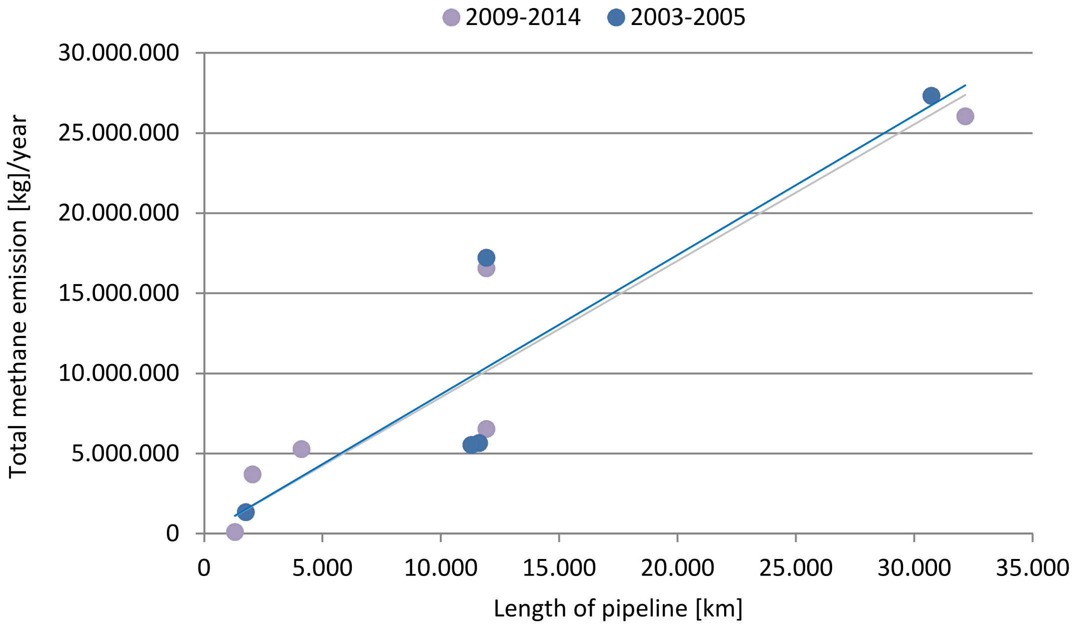

Figure 3: Representative emission factors for transmission data.

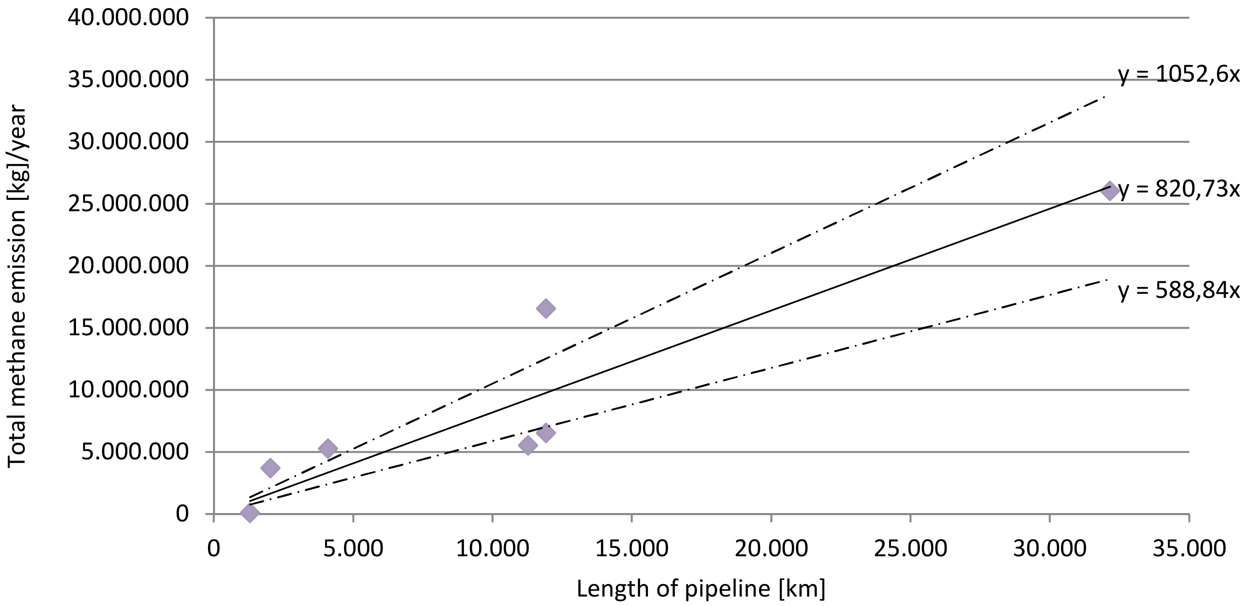

Figure 4: Representative emission factors for transmission data 2009-2014.

