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Analyses of methane emissions in the natural gas sector

Interim report

Energy with Future. Environment and Responsibility.

Imprint

Interim report

Analyses of methane emissions in the natural gas sector

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Duration

01.05.2024 until 15.03.2025

Executive Summary

The goal of the report was to calculate the methane emissions of the natural gas supply chain in Germany and the EU27.

This report shows the high variation in methane emissions intensities across different natural gas exporting countries and their impact on the composition of the total supply chain footprint. Therefore, this report helps create some transparency for importers to base purchasing decisions on. At the same time this report underlines the need for consistent, accurate and more granular emissions data.

Methodology

In order to calculate the methane emissions of the natural gas supply chain in Germany and the EU27, the methane intensities of the individual supplier countries were multiplied by the gas mix of Germany and EU27.

Natural gas is a globally traded commodity, frequently exchanged multiple times before reaching its final destination. Available statistics pertain solely to physical flows, which complicates the task of determining the natural gas composition for Germany and the EU27 by country of origin. Consequently, various assumptions were applied, and the resulting gas mix calculations represent approximations.

The methane intensities for the reference year 2023 were sourced from the IEA Methane Tracker. The IEA Methane Tracker determines country-specific emission intensities. Assumed emission intensities of the United States are scaled to other countries based on factors such as infrastructure age, operator structures, and flare intensity. Furthermore, atmospheric methane concentrations are included by means of expert estimates.

In the case of Germany, data from the Federal Environment Agency (UBA), was used as a data source to assess methane intensity of gas operations.

Results for natural gas distributed in Germany

The calculated German gas mix in 2023 consisted of 81 bcm. A share of 73 % of the gas mix was supplied by pipeline and 27 % by LNG. Norway supplied the largest share of 60 %, followed by the US with 17 % and the Netherlands with 7 %. Other production countries in the German gas mix in descending order are the national production within Germany, Qatar, Russia, Angola, United Kingdom, Trinidad and Tobago, Algeria, Nigeria, and other countries such as Cameroon, Egypt, Equatorial Guinea, Peru, and the United Arab Emirates.

Natural gas distributed in Germany is associated with a methane emissions intensity of 2.3 ktCH_4 per bcm, equivalent to 63 gCH_4 per GJ. Total methane emissions of the German natural gas supply chain amount to 0.18 Mt CH_4 (5.13 MtCO_2eq), approximately equivalent to GHG-emissions of Germany's waste sector (5.4 MtCO_2eq in 2024 [1]). A significant portion of methane supply chain emissions (89%) originates from production and transport processes outside of Germany.

The analysis reveals substantial differences in the contributions of emissions from individual natural gas supplying countries. Although Norway is Germany's largest supplier, providing around 60 % of Germany's net gas mix, Norwegian gas accounts for only about 2 % of the total CH_4 emissions of the gas used in Germany. In contrast, the U.S., which supplies a smaller share of 17 % of Germany's natural gas, is responsible for 50 % of the total methane emissions associated with Germany's gas mix. This discrepancy highlights the variations in emissions intensity due to differing production and transportation practices across countries.

Results for natural gas distributed in the EU27

The calculated EU27 gas mix in 2023 consisted of 293 bcm. A share of 56 % of the gas mix was supplied by pipeline and 44 % by LNG. Norway contributed the largest share at 28 %, followed by the US with 20 %, Algeria with 12 % and EU27 production with 11 %. Other production countries in the EU27 gas mix in descending order are Qatar, Azerbaijan, Nigeria, Trinidad and Tobago, Angola, United Kingdom, and a series of minor producers from other countries.

Natural gas distributed in the EU27 is associated with a methane emissions intensity of 5.8 ktCH_4 per bcm, equivalent to 161 gCH_4 per GJ. Total methane emissions of the EU27 natural gas supply chain amount to 1.70 Mt CH_4 (47.52 MtCO_2eq), comparable to the annual GHG-emissions of Switzerland (41.6 MtCO_2eq in 2022 [2]). A significant portion of these emissions (93 %) originates from production and transport activities outside the EU27. The methane intensity of the EU27 gas mix is notably higher than that of the German gas mix, largely due to the higher proportion of imports from Algeria and Russia, and a lower share of Norwegian gas. Although Norway is with 28 % the greatest contributor to the EU27 gas mix, Norwegian gas is responsible for less than 1 % of CH_4 emissions. In contrast, the Algerian gas supply is responsible for 30 % of the CH_4 emissions of the natural gas supply chain, although only accounting for around 12 % of the gas mix.

If all production imported to the EU27 was associated with a leakage rate comparable to Norwegian levels, total CH_4 emissions in the supply chain for deliveries to the EU27 would be 0.02 MtCH_4 (0.59 MtCO_2eq), so 1.25 % of the current Mt CH_4 total.

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Glossary

Gas distribution	Refers to a part of the natural gas value chain. “Gas distribution” is the part between gas transportation and the end customer. It consists of a network of smaller pipelines, pressure regulation stations and metering systems to ensure safe and efficient delivery of natural gas. On a municipal level, natural gas is distributed via high-, medium-, and low-pressure pipelines.
Gas mix	Natural gas, which is distributed e.g. in Germany and EU27, consists of gas from different sources or from different supplier countries. The term “gas mix” refers to the mixture of the different sources.
Natural gas sector	Is a segment of the energy industry regarding to the exploration, production, processing, transportation, distribution and consumption of natural gas.

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Bcm:	Billion cubic meter (unit of volume used for natural gas)
BNetzA:	German federal network agency, Bundesnetzagentur
BRVF:	Limits or ban on routine venting and flaring
CBAM:	Carbon Border Adjustment Mechanism
CH_4:	Methane
CO_2:	Carbon dioxide
EU27:	European Union
GHG:	Greenhouse Gas
IEA:	International Energy Agency
IOGP:	International Association of Oil and Gas Producers
LDAR:	Leak detection and repair
LNG:	Liquefied natural gas
MRV:	Measurement, Reporting, and Verification
NIR:	National inventory report
TSO:	Transmission system operators
UBA:	German federal environmental agency. Umweltbundesamt
UNFCCC:	United Nations Framework Convention on Climate Change

1 Background and motivation

The increase in greenhouse gases in the earth's atmosphere and their contribution to global warming has drawn significantly more attention to the issue of methane (CH_4) emissions. CH_4 is the second largest source of the anthropogenic contribution to climate change after carbon dioxide (CO_2) [3, p. 1034]. In addition to agreements on CO_2 reduction targets, CH_4 is therefore also becoming a field of political regulation efforts. At the COP26 climate summit in November 2021, the "Global Methane Pledge" was initiated, which has since been signed by 158 countries. The agreement aims to reduce CH_4 emissions by 30 % by 2030 compared with 2020 levels, meaning that a reduction in global warming of 0.2 K could be achieved by 2050 [4].

Natural gas consists of 83 to 98.3 % CH_4 by volume, which has a global warming potential in the atmosphere 29.8 times higher than CO_2 over 100 years and 82.5 times over 20 years [3, p. 1017]. Fugitive and venting emissions can lead to releases into the atmosphere along the entire natural gas infrastructure and supply chain. According to the IPCC [3, p. 703], the oil and gas sector emitted 20 % of global anthropogenic CH_4 emissions in the period from 2008 to 2017. The European Commission sees great potential to reduce these emissions cost-effectively [5].

This study analyses the CH_4 emissions of the natural gas supply chain to assess the potential of the EU Methane Regulation which has entered into force on the 4th of August 2024. It sets out strategies for various sectors related to fossil energy sources with the aim to monitor and reduce CH_4 emissions. EU27 operators of fossil fuel infrastructure are obliged to regularly measure and report CH_4 emissions, repair leaks, reduce venting and flaring of gas [6]. Due to the European economic area, the regulation might extend also to Norway. The regulation also contains requirements for importers to include producers outside the EU27 in the monitoring process.

This study contains information on the CH_4 emissions associated with the natural gas distributed in Germany and the EU27. The countries from which Germany and the EU27 import gas are presented, and the CH_4 emissions associated with the import are then determined.

While only methane emissions were examined in this study, other studies [7, p. 47] determine the GHG footprint of natural gas. It is important to note that for natural gas transported by pipeline methane emissions account for 20-40 % of the total GHG footprint (using GWP100), while CO_2 accounts for around 50-75 % [7].

2 General information

2.1 Natural gas and LNG supply chain

This study addresses CH_4 emissions along the natural gas supply chain. It does not address the GHG footprint of natural gas.

The natural gas supply chain by pipeline is shown in Figure 2.1. The liquified natural gas (LNG) supply chain is shown in Figure 2.2.

This study considers the natural gas supply chain up to and including the distribution grid and service lines (without the usage of natural gas).

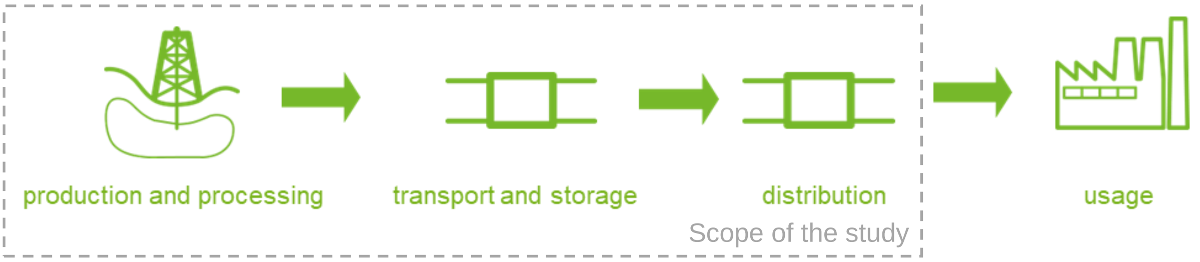

Figure 2.1: Natural gas pipeline supply chain

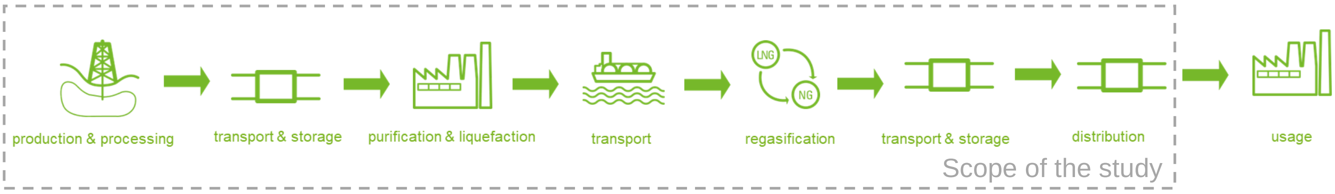

Figure 2.2: LNG supply chain

The following section explains the structure of the natural gas supply chain. The description was adapted from [7, 10f].

Natural gas production

Natural gas can be found either together with oil deposits or in gas fields. When natural gas reserves are identified during exploratory drilling, production wells are built for extraction. Natural gas production is divided into conventional and unconventional (fracking). Natural gas from conventional production is found in permeable rock formations such as sandstone or limestone, where the gas flows easily. Production involves drilling a well into the reservoir, allowing the gas to flow freely or with minimal stimulation to the surface. This type of extraction is generally more straightforward, less costly, and requires less advanced technology than unconventional methods. In contrast unconventional natural gas is found in less permeable rock formations such as shale, coal beds, or tight sandstone, where the gas is tightly trapped and does not flow easily. For extraction, techniques like hydraulic fracturing (fracking) and horizontal drilling are required. Hydraulic fracturing involves injecting high-pressure fluid into the rock to create fractures, allowing the gas to flow into the well. These methods are more complex, costly, and often raise environmental concerns, such as groundwater contamination and increased seismic activity.

Natural gas processing

Natural gas has various components, including CH_4, propane, CO_2, hydrogen sulphide, and water. Certain components, particularly hydrogen sulphide and water, are removed at the production site. This helps to prevent operational issues, such as pipeline corrosion. Another step is the separation of other components, such as CO_2, to achieve the desired calorific value of the gas. This is critical for the proper functioning of end-user equipment. The gas processing consists of various processes, including dehydration and the separation of condensates.