From this the following methane emissions can be calculated for transmission pipelines in Europe:

type	parameter	total length transmission pipeline [km]	EU methane emission [ton]
polynomial	95% upper control limit	217.685	229.135
	average		178.661
	95% lower control limit		128.182

Table 4: Methane emission for transmission pipelines in Europe 2002-2013 representative datasets

4.5. Distribution data sets

The same methodology as used for transmission is used to process the distribution data sets.

4.5.1. Evaluation of the quality of the data set

In 2004 four European gas distribution companies provided data related to Natural Gas emissions from their infrastructure, for the year 2003-2005. In 2014 five European gas distribution companies provided data, related to the years 2012-2013.
The following tables show the gas infrastructure evaluated for the different companies. They consider different network materials, including service lines, so the data provided are comparable, except for company C.

Legend:
■ data provided
□ not existing material in that specific company

2003	A	B	C	D
Grey cast iron	■	■	■	■
Ductile cast iron	■	■	■	■
Steel	■	■	■	■
Plastic Polyethylene	■	■	■	■
Plastic PVC	□	■	□	□
Material in general not specified	■	■	■	□
Service Lines	■	■	■	■

Table 5: Distribution data per company 2003-2005

2012-13	A	B	C	D	G	K
Grey cast iron	■	■	■	■	■	■
Ductile cast iron	■	■	■	■	■	■
Steel	■	■	■	■	■	■
Plastic Polyethylene	■	■	■	■	■	■
Plastic PVC	□	■	□	□	□	■
Material in general not specified	■	■	■	□	■	■
Service Lines	■	■	■ [6]	■	■	■

Table 6: Distribution data per company period 2012-2013

The datasets were grouped in the following categories:

Activity factors i.e.:
Distribution grey cast iron pipeline [km]
Distribution ductile cast iron pipeline [km]
Distribution steel pipeline [km]
Distribution polyethylene pipeline [km]
Distribution PVC pipeline [km]
Distribution material not specified [km]
Total length distribution pipelines [km]
Number of service lines
Service lines % of total
Number of city gates

[6] Service lines data not taken into account in scenario 4. Not enough information about the method at the moment of writing the report.

Total methane emissions for:
CH_4 grey cast iron [kg]
CH_4 ductile [kg]
CH_4 Steel [kg]
CH_4 polyethylene [kg]
CH_4 PVC [kg]
CH_4 not specified [kg]
CH_4 distribution total [kg]
CH_4 service lines total [kg]
CH_4 city gate [kg]
CH_4 other [kg]
CH_4 total [kg]

4.5.2. Further analysis

To investigate correlation between activity factors and emission factors a correlation matrix was calculated.

Although some of the correlations between activity factors and total or partial methane emissions are high it has to be recognized that some of the correlations in the matrix cannot be used for linear polynomial fit purposes. This because of the limited number of datasets for this analysis (some correlation are calculated from only 3 data points).

From the correlation matrix it was found that the correlation between the total length of the distribution pipeline has a poor correlation (0,56) with the total methane emissions for distribution pipelines (including city gates and service pipelines). For this reason, the activity factor was used to make an estimate of the total methane emission for distribution in Europe using not only the average activity factor derived from the polynomial fit but also the activity factors of the upper and lower confidence interval of the fit.

4.5.2.1. Scenario 1: Emission factors from polynomial fit

It was examined if the results of 2003-2005 were different from the results in 2012-2013. This is depicted in Figure 5 were the total methane emission from distribution can be seen as a function of distribution pipeline length. Statistically It is not possible to distinguish between the two time periods to evaluate the progress of the emission factors in time.

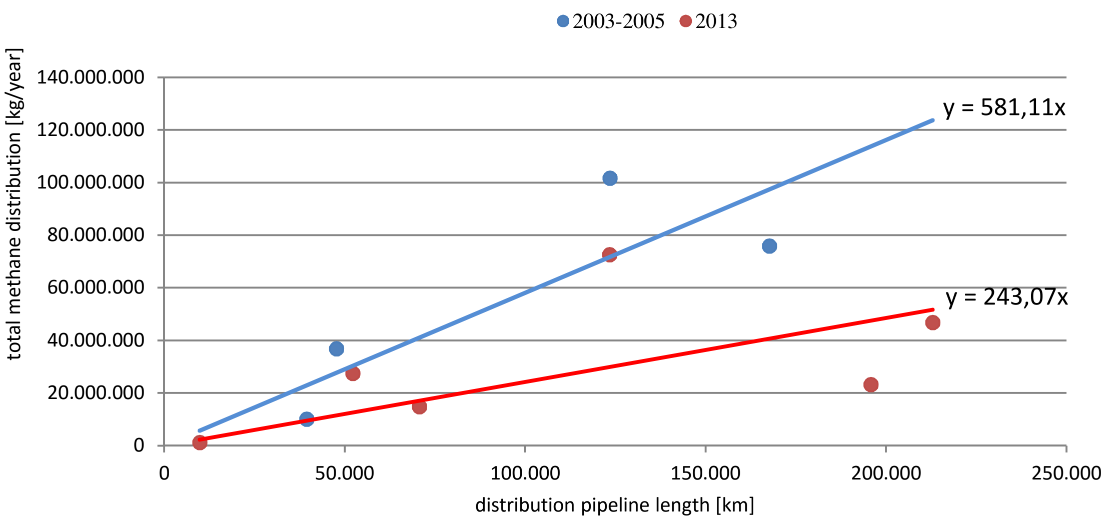

Figure 5: Methane emission versus pipeline length for different time periods

Figure 6 shows the polynomial fit of the methane emission as a function of the pipeline length. In this figure the 95% confidence intervals of the polynomial are also plotted (dashed lines).

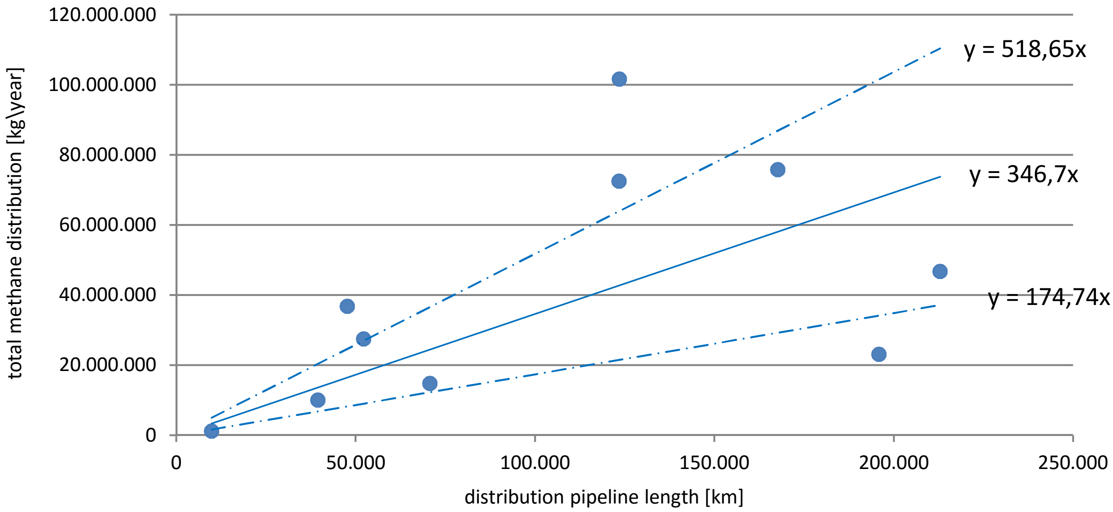

Figure 6: Polynomial fit between pipeline length and emissions 2003-2013

Using the polynomial coefficients, the following methane emissions for pipelines in Europe can be calculated (see Table 7).

type	parameter	total length of distribution pipeline [km]	methane emissions [ton]
polynomial	95% Upper control limit	1.640.667	850.932
	average		568.819
	95% Lower control limit		286.690

Table 7: Total methane emission for distribution pipelines in Europe 2003-2013.

4.5.2.2. Scenario 2: Median emission factors

With the median emission factor of 354,3 kg methane per kilometer of pipeline per year (Figure 7) the total methane emission in Europe was calculated for distribution. The total amount of methane in this case is 581.305 ton of methane, what is in the same order than the calculated average methane emission in the previous paragraph (see §4.5.2.1).