Natural gas pipeline transport

High-pressure pipelines transport natural gas from the production and processing sites. Due to friction within the pipeline, the gas pressure gradually decreases over distance. Compressor stations along the pipeline counteract the pressure decrease. Typically, the stations can be found each 100 to 150 kilometres in onshore pipelines.

LNG supply chain

Liquified natural gas (LNG) enables natural gas transport over long distances, often between continents, where pipeline infrastructure is not feasible. In the liquefaction process, natural gas is cooled to approximately -162°C to convert it into a liquid state, significantly reducing its volume for transportation. After liquefaction, the LNG is temporarily stored in specially designed insulated tanks to maintain its low temperature. LNG is transported using LNG tankers with cryogenic storage systems to ensure the gas remains in liquid form throughout the journey. Upon reaching its destination, the LNG undergoes regasification, where it is warmed and returned to its gaseous state for pipeline transport and distribution.

Natural gas storage

The storage of natural gas in underground facilities flattens seasonal demand fluctuations or peak loads. There are two main types of storage facilities: porous storage and salt cavern storage. Porous storages contain the gas within porous rock formations. The surrounding impermeable rock layers prevent gas escape. Depleted gas reservoirs and natural aquifers are often repurposed for this use. In cavern storages, natural gas is filled in a sealed space within salt rock formations. In addition to underground storage, above-ground storage facilities also exist but they are becoming increasingly irrelevant.

Natural gas distribution

On a municipal level, natural gas is distributed via high-, medium-, and low-pressure pipelines. It is primarily used in residential heating, industrial processes, electricity generation, the chemical industry, and to a lesser extent, the transportation sector.

Gas pressure regulating and metering stations reduce the pressure of the gas within the pipeline, which is necessary for delivery to end users. They also measure gas volume, preheat the gas, and add an odorant. Preheating is required because reducing the pressure of the gas leads to a temperature drop (Joule-Thomson effect). Odorization is essential since natural gas is naturally odourless and the added odorant allows for leak detection.

2.2 Potential emission sources

There are different categories of CH_4 emission sources in the natural gas sector:

- fugitive emissions
- vents
- incomplete combustion.

Regarding the data of OGMP 2.0 companies, the upstream sector accounts for 83 % of the reported emissions. 90 % of these are caused by production assets. The major sources are venting, followed by fugitive emissions and incomplete combustion. [8, p. 5]

Fugitive emissions such as leakages or permeation occur over longer periods of time, typically with a low leakage rate.

Vents in the form of operational emissions are planned measures. They occur e.g., from gas analysis devices, during regular maintenance or repair work as safety measures, or during commissioning or decommissioning. Vents in the form of losses from incidents are unplanned interventions in the gas network. Third parties can cause these vents, e.g., an excavator damaging a pipeline. Also, accidents such as pipeline rupture due to landslide (e.g., because of flooding) can cause incident vents. Significant emissions are possible, despite short periods of time until shut-off and repair.

Emissions from incomplete combustion arise during flaring, preheating, in gas turbines or household equipment, e.g. stoves. CH_4 is not 100 % oxidised to CO_2, emissions from incomplete combustion occur. The IEA Global Methane Tracker estimates that the incomplete combustion of gas from flares causes around 10 % of methane emissions from oil and gas operations. Global combustion efficiency is estimated at around 92 % [9]. Flaring occurs in the following contexts:

- Oil production: Associated gas, which is released as a by-product of oil extraction, is often flared. Flaring is especially prevalent in regions lacking sufficient infrastructure to utilize, reinject or transport the gas. An alternative to flaring is gas reinjection, where excess gas is injected back into underground reservoirs. This method not only helps maintain reservoir pressure but also increases oil production through a process known as Enhanced Oil Recovery (EOR). While gas reinjection is a less environmentally damaging option compared to flaring, the percentage of gas that is reinjected varies widely by country and region. [10]
- Gas production: Even in dedicated natural gas fields, flaring can occur, particularly when processing facilities or pipelines are unavailable or during maintenance operations, but it occurs less frequently than in oil production.

3 Methodology

3.1 General data sources

3.1.1 Global data on methane emissions

Figure 3.1 shows a comparison of different data sources of CH_4 emissions from oil and gas. Based on atmospheric observations, global oil and gas emissions are estimated at 80-140 Mt per year (Schwietzke et al. 2016 [11]; Hmiel et al. 2020 [12]; Saunois et al. 2020 [13]). The Global Methane Budget [13] reports 84 Mt CH_4 and Shen et al. 2023 [14] published 63 Mt CH_4 (using data from 2018 to 2020). Both have top-down and bottom-up approaches. The IEA Methane Tracker reports 77 Mt CH_4 in 2023 and the UNFCCC reported only 38 Mt CH_4 in the latest year available. Both follow a country-level reporting.

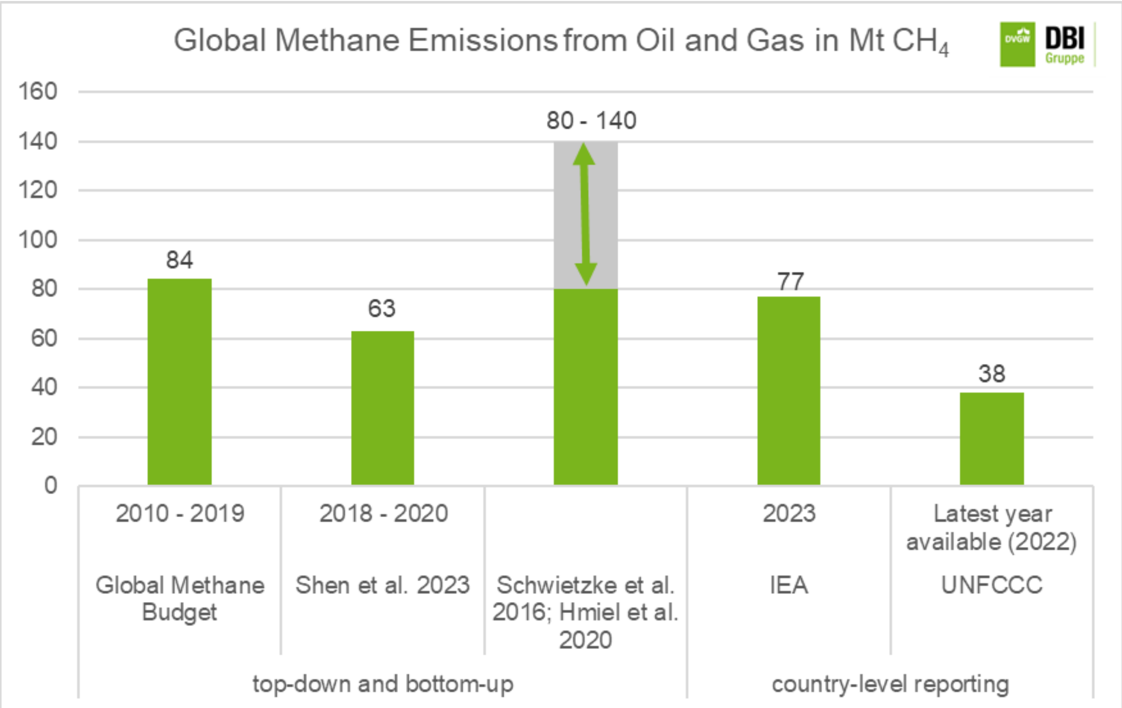

Figure 3.1: Comparison of data sources of CH_4 emissions from oil and gas in Mt CH_4 [9], [10], [11], [12], [13]

3.1.2 IEA Global Methane Tracker

The IEA Global Methane Tracker is the main source of this study regarding methane emissions.

The database includes emissions from the entire oil and gas supply chain. The oil and gas sectors are divided into upstream, gas transportation, and other segments. The upstream segment includes emissions from production, gathering and processing at both onshore and offshore facilities. Gas transportation includes emissions from the transmission and distribution of gas via pipelines or as LNG and regasification. Other segments include refining, oil transport, and emissions associated with the consumption of oil and gas.

Emissions are divided into fugitive, vented, and incompletely flared CH_4 emissions.

The basic principle of the IEA Methane Tracker is the creation of country-specific and production-type-specific emission intensities. These are applied to the production and consumption data of the individual countries. The starting point is the creation of emission intensities for upstream and downstream activities in the United States. The emission intensities are divided into 19 different segments (see Annex 2). Sources are the US Greenhouse Gas Inventory and a wide range of other publicly available data sources. Furthermore, atmospheric methane concentrations are included by means of expert estimates.

US emission intensities are scaled to obtain emission intensities for all other countries (see Figure 3.2). Scaling is based on country-specific data for upstream emission intensities: Age of infrastructure, types of operators in each country (international oil companies, independents or national oil companies) average flare intensity (flare volume/oil production volume). However, the scaling factors might not reflect country-specific situations accurately. Figure 3.2 shows the methodological approach for estimating CH_4 emissions from oil and gas operations as flow chart. [15]

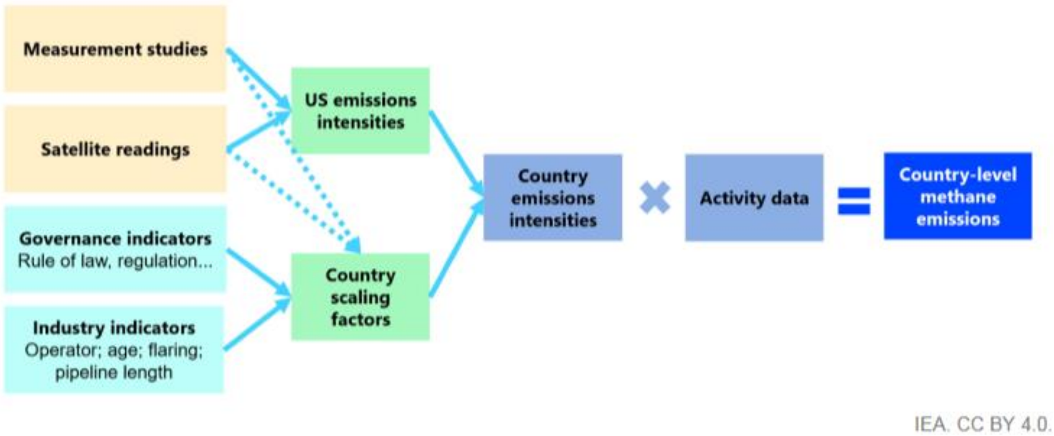

Figure 3.2: Methodological approach for estimating CH_4 emissions from oil and gas operations [15].

Global CH_4 emissions from oil and gas industry are characterised by a lack of accurate data since operations are largely not continuously monitored. There are uncertainties in the estimation of CH_4 emissions of the IEA Methane Tracker. Some key uncertainties are:

- **Scaling factors**: As mentioned above, the scaling factors for upstream emission intensities are based on the age of the infrastructure, the type of operator in each country and the average flaring intensity. Expert judgement is also included in the scaling process. Measurement studies, satellite data and governments effectiveness (strength of regulation and oversight) are considered. This reliance on expert judgement can lead to uncertainties.
- **Integrating emission estimates from satellites** (see 3.1.4)
- **Incomplete combustion of flares**: The approach to estimating CH_4 emissions from flaring relies on generating country-specific and production type-specific combustion efficiencies that are applied to flaring data on a country-by-country basis. Variability in combustion efficiency is influenced by factors such as production rates, wind conditions, and maintenance practices. Emission assessments rely on country-specific auxiliary data, where expert judgements used to evaluate these factors may introduce further uncertainties.

3.1.3 United Nations Framework Convention on Climate Change (UNFCCC)

The United Nations Framework Convention on Climate Change (UNFCCC) provides detailed guidelines for the preparation of greenhouse gas inventories. According to the Paris Agreement, the participating countries report their data in the national inventory documents (NID) and common reporting tables (CRT) [16]. The reports include comprehensive data on various sectors, such as energy, transportation, and agriculture. They outline national policies and measures to address climate change.