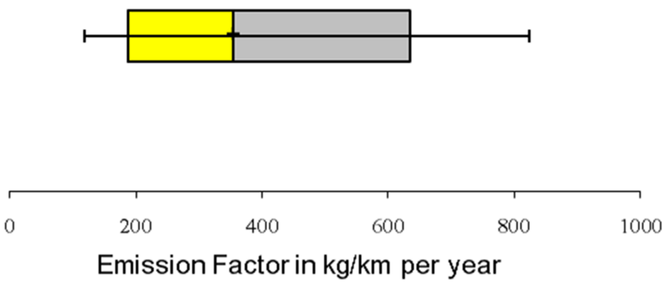

Figure 7: Box and Whisker plot emission factor distribution

4.5.2.3. Scenario 3: Worst case emission factor

Taking into account the highest emission factor of the dataset (823,2 kg methane / km pipeline per year) (see Figure 7) the total emission of approximately 1,7. 10^6 kilometers of distribution pipeline in Europe will be will be 1.350.531 ton of methane.

4.5.2.4. Scenario 4: Representative emission factors

Safety has always been number one priority for distribution companies. Therefore, distribution companies put a lot of effort in replacing cast iron network.

In Figure 5 – page 16 - it can be seen that there is decrease in the average emission factor for the period 2009-2013 in comparison to the period 2003-2005.

Although via hypothesis testing (see paragraph 4.5.2.1, *Figure 5*) it cannot be proven statistically that the datasets for both periods are different, it was decided to perform an analysis for the period 2009-2013 exclusively. One of the companies did not report on the service lines. The result of this is that for this company the total methane emissions are lower than expected. For this reason, this company is not taken into account for the most representative results.

The remaining dataset can be considered as the most actual and representative at this moment. Regression analysis (see also Table 13 – page 26) gives polynomials and their uncertainties as given in Figure 8.

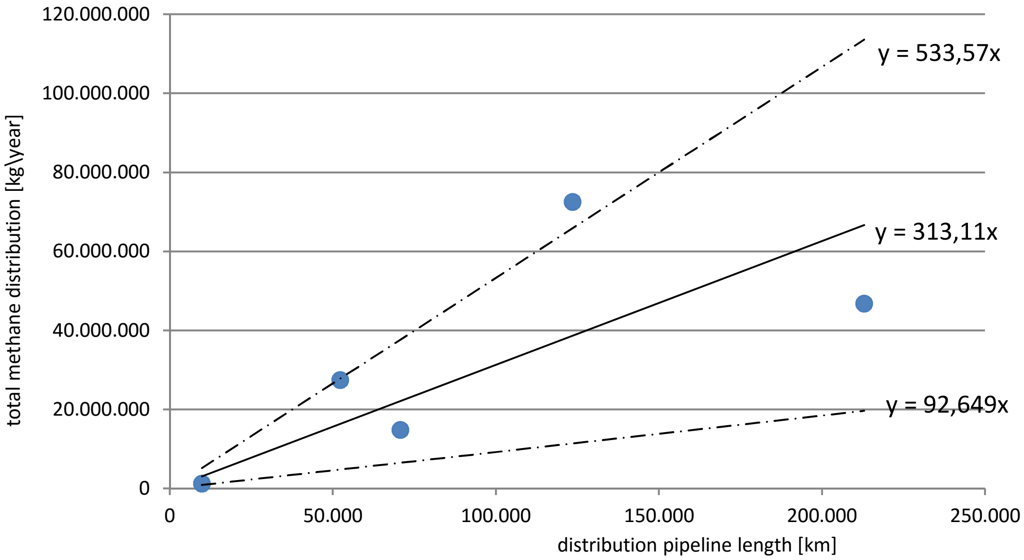

Figure 8: Polynomial fit between pipeline length and emissions 2013

type	parameter	total length of distribution pipeline [km]	methane emissions [ton]
polynomial	95% Upper control limit	1.640.667	875.411
	average		513.709
	95% Lower control limit		152.008

Table 8: Total methane emission for distribution pipelines in Europe 2013

Considering the graph of the most recent emission factors for distribution pipelines it can be concluded that a safe way to describe the emission factors is to use the upper control limit since most of the emissions are lower than this line. Also the difference of the 95% upper control limit of the period 2003-2013 and the most recent period 2009- 2013 is relative small what can be seen in *Table 7* and in *Table 8*.

4.6. Discussion

In this paper the total methane emission in Europe[7] was estimated for transmission and distribution pipelines. Therefore, several methods were used to estimate the total emissions.

method	gas sales [kg]	transmission				distribution			
		EF [kg/km]	pipeline length EU [km]	emission EU [ton]	emisson to sale ratio [%]	EF [kg/km]	pipeline length EU [km]	emission EU [ton]	emisson to sale ratio [%]
average 2003-2013	3,33E+11	953	217.685	207.358	0,06	347	1.640.667	568.819	0,17
upper conrol limit 2003 - 2013		1.313		285.907	0,09	519		850.932	0,26
median 2003 -2013		620		135.022	0,04	354		581.305	0,17
worst case 2003 -2013		1.654		360.049	0,11	823		1.350.531	0,41
representative average		821		178.661	0,06	313		513.709	0,15
representative upper control limit		1.053		229.135	0,07	534		875.411	0,26

Table 9: Overview of emission factors and accompanying EU emissions

[7] Romania and Russia are not included

Because of the limited number of data set this result is a qualitative characterization of the total methane emissions arising from Natural Gas distribution and transportation networks in Europe.

It is acknowledged due to the lack of available data results may sometime be not robust enough. However, as more data will be available the robustness can be improved. The Working Group would urge its Members to use the methodology to calculate its emissions of Natural Gas and to report these results.

The emission factors of the datasets for both transmission and distribution infrastructure are calculated via different methods. What can be seen from the results in Table 9 is that the lowest and the **highest estimation of the EU methane emissions can differ by approximately a factor 2 to 3**.

The most representative values will be given by the last 2 rows of Table 9 representing an estimate of the average and the upper control of the emission factors derived from the most representative datasets.

The Working Group advises to use the data of the representative values together with the worst case values for further communication of the methane emissions at this moment which is conservative.

The calculations via the most representative datasets gave the result that the total amount of methane emitted in Europe will be between 170.000 and 230.000 ton for transmission pipelines and between 500.000 and 900.000 ton for distribution pipelines.
Estimation via the worst case emission factors derived from the datasets will give emission of about 360.000 ton for transmission and 1.360.000 ton for distribution pipelines.

The total amount of GHG emissions caused by the methane emissions from Natural Gas transmission and distribution grids is estimated to be between **0,3% and 0,7%** of the total of anthropogenic[8] GHG emission (CO_2 equivalents) in Europe (EU28) (Reference 3) using the representative datasets.
Using the worst case emission factors for this estimation the values will be around **0,2% for transmission and 0,7% for distribution pipelines** of the total of anthropogenic GHG emission (CO_2 equivalents) in Europe (EU28) (Reference 3).

Taking the results from the worst case approach together with the more representative approach the total methane emission for transmission and distribution combined is estimated to be between **0,5% and 0,9%** of the total of anthropogenic GHG emission (CO_2 equivalents) in Europe (EU28) (Reference 3).

Compared to the total mass [tons] of Natural Gas sales in Europe[9], the aggregated European methane emission is calculated to be **0,1%** for transmission and **0,4%** for distribution grids.

To express the EU methane emissions, the total volume of gas sales in Europe was used. The total gas sales in Europe per year were estimated as: 5095 TW/annual ([Reference 2] - page 22).

Assuming that $1m^3_n$ Natural Gas equals 11 KWh and assuming a density of 0,72 kg/ m^3_n the calculated total mass for Natural Gas for gas sales is about $3{,}33.\ 10^{11}$ kg. From this the emission to sale ratio was calculated as kg methane per kg gas sales (see Table 9).

[8] Anthropogenic emissions: emissions originating in human activity

[9] This calculation included the countries: Austria, Belgium, Czech Republic, Denmark, France, Finland, Germany, Greece, Italy, Ireland, the Netherlands, Norway, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Switzerland, United Kingdom

5. CONCLUSIONS

In this study the total methane emission from Natural Gas transmission and distribution networks was estimated.

The impact of Greenhouse Gases on climate change has been recognized for some time which has led to measures aimed to reduce global warming. Methane (CH_4) which is a major component of Natural Gas has an impact on climate changes.

As Natural Gas is a major source of energy for the society, it is the role of the gas network operators to deliver continuous and safe service whilst managing responsibly impact on the environment.

MARCOGAZ, the Technical Association of European Gas Companies, considers that it is important for the Gas Industry to understand and quantify its emissions of Natural Gas. It is also important to be transparent about the methodology used to calculate emissions and to demonstrate that best practices are used across the European Gas Industry.

The total amount of methane emitted in Europe[10] via the Natural Gas transmission and distribution network was estimated via different statistical methods.