Figure 3.3 compares the data from the IEA Methane Tracker for the United States, Russia, Norway and Germany with the data from the UNFCCC. While the data for the United States and Norway are comparable in both sources, the data for Russia and Germany vary considerably.

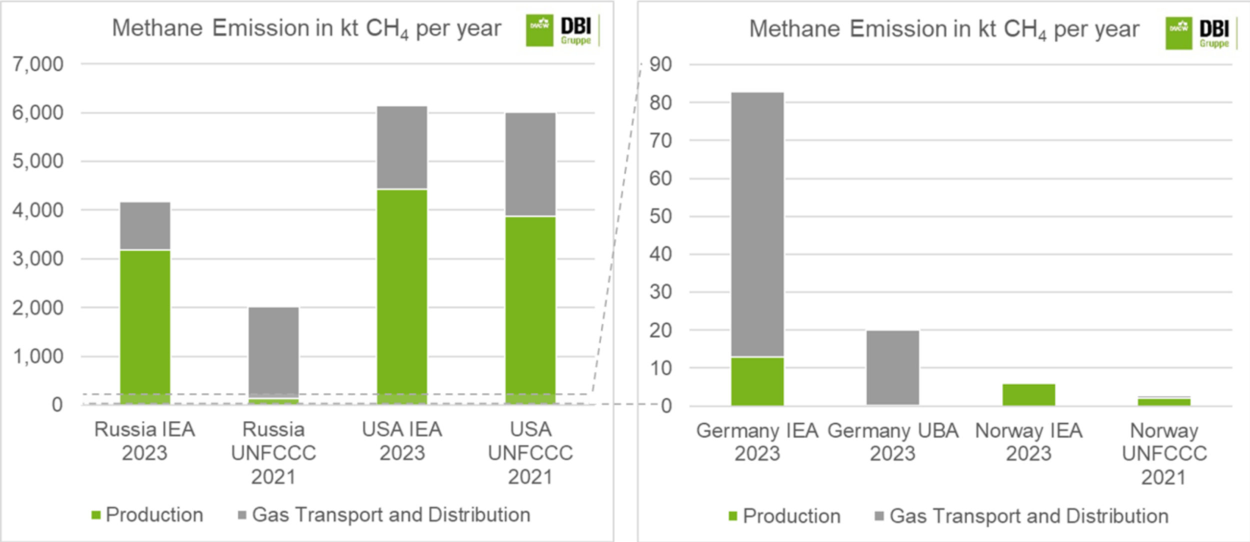

Figure 3.3: Comparison of data for methane emissions of Russia, United States, Germany and Norway in kt CH_4 per year

For Germany it is assumed, that the UNFCCC data set is more accurate than data from the IEA Methane Tracker, since the data (provided by the German Environment Agency (UBA)) is based on recent national measurement campaigns. For the purpose of this study, for Germany the UBA data (which is also used within UNFCCC) is used instead of IEA Global Methane Tracker data.

3.1.4 Role of satellite measurements in methane data

Monitoring methane emissions from the oil and gas industry increasingly relies on satellite data and many major emissions events are detected by satellites.

The most important satellites and platforms include for example

- Sentinel-5P (European Space Agency),
- WorldView-3 (DigitalGlobe),
- GHGSat (private Canadian initiative),
- MethaneSAT (EDF) and
- Geostationary Operational Environmental Satellite GOES (National Oceanic and Atmospheric Administration (NOAA)).

Various data platforms such as the IEA Global Methane Tracker and the Methane Alert and Response System MARS (partnership of IMEO, IEA and CCAC), to name a few, provide processed data and additional analysis. In the IEA Global Methane Tracker super emitter event detections make up 5 % of global CH_4 emission estimations of the oil and gas industry.

Despite the progress made, there are considerable uncertainties in the use of satellite data. Satellites primarily detect large emissions and are often unable to reliably detect smaller or diffuse sources. There are also limitations due to weather conditions, limited geographical coverage, lack of source attribution and technical challenges. Therefore, bottom-up measurements, such as ground-based sensors and direct measurements, remain essential to obtain a comprehensive and accurate picture of methane emissions. Satellite measurements are a valuable tool, but are not a substitute for detailed analysis using direct measurement methods. [17]

3.2 Natural gas mix

3.2.1 Data sources

For this study, the following sources were used that publish information about the German and European gas mix:

The German Federal Network Agency (Bundesnetzagentur, BNetzA) publishes information on annual natural gas imports and exports from and to Germany together with an assessment of the development of stored gas and gas prices. [18]

Eurostat is the statistical office of the European Union (EU27). The energy statistics (provide data on natural gas supply, transformation and consumption. [19]

Entsog is a cooperation initiative of the European gas transmission system operators (TSOs). It has created a European gas flow dashboard containing European gas flows, LNG and storages. It shows e.g. imports and exports from and to the EU27 within different time periods. [20]

For this study, 2023 was chosen as reference year.

3.2.2 Calculation of the German gas mix

Natural gas is internationally traded and often resold. As of 2024 many buyers have no information about the origin of the imported product. Available statistics pertain solely to physical flows, which complicates the task of determining the natural gas composition for Germany and the EU27 by country of origin. For instance, the German gas mix published by the BNetzA only includes the countries from which natural gas is directly imported via pipeline, such as The Netherlands or Belgium. However, these countries are not necessarily the producing countries, as many serve as transit hubs transporting natural gas from the actual producers. Neither does Eurostat differentiate between transit and production. It only includes data about the countries from which natural gas is directly imported (imports from neighbouring countries instead of production countries) [21, p. 25]. Therefore, a series of assumptions were made, and the calculated gas mix is an approximation. The estimation was done as follows:

- Collection of BNetzA data on natural gas imports to Germany by country [18].
- Collection of BNetzA data on natural gas exports from Germany to other countries [18].
- Collection of BNetzA data on natural gas production in Germany [18].

- Calculation of the net natural gas supply in Germany: natural gas imports and production minus natural gas exports.
- Direct LNG imports from production countries to Germany: Use of data from the Independent Commodity Intelligence Services (ICIS) [22].
- Evaluation of data from the physical flow in billion cubic meters (bcm) of the Entsog gas flow dashboard for Germany, the Netherlands, Belgium, France, and United Kingdom [23].
- Data on natural gas production in the Netherlands, Belgium and France, United Kingdom, and Norway based on IEA data (available for 2023) [22–24].
- Collection of GIIGNL2024 data on the LNG-producing countries exporting LNG to Belgium, the Netherlands, France, and United Kingdom in bcm per country of origin [24].
- Calculation of the gas mix of the Netherlands, Belgium, France, and United Kingdom using the Entsog and GIIGNL data and the domestic production of the IEA data. The natural gas mix of these countries is illustrated in Annex 3.
    - The Entsog gas flow dashboard shows one gas flow from Norway + United Kingdom to United Kingdom and one from Norway to United Kingdom. It is not clear what share of the first flow comes from Norway or the United Kingdom. For simplicity's sake it is assumed that the entire flow consists of Norwegian gas. The United Kingdom's own production is added separately to the United Kingdom gas mix.
- Assumption: The gas exported from the Netherlands, Belgium, and France to Germany corresponds to the gas mix of the respective country. That means for example for the Netherlands that the gas mix (Pipeline gas, LNG) within the Netherlands is thus assumingly transported further to Germany with the same shares.
- Note: The BNetzA data shows no natural gas import from the United Kingdom directly to Germany. But Belgium imports natural gas from United Kingdom, which is further transported to Germany as part of Belgium's natural gas mix.
- Calculation of the natural gas that is transported from the production countries via the Netherlands, Belgium, and France to Germany. Example: Germany's gas mix contains 13 bcm from the Netherlands, 25 % of the Netherlands' gas mix consists of natural gas from Norway, therefore the German gas mix is assumed to contain 3 bcm of Norwegian gas that arrives in Germany via the Netherlands.
- Calculation of Germany's gas mix based on the actual production countries.

The calculated natural gas mix of Germany for the year 2023 in bcm is shown in Figure 3.4. In total, the gas volume amounts to 81 bcm (deviations in the graph are due to rounding).

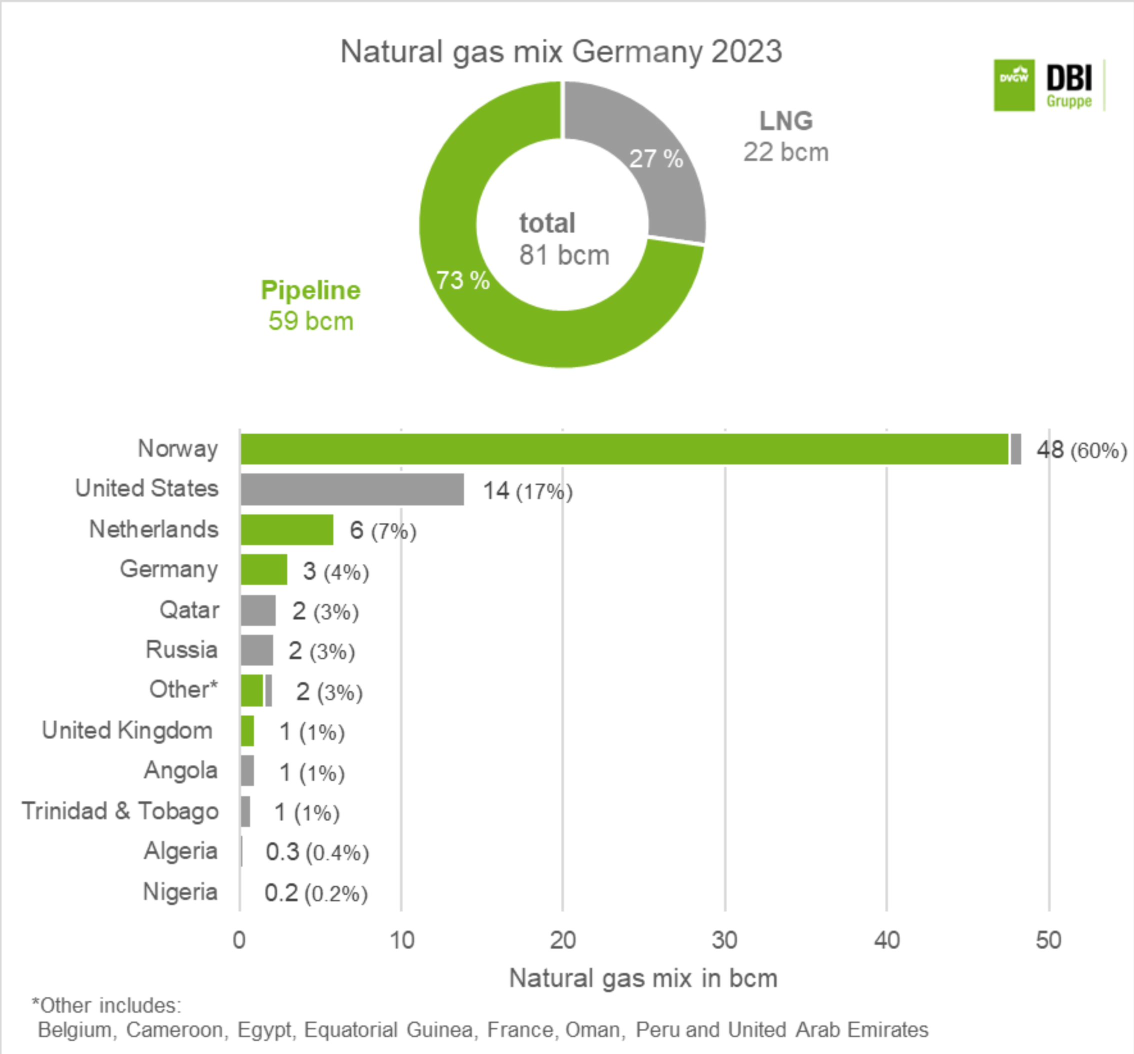

Figure 3.4: Natural gas mix Germany 2023 in bcm, estimation by DBI

The assumption regarding the share of Russian gas in the German gas mix arises from the fact that the gas mix of Germany’s neighbouring countries contain Russian LNG (LNG from Russia accounts for 2 % of the Dutch, 9 % of the Belgian and 11 % of the French gas mix). As a result, the import of Dutch, Belgian, and French natural gas to Germany is assumed to contain a share of Russian gas which is transported further to Germany.