The total amount of GHG emissions caused by the methane emissions from Natural Gas transmission and distribution grids is estimated to be between **0,5% and 0,9%** of the total of anthropogenic GHG emission (CO_2 equivalents) in Europe (EU28)[11].

Compared to the total mass [tons] of Natural Gas sales in Europe[12], the aggregated European methane emission is calculated to be **0,1%** for transmission and **0,4%** for distribution grids.

Because of the limited number of datasets this result is a first preliminary qualitative characterization of the total methane emissions arising from Natural Gas distribution and transportation networks in Europe.

MARCOGAZ continues through its Working Group Methane Emissions to investigate better methods to measure and estimate methane emissions in the gas supply chain.

[10] Romania and Russia are not included in the MARCOGAZ dataset

[11] Annual European Union greenhouse gas inventory, 1990–2012 and inventory report 2014, Submission to the UNFCCC Secretariat, page 10 - 11

[12] This calculation included the countries: Austria, Belgium, Czech Republic, Denmark, France, Finland, Germany, Greece, Italy, Ireland, the Netherlands, Norway, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Switzerland, United Kingdom

6. REFERENCES

- *[Reference 1]: Chemometrix a textbook, Data handling in Science and Technology, D.L. Massart, B.G.M. Vandenginste, S.N. Deming, Y. Michotte, L. Kaufman., Elsevier Science Publishers B.V. 1988.*
- *[Reference 2]: MARCOGAZ technical statistics (date 01-01-2013). (http://www.MARCOGAZ.org/index.php/latest-news/news/86-technical-statistics-at-01-01-2013)*
- *[Reference 3]: Annual European Union greenhouse gas inventory, 1990–2012 and inventory report 2014, Submission to the UNFCCC, page 11*
- *[Reference 4]: Microsoft Excel Analysis Toolpack*
- *[Reference 5]: MARCOGAZ document: ”Methodology for estimation of methane emissions in the gas industry” (Ref. WG-MET-05-07: 2005)*

7. APPENDIX

7.1. Appendix I: MARCOGAZ forms methane emission

METHANE EMISSION Calculation for Distribution

Organisation			**Natural Gas Composition**		
Company:			Average Methane Content of Natural Gas:		% (Vol.)
Emissions for the Year:			Density of Methane:	0,7175	kg/m^3
Responsible Person:			Conversion Factor from m^3 Nat.gas to g CH_4	0	g CH_4 / m^3 Gas

Calculation

			Activity Factors		Emission Factors						Total Emissions		Source for own factor			
					Marcogaz Range*				Company		Nat.Gas	Methane				
No.	System Category	Pressure	Data	Unit		Minimum	Maximum		Data	Unit	m^3/a	g/a	Measurement	Literature	Estimation	Remark (please specify, if possible)
1.	**Distribution Lines**															
1.1.	Grey cast iron with lead joint	Low		km	M			M		m3/km	0,0E+00	0,0E+00				
		Medium		km	M			L		m3/km	0,0E+00	0,0E+00				
		(1)		km						m3/km	0,0E+00	0,0E+00				
1.2.	Ductile cast iron	Low		km	L			L		m3/km	0,0E+00	0,0E+00				
		Medium		km	M			L		m3/km	0,0E+00	0,0E+00				
		(1)		km						m3/km	0,0E+00	0,0E+00				
1.3.	Steel	Low		km	L			L		m3/km	0,0E+00	0,0E+00				
		Medium		km	L			L		m3/km	0,0E+00	0,0E+00				
		(1)		km						m3/km	0,0E+00	0,0E+00				
1.4.	Steel with cathodic protection	Low		km	L			L		m3/km	0,0E+00	0,0E+00				
		Medium		km	L			L		m3/km	0,0E+00	0,0E+00				
		(1)		km						m3/km	0,0E+00	0,0E+00				
1.5.	Steel without cathodic protection	Low		km	L			M		m3/km	0,0E+00	0,0E+00				
		Medium		km	M			M		m3/km	0,0E+00	0,0E+00				
		(1)		km						m3/km	0,0E+00	0,0E+00				
1.6.	Plastic Polyethylene PE	Low		km	L			M		m3/km	0,0E+00	0,0E+00				
		Medium		km	M			L		m3/km	0,0E+00	0,0E+00				
		(1)		km						m3/km	0,0E+00	0,0E+00				
1.7.	Plastic PVC	Low		km						m3/km	0,0E+00	0,0E+00				
		Medium		km						m3/km	0,0E+00	0,0E+00				
		(1)		km						m3/km	0,0E+00	0,0E+00				
1.8.	Material in general not specified	Low		km	M			M		m3/km	0,0E+00	0,0E+00				
		Medium		km	M			L		m3/km	0,0E+00	0,0E+00				
		(1)		km						m3/km	0,0E+00	0,0E+00				
1.9	Total of Distribution Lines (1.1-1.8)										0,0E+00	0,0E+00				
2.	**Service Lines (2)**															
2.1.	No. Of Customers			No.	M			M		m^3/No./a	0,0E+00	0,0E+00				
2.2.	Percentage of Total of Distribution Lines		0,0E+00	m^3/a	L			L		%	0,0E+00	0,0E+00				
2.3.	Total Emissions Service Lines										0,0E+00	0,0E+00				
3.	**City Gate and Customer Supply Stations for Metering and Regulating**															
	Number of Stations			No	M			M		m^3/No/a	0,0E+00	0,0E+00				
4.	**Other (please specify)**															
											0,0E+00	0,0E+00				
5.	**Total Emissions**									Nat. Gas	0,0E+00	0,0E+00	Methane			
										Mio. m^3	0,0	0	t/a			

Note (1): Use this when the emission factor is refered only to the material and not to pressure
Note (2): One alternative should be chosen

Note: In the templates, "M" and "L" refer to medium and low pressure ranges. For additional explanations see §6, [Reference 5].

METHANE EMISSION Calculation for Transmission

Organisation		**Natural Gas Composition**		
Company:		Average Methane Content of Natural Gas:	0%	% (Vol.)
Emissions for the Year:		Density of Methane:	0,7175	kg/m³
Responsible Person:		Conversion Factor from m³ Nat.gas to g CH4:	0	g CH4 / m³ Gas

Calculation

		Activity Factors			Emission Factors					Total Emissions		Source for own factor			
					Marcogaz Range*			Company		Nat.Gas	Methane				
No.	System Category	Data	Unit		Minimum	Maximum		Data	Unit	m³/a	g/a	Measurement	Literature	Estimation	Remark (please specify, if possible)
1.	**Pipeline System**														
1.1.	**Fugitive Emissions**														
	Length of pipelines including valves, flanges etc.		km	M			M		m³/km/a	0,0E+00	0,0E+00				
1.2.	**Pneumatic Emissions**														
	Number of valves with pneumatic operation		No.	M			M		m³/No./a	0,0E+00	0,0E+00				
1.3.	**Vents**														
1.3.1.	**Maintenance vents**														
	Total emission caused by maintenance incl. Pigs, deviations, commissioning etc.										0,0E+00				
											0,0E+00				
1.3.2.	**Incident vents**														
	Total emission caused by incidents										0,0E+00				
1.3.3.	**Flares**														
	Total emission caused by flares										0,0E+00				
2.	**Compressor Stations**														
2.1.	**Fugitive Emissions**														
	Mechanical power of gas turbines		MW	E			M		m3/MW/a	0,0E+00	0,0E+00				
	Mechanical power of gas engines		MW	E			L		m3/MW/a	0,0E+00	0,0E+00				
	Number of Blow Down Valves		No	E			M		m3/No/a	0,0E+00	0,0E+00				
			No												
			No												
			No												
			No												
2.2.	**Pneumatic Emissions**														
	Number of valves with pneumatic operation		No.	M			M		m3/No/a	0,0E+00	0,0E+00				
2.3.	**Vents**														
2.3.1.	**Maintenance vents**														
	Total emission caused by maintenance vents										0,0E+00				
											0,0E+00				
											0,0E+00				
											0,0E+00				
											0,0E+00				
											0,0E+00				
2.3.2.	**Incident vents**														
	Total emission caused by incident										0,0E+00				
2.3.3.	**Start vents**														
	Total emission caused by starts										0,0E+00				
											0,0E+00				
											0,0E+00				
											0,0E+00				
2.3.4.	**Stop vents**														
	Total emission caused by stops										0,0E+00				
	...										0,0E+00				
	...										0,0E+00				
	...										0,0E+00				
2.3.5	**Flares**														
	Total emission caused by flares										0,0E+00				
2.4.	**Combustion**														
2.4.1.	**Waste gas**														
2.4.1.1.	Fuel gas consumption turbines		m³	E			M		%	0,0E+00	0,0E+00				
2.4.1.2.	Fuel gas consumption engines		m³	E			M		%	0,0E+00	0,0E+00				
3	**R&R Reduction and Regulating Stations**														
3.1.	**Fugitive Emissions**														
	Number of Stations		No	M			M		m³/No/a	0,0E+00	0,0E+00				
			No												
			No												
			No												
			No												
			No												
			No												
			No												
3.2	**Pneumatic Emissions**														
	Number of Stations		No.	M			M		m³/No./a	0,0E+00	0,0E+00				
3.3.	**Vents**														
3.3.1.	Total emission caused by maintenance										0,0E+00				
3.3.2.	Total emission caused by incident										0,0E+00				
3.4.	**Combustion**														
3.4.1.1.	Fuel gas consumption		m³	E			E		%	0,0E+00	0,0E+00				
4	**City Gate and Customer Supply Stations for Metering and Regulating**														
	Number of Stations		No	M			E		m³/No/a	0,0E+00	0,0E+00				
5.	**Other (please specify)**														
										0,0E+00	0,0E+00				
6.	**Total Emissions**								Nat. Gas	0,0E+00	0,0E+00	Methane			
									Mio. m³	0,000	0	t/a			