3.2.3 Calculation of the EU27 natural gas mix

The EU27 natural gas mix in 2023 was calculated with information from Eurostat regarding imports and exports of natural gas by partner country. As with the German gas mix, it is assumed that the listed import or export countries reflect the direct gas rather than the original production sources. For example, according to Eurostat, in 2023 15 bcm was imported from Belgium to the EU27, but Belgium only produced 0,01 bcm in 2023. Therefore, it can be assumed that the 15 bcm from Belgium represent Belgium's gas mix rather than domestically produced gas. The gas mix of selected countries (Belgium, France, Germany, and the Netherlands) was calculated and used for the calculation of the EU27 gas mix. E.g., LNG from the United States as part of the German gas mix is considered as LNG from the United States in the EU27 gas mix instead of gas from Germany. Therefore, assumptions were made. The calculated EU27 gas mix it is an approximation which was carried out as follows:

- Collection of Eurostat data on natural gas imports and exports to the EU27 by country.
- Calculation of the share of each country of the import volume.
- Calculation of the total net natural gas volume of the EU27 as the imports minus exports.
- Multiplication of the share of each country of the import volume with the net natural gas volume to receive adjusted import amounts.
- Collection of data regarding the gas mix of Belgium, France, Germany, and the Netherlands as it was calculated in chapter 3.2.2.
- Substitution of natural gas from Germany, Belgium, France, the Netherlands in the EU27 gas mix according to Eurostat by the country's calculated gas mix.
- Summary of other countries not defined as relevant production countries to the category Other.

The calculated natural gas mix of the EU27 in 2023 in bcm is shown in Figure 3.5. In total, the gas volume amounts to 293 bcm (deviations in the graphic are due to rounding).

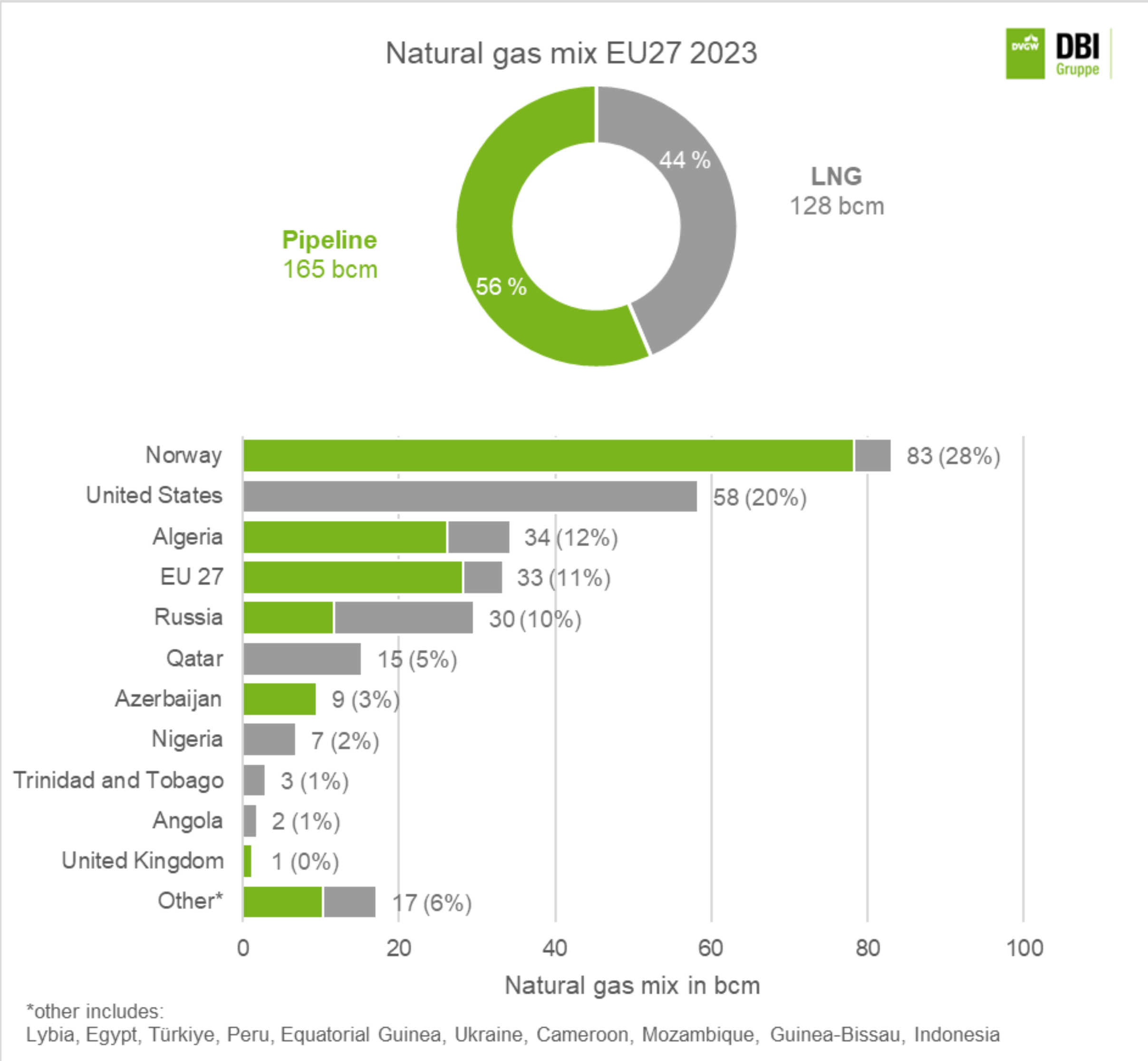

Figure 3.5: Natural gas mix EU27 2023 in bcm, estimation by DBI

3.3 Methane emissions of natural gas

3.3.1 Data sources

The IEA provides methane intensities of oil and gas operations for different countries in kg CH_4 per GJ. The total CH_4 emissions of oil and gas operations in a country are related to the oil and gas production of the country.

Table 3.1: Methane intensities of oil and gas operations according to IEA Methane Tracker in 2023 for key supply countries to the EU27 [25]

Country	Methane emissions in 2023 in kt CH_4 per country	Methane intensity in 2023 in kg CH_4 per $GJ_{produced}$	Methane intensity in 2023 in gCO_2e per $MJ_{produced}$ *	Methane intensity in 2023 in %
Algeria	2,767	0.42	11.70	2.32 %
Angola	804	0.31	8.65	1.71 %
Azerbaijan	348	0.14	3.81	0.75 %
Nigeria	1,853	0.42	11.70	2.32 %
Norway	14	0.002	0.06	0.01 %
Qatar	980	0.10	2.88	0.57 %
Russia	11,186	0.25	6.94	1.38 %
The Netherlands	3	0.01	0.28	0.06 %
Trinidad and Tobago	151	0.14	3.92	0.78 %
United Kingdom	164	0.06	1.74	0.34 %
United States	13,245	0.18	5.12	1.02 %

* Conversion to CO2e based on a GWP100 of 28 according to the IPCC AR5 at the request of the client. The latest factor according to the IPCC AR6 is 29.8 [26]. The conversion to % is based on a gross calorific value of methane (55.5 MJ per kg).

The methane intensities are based on scaling factors that might not reflect country-specific situations accurately. The IEA is willing to include other data, for example, from measurement campaigns carried out in the countries, but there was no adaption of German data, yet. In the case of Germany, data from the Federal Environment Agency UBA (reference year 2023), which is also used in reporting for the UNFCCC, was used as a data source for this study to assess methane intensity of gas operations. UBA also provides more recent information on emissions related to gas transport and distribution and the data is directly related to natural gas, rather than total oil and gas.

The IEA Methane Tracker does not provide methane emissions for the EU27, but rather for Europe, so this was assumed as an approximation for EU27 in the following sections.

Table 3.2: Methane intensities of German gas operations according to UBA in 2023 and of Europe according to IEA and own calculations

Country	Segment	Methane emissions in 2023 in kt CH_4	Methane intensity in 2023 in kgCH_4 per GJ	Methane intensity in 2023 in gCO_2eq per MJ	Methane intensity in 2023 in %
Germany	production and processing	0.17	0.002	0.04	0.01
	transport	9.94	0.003	0.10	0.02
	distribution	10.01	0.003	0.10	0.02
EU27	production	623	0.04	1.13	0.22
	transport and distribution	570	0.01	0.31	0.06

3.3.2 Calculation of the emissions of the gas mix

In order to calculate the methane emissions of the German and EU27 gas mix, the methane intensities of the individual countries were multiplied by the gas mix of Germany and EU27 (refer section 3.2.2 and 3.2.3.). The results are shown in chapter 4.

4 Methane emissions of natural gas

4.1 Methane emissions of natural gas supply chain per bcm natural gas distributed in Germany

The German natural gas mix is associated with 2.3 ktCH_4 (0.06 Mt CO_2eq) per bcm in the supply chain (compare Figure 4.1) resulting in total emissions of 0.18 Mt CH_4 (5.13 MtCO_2eq). Detailed values of the figures used for the calculation can be found in Annex 4.

Broken down into the individual processes in the supply chain, 89 % of emissions occur during production and transport outside of Germany. A total of 11 % occurs during transport and distribution within Germany. Germany's own production is very low and accounts for only 0.1 % of associated methane emissions.

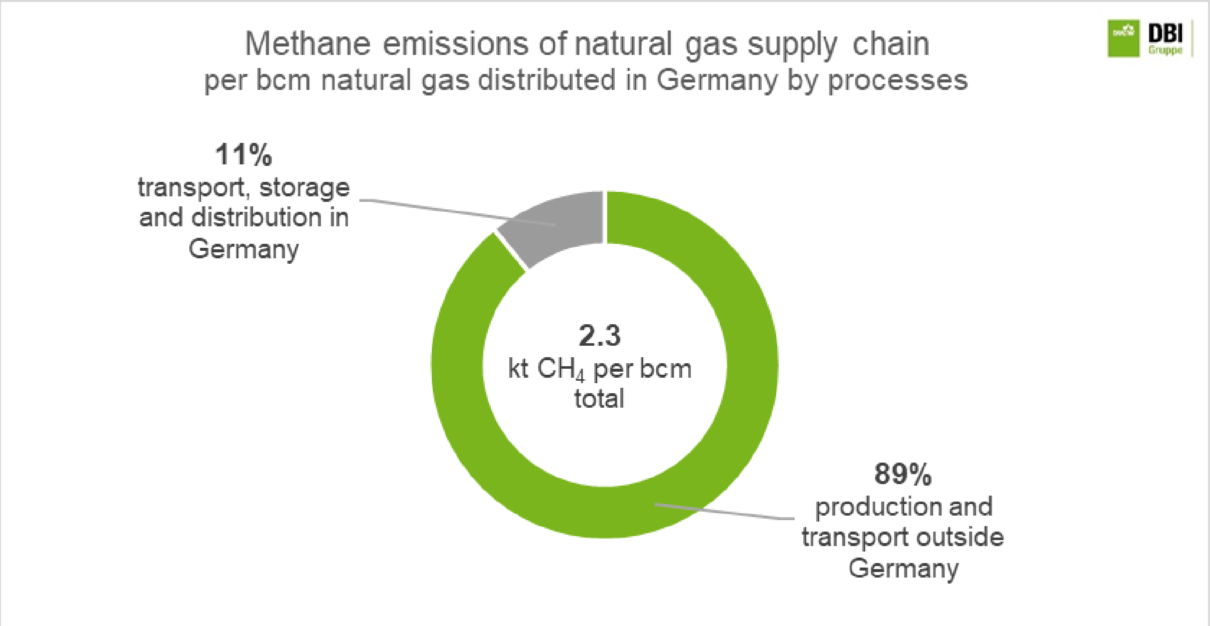

Figure 4.1: Methane emissions of natural gas supply chain per bcm natural gas distributed in Germany by processes, estimation by DBI

The United States, Russia, and Angola are assumed to be the three countries that contribute most to the methane emissions of the natural gas supply chain (Figure 4.2). Although Germany does not import gas directly from Russia, some of its neighbouring countries do import LNG from Russia (according to Eurostat). Since the assumption is that Germany receives its gas mix from its neighbours, the modelling shows that the German gas mix also contains Russian gas and needs to be regarded for the determination of the methane emissions of the natural gas supply chain.

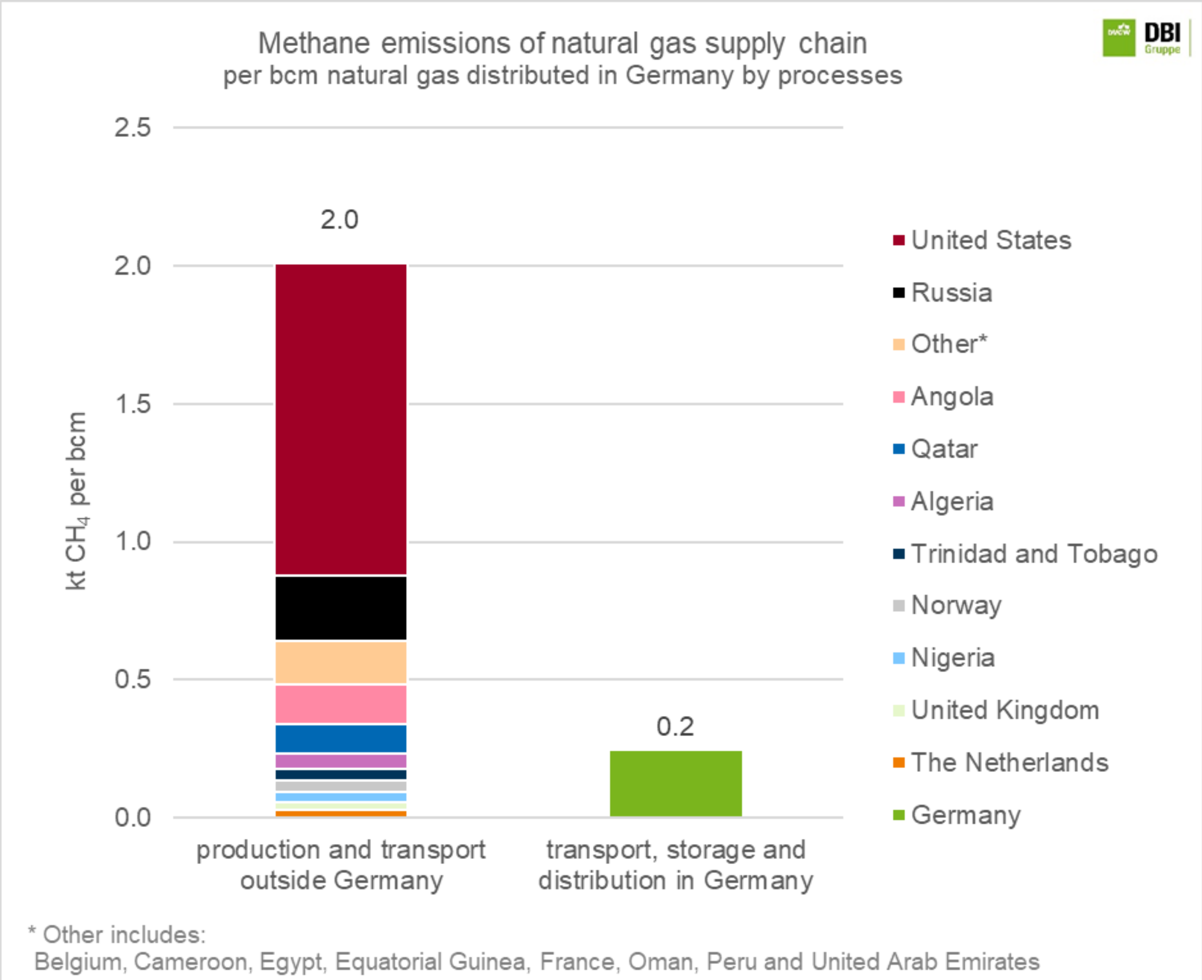

Figure 4.2: Methane emissions of natural gas supply chain per bcm natural gas distributed in Germany by processes in 2023, estimation by DBI

In order to contextualise the shares of individual production countries, it is important to know what proportion of gas is imported from which country. This is shown in Figure 4.3, which shows the total contribution of each country to the associated CH_4 emissions per bcm distributed in Germany compared to the share in the natural gas mix in Germany.

US-imports have a share of 50 % of the associated CH_4 emissions, although only 17 % of the natural gas supply originates from the United States. In contrast, 60 % of natural gas is imported from Norway, which only accounts for about 2 % of associated emissions.

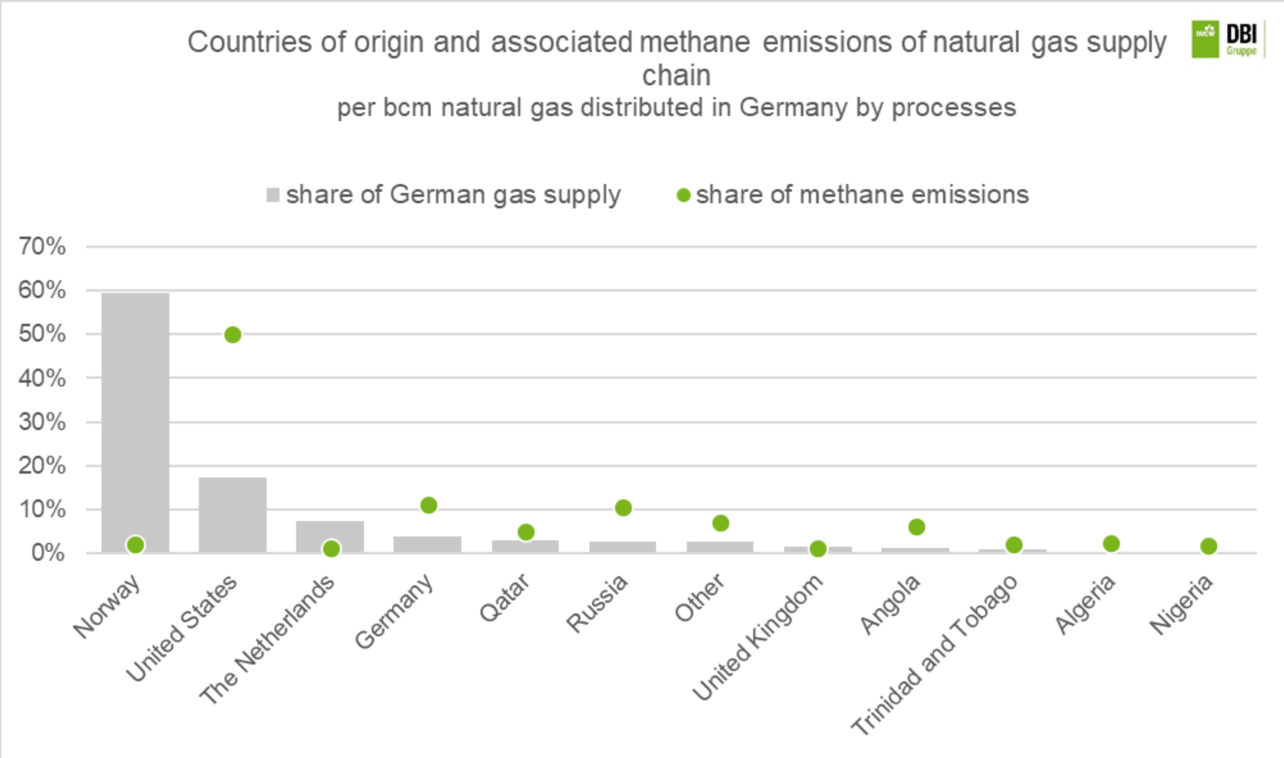

Figure 4.3: Share of methane emissions of natural gas distributed in Germany in % in comparison to share of gas import in % in 2023, estimation by DBI

4.2 Methane emissions of natural gas supply chain per bcm natural gas distributed in the EU27

The natural gas distributed in the EU27 is associated with 5.8 ktCH_4 (0.16 Mt CO_2eq) per bcm in the supply chain (compare Figure 4.4) , which is significantly higher than the methane emissions of the German gas mix. This is mainly due to the higher proportion of natural gas from Algeria and Russia and also because transportation and distribution in the EU27 has a higher methane intensity than transportation and distribution in Germany. In total the CH4 emissions in the supply chain are 70 Mt CH_4 (47.52 MtCO_2eq).

Broken down into the individual processes in the supply chain, most emissions occur during production and transport outside EU27 (93 %). A total of 7 % occurs during transport and distribution in EU27.

Detailed information on the figures used for the calculation can be found in Annex 5.

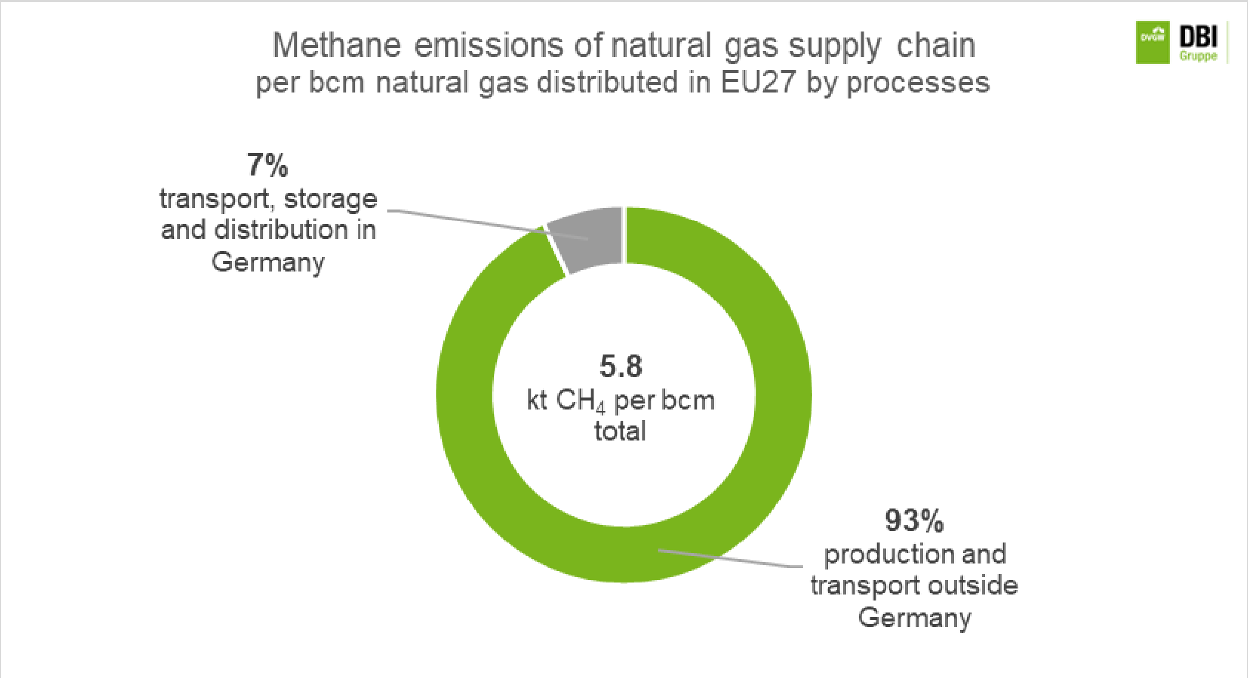

Figure 4.4: Methane emissions of natural gas supply chain per bcm natural gas in EU27 by processes in 2023, estimation by DBI

Algeria, the United States and Russia are the three countries that contribute most to the emissions (Figure 4.5).