7.2. Appendix II: Data set gas transmission

SUMMARY OUTPUT[13]

Regression Statistics	
Multiple R	0,856482227
R Square	0,733561805
Adjusted R Square	0,650228472
Standard Error	10168614,02
Observations	13

ANOVA

	df	SS	MS	F	Significance F
Regression	1	3,41621E+15	3,41621E+15	33,03858773	0,000128764
Residual	12	1,24081E+15	1,03401E+14		
Total	13	4,65702E+15			

	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%
Intercept	0	#N/B	#N/B	#N/B	#N/B	#N/B
pipeline length [km]	952,3547327	165,6868369	5,747920296	9,19334E-05	591,3541267	1313,355339

Table 10: Regression analysis gas transmission data (all data)

SUMMAY OUTPUT

Regression Statistics	
Multiple R	0,962251231
R Square	0,925927431
Adjusted R Square	0,759260765
Standard Error	3630141,62
Observations	7

ANOVA

	df	SS	MS	F	Significance F
Regression	1	9,88366E+14	9,88366E+14	75,0016463	0,000339238
Residual	6	7,90676E+13	1,31779E+13		
Total	7	1,06743E+15			

	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%
Intercept	0					
pipeline length [km]	820,7339075	94,76914838	8,660349085	0,0001307	588,8421552	1052,62566

Table 11: Regression analysis gas transmission representative emission factors

[13] For a description of the statistical terms and the lay-out see Microsoft Excel Analysis Toolpack

7.3. Appendix III: Dataset gas distribution

SUMMARY OUTPUT[14]

Regression Statistics	
Multiple R	0,8354693
R Square	0,698008951
Adjusted R Square	0,586897839
Standard Error	29822078,69
Observations	10

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	1,85006E+16	1,85006E+16	20,80220777	0,001847618
Residual	9	8,00421E+15	8,89356E+14		
Total	10	2,65048E+16			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	0					
pipeline length	346,6966908	76,01424416	4,560943737	0,001364427	174,7405239	518,6528577

Table 12: Regression analysis gas distribution data 2003 – 2013

SUMMARY OUTPUT

Regression Statistics	
Multiple R	0,891845428
R Square	0,795388267
Adjusted R Square	0,545388267
Standard Error	20763729,58
Observations	5

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	6,70377E+15	6,70377E+15	15,5492211	0,029073832
Residual	4	1,72453E+15	4,31132E+14		
Total	5	8,4283E+15			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	0					
Total distr. pipelines [km]	313,1110857	79,40431886	3,943250068	0,016913553	92,64935328	533,5728181

Table 13: Regression analysis gas distribution period 2013

[14] For a description of the statistical terms and the lay-out see Microsoft Excel Analysis Toolpack

7.4. Appendix IV: List of countries used for extrapolation.

Country	Transmission network length (in km)	Distribution network length total (in km)
Austria	3.007	37.495
Belgium	4.057	69.687
Czech Republic	3.810	72.868
Denmark	831	18.175
France	37.246	203.092
Finland	1.318	1.911
Germany	62.500	371.000
Greece	1.819	6.087
Italy	34.415	249.180
Ireland	2.417	11.137
the Netherlands	11.896	124.073
Norway	na	125
Poland	10.077	125.890
Portugal	1.298	16.296
Romania		17.218
Slovakia	8.533	33.079
Slovenia	1.094	4.342
Spain	12.987	64.115
Switzerland	292	18.762
Turkey	12.440	69.800
UK	7.648	126.335

Table 14: Network