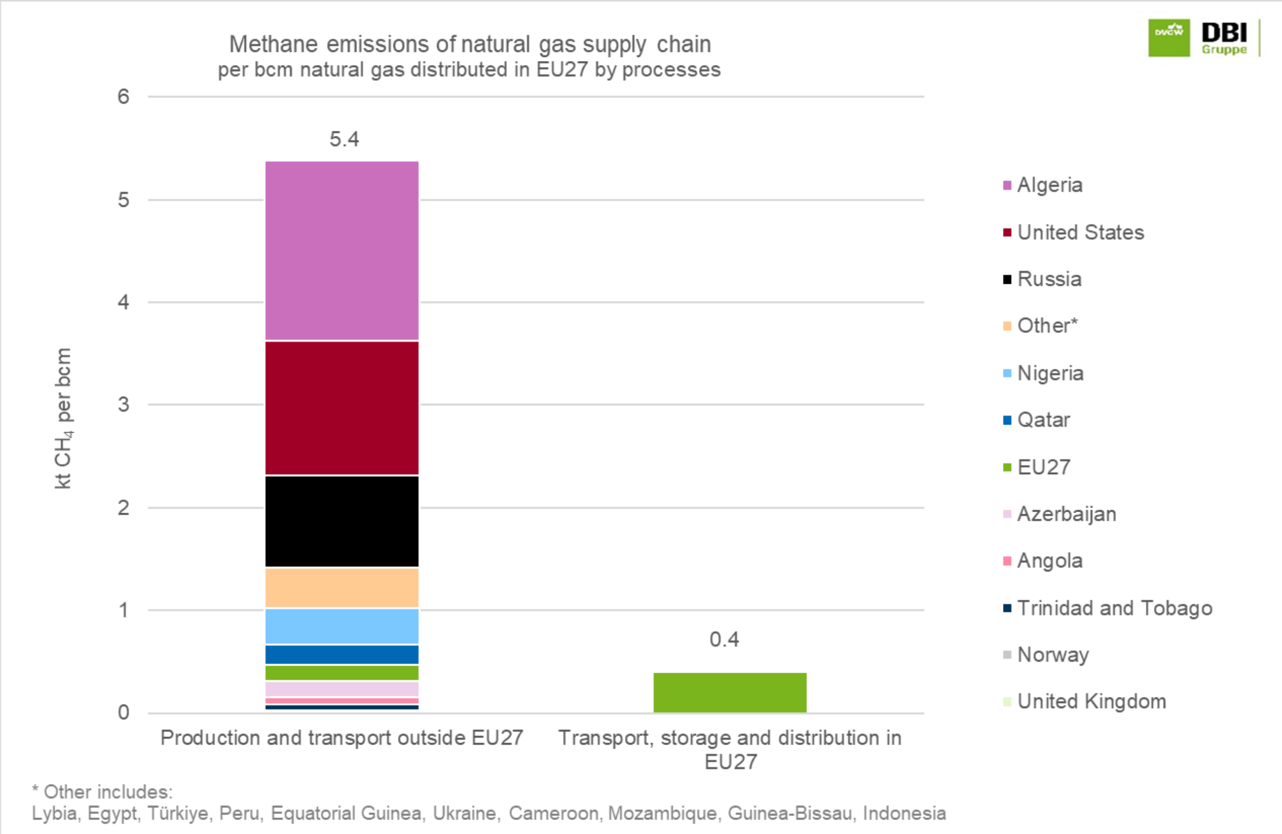

Figure 4.5: Methane emissions of natural gas supply chain per bcm natural gas distributed in EU27 by processes in 2023, estimation by DBI

Figure 4.6 shows the total contribution of each country to the associated CH_4 emissions per bcm distributed in EU27 compared to the supply share of the natural gas mix in EU27.

Although Norway is with 28 % the greatest contributor to the EU27 gas mix, Norwegian gas is responsible for less than 1 % of CH_4 emissions. In contrast, the Algerian gas supply is responsible for 30 % of the CH_4 of the natural gas supply chain, although it only accounts for around 12 % of the gas mix.

If all production imported to the EU27 was associated with a leakage rate comparable to Norwegian levels, total CH_4 emissions in the supply chain for deliveries to the EU27 would be 0.02 $MtCH_4$ (0.59 $MtCO_2eq$), thus 1.25 % of the current Mt CH_4 total.

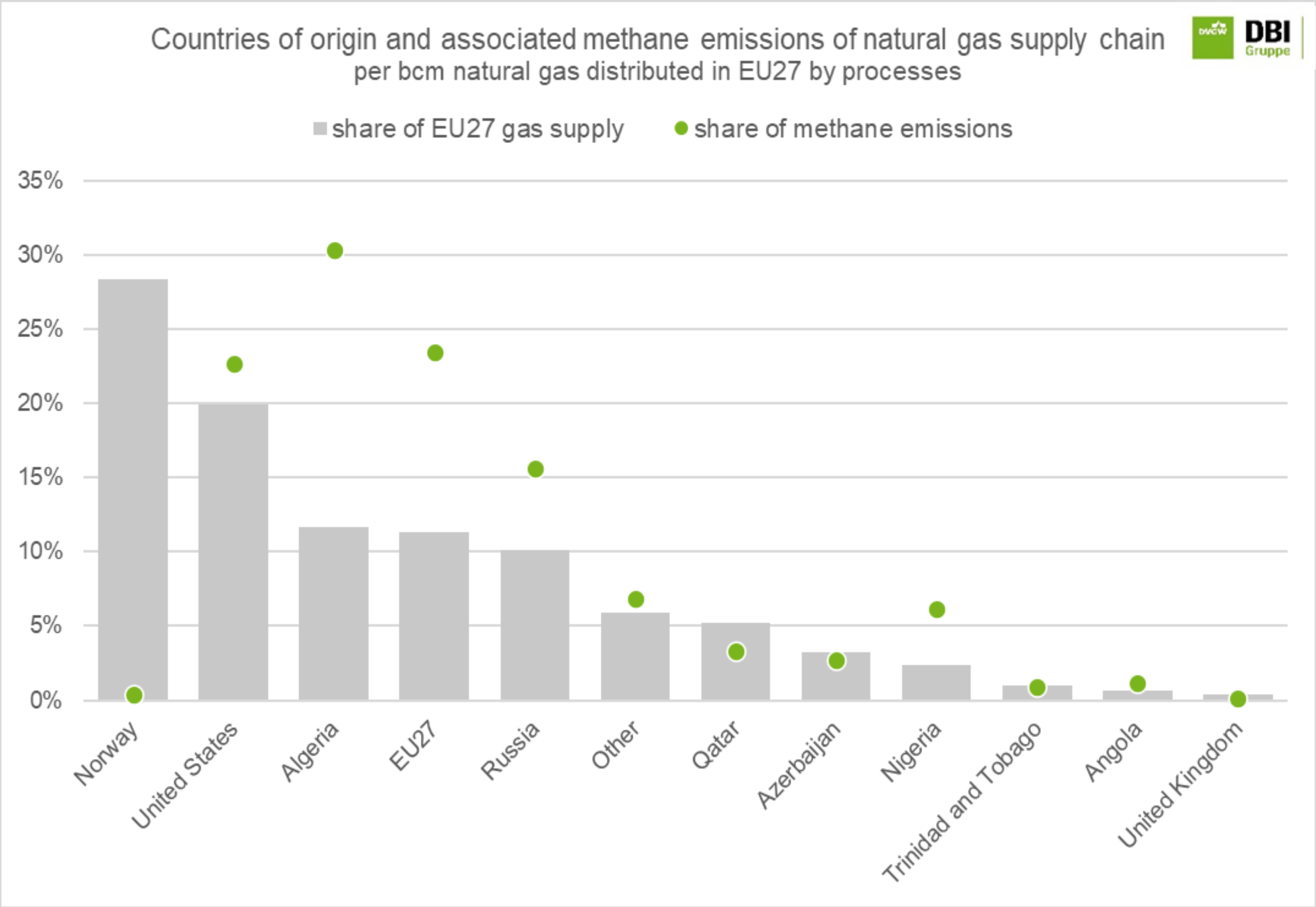

Figure 4.6: Share of methane emissions of natural gas distributed in EU27 in % in comparison to share of gas import in % in 2023, estimation by DBI

5 Conclusions

For this study, the methane intensities for the reference year 2023 were sourced from the IEA Methane Tracker. The IEA Methane Tracker shows significant differences between production countries. For the relevant suppliers of Germany and the EU27 the highest intensities are prevalent in Nigeria (2.3%), Algeria (2.3%), Angola (1.7%), Russia (1.4%) and the United States (1.0%). Norway (0.01%) and the Netherlands (0.06%) have the lowest methane intensities.

Regarding the German natural gas mix, in 2023, according to the assumptions made in this study, approximately 60 % of the natural gas used in Germany was sourced from Norway, followed by imports from the United States (17 %) and the Netherlands (7 %). Methane emissions of natural gas distributed in Germany equal 2.3 kt CH_4 per bcm (ca. 63 g CH_4 per GJ). Total methane emissions of the German natural gas supply chain amount to 0.18 Mt CH_4 (5.13 $MtCO_2eq$). Despite its smaller share in the supply mix, U.S. natural gas contributed the largest portion of emissions - around 50 % of CH_4 emissions associated with natural gas distributed in Germany. Conversely, Norway, the largest supplier by volume, was responsible for only about 2 % of Germany's methane supply chain emissions, underscoring the varying environmental impacts based on production and transport practices in different countries. Whilst control of methane leakages at the production and processing is key and is responsible for 89% of emissions, long-distance transport and distribution combined account for 11% and cannot be disregarded.

Regarding the EU27 natural gas mix, in 2023, according to the assumptions made in this study, approximately 28 % of the natural gas used in the EU27 countries was sourced from Norway, followed by imports from the United States (20 %), Algeria (12 %) and own production of the EU27 (11 %). Methane emissions of natural gas distributed in the EU27 equal 5.8 kt CH_4 per bcm (ca. 161 g CH_4 per GJ). Total methane emissions of the EU27 natural gas supply chain amount to are 1.70 Mt CH_4 (47.52 $MtCO_2eq$). Although Norway is with 28 % the greatest contributor to the EU27 gas mix, Norwegian gas is responsible for less than 1 % of CH_4 emissions. In contrast, Algerian gas is responsible for 30 % of CH_4 emissions, although it only accounts for around 12 % of the gas mix. If all production imported to the EU27 was associated with a leakage rate comparable to Norwegian levels, total CH_4 emissions in the supply chain for deliveries to the EU27 would be 0.02 $MtCH_4$ (0.59 $MtCO_2eq$), so 1.25 % of the current Mt CH_4 total.

Production and processing is responsible for 93 % of emissions, transport and distribution in the EU27 account for 7 %.

Data of CH_4 emissions from oil and gas operations are characterised by a fundamental lack of accuracy. Looking ahead, improving accuracy and consistency of methane emissions data remains a priority, as current discrepancies between sources like the IEA Methane Tracker, UNFCCC, and OGMP 2.0 illustrate significant variations. These differences, stemming from diverse methodologies, such as top-down satellite measurements versus bottom-up inventory approaches, affect emissions calculations and regulatory outcomes. Future advancements in data harmonization and integration – also brought forward with mandatory monitoring requirements such as in the EU Methane Regulation – will help to bridge these gaps, allowing for more reliable emissions tracking and more effective policy implementation.

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Annex 1: Conversion of Units

In this study, units of natural gas are presented as billion cubic meters (bcm). Other units were converted in accordance with [27, p. 71] as follows:

$$1\ Mt\ LNG = 1.36\ bcm$$

Formula 1: Conversion from Mt LNG to bcm

$$1\ TWh\ (natural\ gas, GCV) = 0.1\ bcm$$

Formula 2: Conversion from TWh to bcm

$$1\ TJ = \frac{1}{3{,}600}\ TWh$$

Formula 3: Conversion from TJ to TWh

$$\rho(CH_4) = 0.717\ \frac{kg}{m^3}$$

Formula 4: Density of CH_4

Annex 2: Categories of emission sources and emissions intensities in the United States

Table 5.1 shows the categories of emission sources and emissions intensities in the United States, used in the IEA Methane Tracker [28, 5f].

Table 5.1: Categories of emission sources and emissions intensities in the United States [28, 5f]

	Segment	Production type	Emissions type	Intensity (mass of CH_4 per mass oil or gas)
Oil	upstream	onshore conventional	vented	0.36 %
Oil	upstream	onshore conventional	fugitive	0.09 %
Oil	upstream	offshore	vented	0.36 %
Oil	upstream	offshore	fugitive	0.09 %
Oil	upstream	unconventional oil	vented	0.72 %
Oil	upstream	unconventional oil	fugitive	0.18 %
Oil	downstream		vented	0.004 %
Oil	downstream		fugitive	0.001 %
Oil		onshore conventional	incomplete flare	0.06 %
Oil		offshore	incomplete flare	0.01 %
Oil		unconventional	incomplete flare	0.04 %
Natural gas	upstream	onshore conventional	vented	0.29 %
Natural gas	upstream	onshore conventional	fugitive	0.11 %
Natural gas	upstream	offshore	vented	0.29 %
Natural gas	upstream	offshore	fugitive	0.11 %
Natural gas	upstream	unconventional gas	vented	0.43 %
Natural gas	upstream	unconventional gas	fugitive	0.17 %
Natural gas	downstream		vented	0.15 %
Natural gas	downstream		fugitive	0.10 %

The IEA scaling factors of the relevant countries are shown in Table 5.2. The starting point is the United States with scaling factors of 1 upstream and downstream.

Table 5.2: Upstream and downstream IEA scaling factors of selected countries [29]

	Scaling factor - upstream	Scaling factor - downstream
Algeria	1.75	1.14
Angola	1.35	1.7
Azerbaijan	0.96	0.86
Germany	0.99	0.49
Netherlands	0.04	0.02
Nigeria	2.44	1.75
Norway	0.02	0.02
Oman	0.96	0.68
Qatar	0.96	0.55
Russia	1.66	1.08
Trinidad and Tobago	1.14	0.8
United Kingdom	0.29	0.37
United States	**1**	**1**

Annex 3: Natural gas mix data for different countries

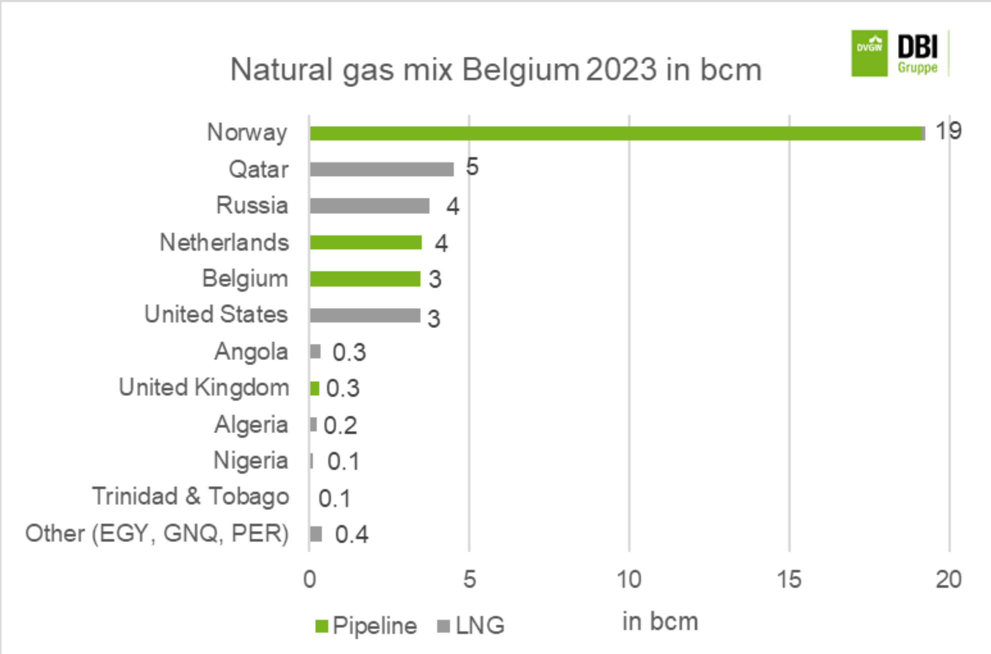


Figure 5.1: Natural gas mix Belgium 2023 in bcm, estimation by DBI

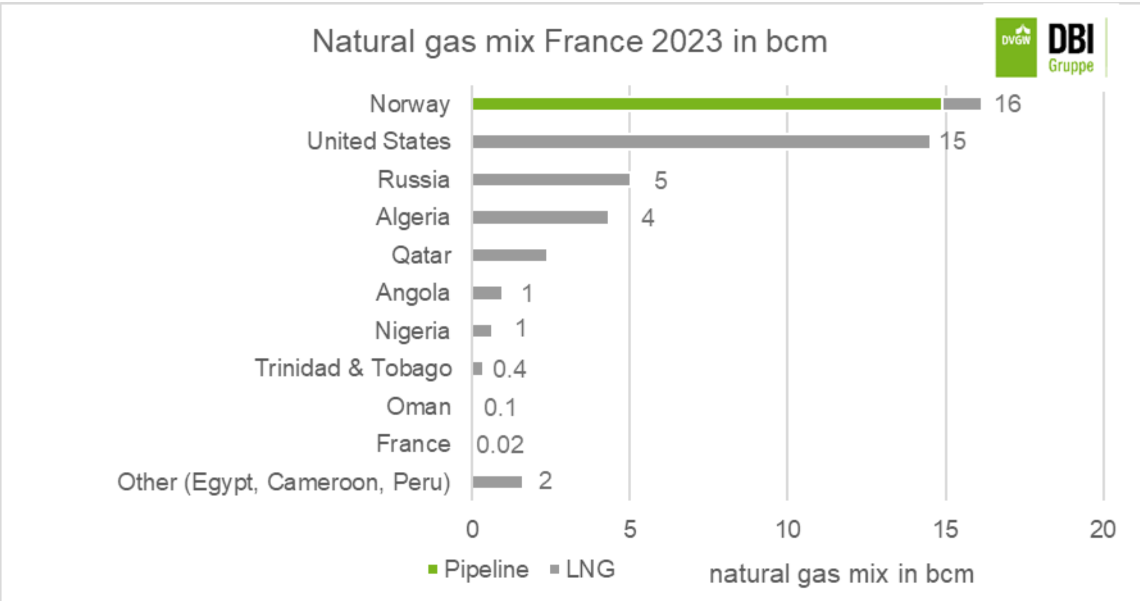


Figure 5.2: Natural gas mix France 2023 in bcm, estimation by DBI

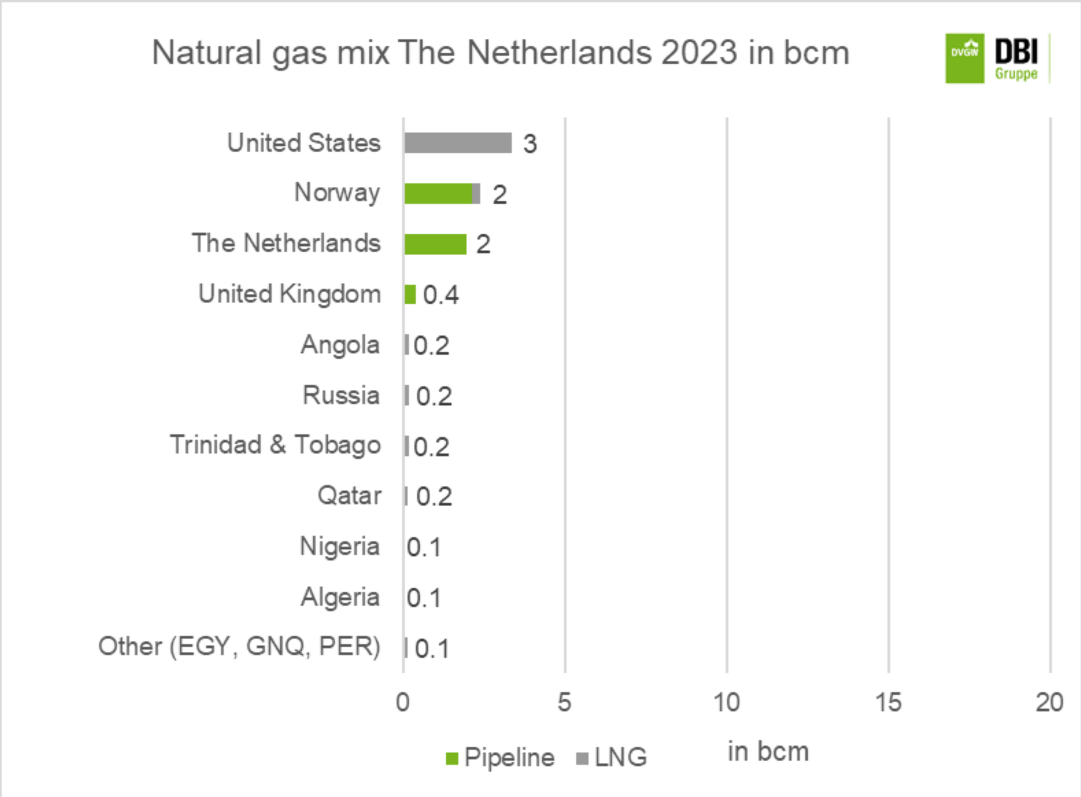


Figure 5.3: Natural gas mix The Netherlands 2023 in bcm, estimation by DBI

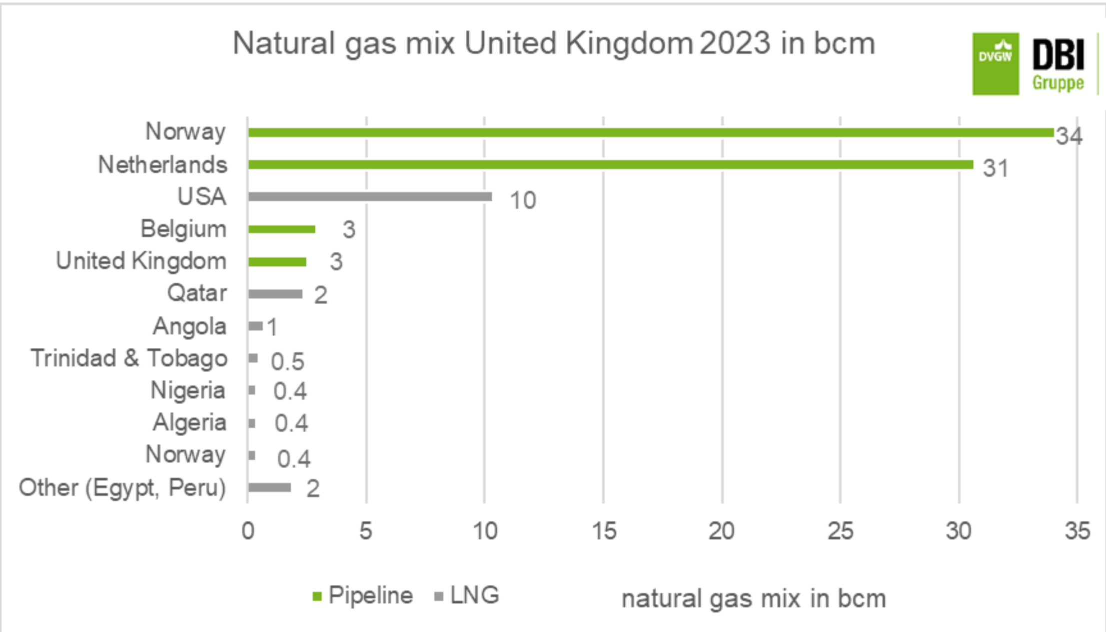


Figure 5.4: Natural gas mix United Kingdom 2023 in bcm, estimation by DBI

Annex 4: Calculation of methane emissions of the natural gas supply chain per bcm natural gas distributed in Germany

The methane intensities for all countries, except for Germany, in kg CH_4/GJ were taken from the IEA [25].

The values were converted to ktCH4/bcm as follows:

Example for Algeria: $$\frac{0.42\ kgCH_4/GJ}{10^6} * \frac{36{,}000{,}000\ GJ}{bcm} = 15\ \frac{ktCH_4}{bcm}$$

The contribution to Germany's CH_4 supply chain emissions for production and transport outside Germany were calculated be taking the methane intensities and multiplying them by the share in German gas supply:

Example for Algeria: 15 ktCH_4/bcm * 0,36 % = 0.05 ktCH_4/bcm.

Table 5.3: Calculation of methane emissions of the supply chain of natural gas distributed in Germany in 2023

Country	Methane intensity of oil and gas operations		Production and transport outside Germany		Transport, storage and distribution in Germany
	kg CH_4/GJ produced	ktCH4/bcm	Share in German gas supply	Contribution to Germany's CH4 supply chain emissions	Contribution to Germany's CH4 supply chain emissions
			%	ktCH4/bcm	ktCH_4/bcm
Algeria	0.42	15.0	0.36%	0.05	-
Angola	0.31	11.1	1.26%	0.14	-
Germany	0.002	0.1	3.71%	0.002	0.25
Nigeria	0.42	15.0	0.23%	0.04	-
Norway	0.002	0.1	59.61%	0.04	-
Other	0.17	6.1	2.58%	0.16	-
Qatar	0.10	3.7	2.92%	0.11	-
Russia	0.25	8.9	2.67%	0.24	-
The Netherlands	0.01	0.4	7.30%	0.03	-
Trinidad and Tobago	0.14	5.0	0.88%	0.04	-
United Kingdom	0.06	2.2	1.26%	0.03	-
United States	0.18	6.6	17.22%	1.13	-
Total	-	-	100.00%	**2.01**	**0.25**

The methane emissions of German gas production were calculated by dividing the UBA data for methane emissions from production and processing for 2023 by the country's own production in 2023:

$$\frac{0.17\ \text{ktCH4}}{3.01\ \text{bcm}} = 0.1\ \text{ktCH4/bcm}$$

The methane emissions of German gas transportation and distribution were calculated by dividing the UBA data for methane emissions from transportation and distribution for 2023 by the gas volume in 2023. This takes into account the fact that significantly more gas is transported and distributed than is produced in Germany.

$$\frac{9.94\ \mathrm{ktCH4} + 10.01\ \mathrm{ktCH4}}{81.21\ \mathrm{bcm}} = 0.25\frac{ktCH4}{bcm}$$

This is a difference compared to the methane intensity of the IEA Methane Tracker, in which the amount of gas produced is always the reference for calculating the methane intensities.

Annex 5: Calculation of methane emissions of the natural gas supply chain per bcm natural gas distributed in EU27

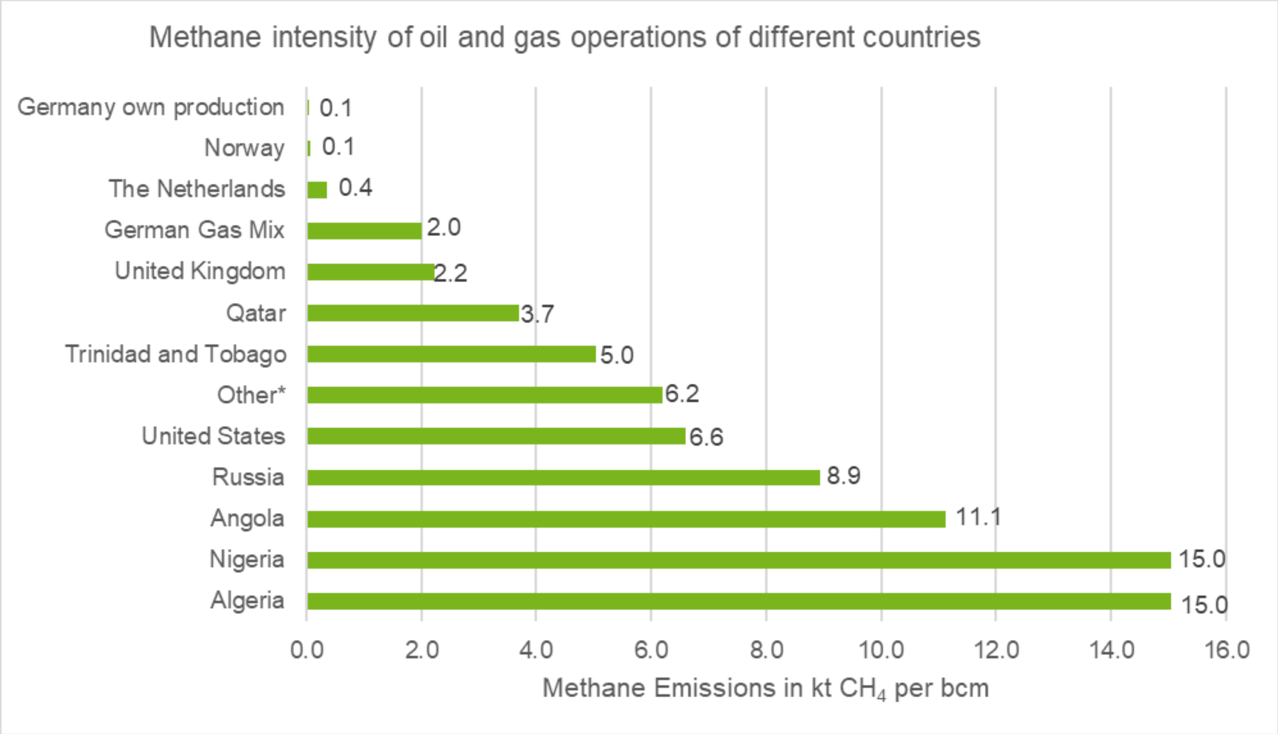
The calculations in Table 5.4 were carried out analogously to those in Appendix 5.

To calculate the methane emissions in kgCH4/GJ for the EU27, the methane emissions of the Europe in kt CH_4 were divided by the natural gas and oil supply (import+own production) of Europe, which was given from the IEA with 50,867,909 TJ for the year 2022 (2023 is not available yet but expected to be comparable) [30].

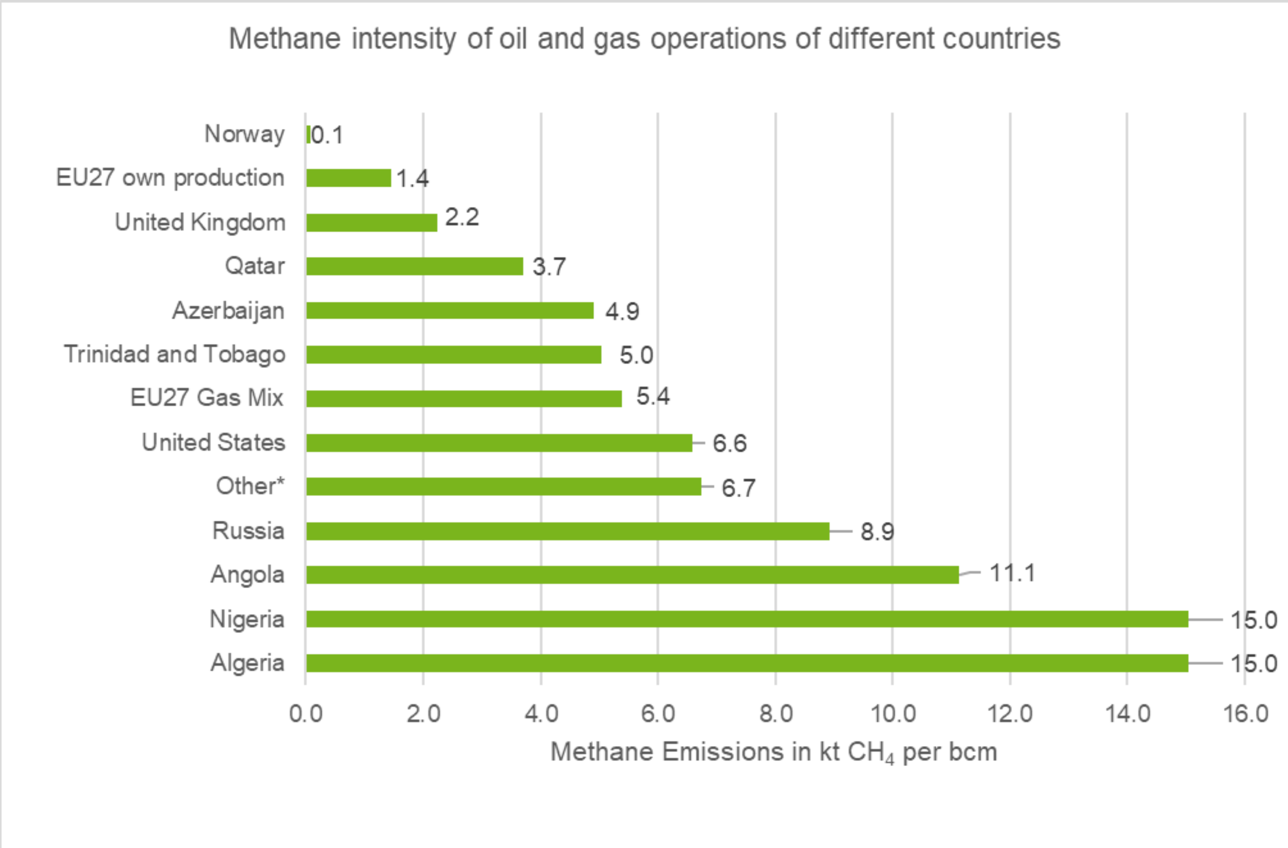
Table 5.4: Calculation of methane emissions of the supply chain of natural gas distributed in EU27 in 2023

Country	Methane intensity of oil and gas operations		Production and transport outside EU27		Transport, storage and distribution in EU27
	kg CH_4/GJ produced	ktCH4/bcm	Share in EU27 gas supply	Contribution to EU27's CH4 supply chain emissions	Contribution to EU27's CH4 supply chain emissions
			%	ktCH4/bcm	ktCH$_4$/bcm
Algeria	0.42	15.0	11.66%	1.76	-
Angola	0.31	11.1	0.62%	0.07	-
Azerbaijan	0.14	4.9	3.23%	0.16	-
EU27	0.04	1.4	11.36%	0.16	0.4
Nigeria	0.42	15.0	2.36%	0.35	-
Norway	0.00	0.1	28.36%	0.02	-
Other	0.19	6.7	5.86%	0.39	-
Qatar	0.10	3.7	5.18%	0.19	-
Russia	0.25	8.9	10.09%	0.90	-
Trinidad and Tobago	0.14	5.0	1.01%	0.05	-
United Kingdom	0.06	2.2	0.43%	0.01	-
United States	0.18	6.6	19.85%	1.31	-
Total	-	-	100.00%	**5.38**	**0.4**

Annex 6: Methane intensity from different production countries relevant for the German Gas Mix



Annex 7: Methane intensity from different production countries relevant for the EU27 Gas Mix



Note: The value for “other” is different in Annex 6 and Annex 7 because it is an average of the other countries and the relevant countries for the German and the EU27 gas mix are slightly different.

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