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FINAL REPORT

Critical Evaluation of Default Values for the GHG Emissions of the Natural Gas Supply Chain

Principal:
Zukunft ERDGAS
Dr. Timm Kehler
Dr. Norbert Azuma-Dicke
Verena Friedl
Neustädtische Kirchstraße 8
D-10117 Berlin

Agent:
DBI Gas- und Umwelttechnik GmbH
Department: Gas Grids/ Gas Facilities
Karl-Heine-Straße 109/111
D-04229 Leipzig

Performing Persons:
Gert Müller-Syring
Tel.: +49 341 24571-29
Fax: +49 341 24571-37
E-Mail: gert.mueller-syring@dbi-gruppe.de

Charlotte Große
Tel.: +49 341 24571-49
E-Mail: charlotte.grosse@dbi-gruppe.de

Josephine Glandien
Tel.: +49 341 24571-80
E-Mail: josephine.glandien@dbi-gruppe.de

Melanie Eyßer
Tel.: +49 341 24571-80
E-Mail: melanie.eysser@dbi-gruppe.de

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Gert Müller-Syring

Charlotte Große

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List of Abbreviations

AR	Assessment Report
BVEG	Federal Gas, Oil, and Geothermal Energy Association (Germany)
CCFB	Climate Carbon Feedback
Central EU	Central Europe
CF	Carbon Footprint
CH_4	Methane
CO_2	Carbon Dioxide
CO_2e	CO_2 Equivalent
FNB	Fernnetzbetreiber (ref. TSO)
GHG	Greenhouse Gas
GPR(M)S	Gas Pressure Regulating (and Metering) Station
GWP	Global Warming Potential
IEA	International Energy Agency
IfEU	Institute for Energy and Environmental Research
IOGP	International Association of Oil & Gas Producers
IPCC	Intergovernmental Panel on Climate Change
ISO	International Standard Organisation
LCA	Life Cycle Assessment
LCI	Life Cycle Inventory Analysis
LCIA	Life Cycle Impact Assessment
LDC	Least Developed Countries
LNG	Liquefied Natural Gas
NGVA	Natural & bio Gas Vehicle Association
NIR	National Inventory Report
NOROG	Norsk olje&gass (Norwegian Oil and Gas Association)
OECD	Organization for Economic Cooperation and Development
TSO	Transmission System Operator
T&S	Transport and Storage
UNFCCC	United Nations Framework Convention on Climate Change
VOC	Volatile Organic Compounds
WTT	Well-to-tank

1. Introduction

Numerous scientific studies have shown that natural gas is the most environmentally-friendly fossil fuel when comparing the greenhouse gas (GHG) emissions. In the current discussion other studies have raised questions about the life cycle emissions ranging from production to dispensing (well-to-tank or WTT). One of these studies (hereafter referred to as the EXERGIA study [1]) was carried out by the Greek institute EXERGIA on behalf of the European Commission and published in July 2015. The subject of the EXERGIA study are greenhouse gas emissions occurring during the life cycle steps production, processing, transport, distribution and dispensing on filling stations for natural gas mobility. The EXERGIA study reports considerably higher upstream emissions than those recorded by other studies, such as the JEC[1] study from 2013 [2]. However, critical analysis (e.g. BDEW (ref. [3]), DNV-GL (ref. [4]), ifeu (ref. [5])) showed that EXERGIA relied partly on obsolete data or estimations, and that weaknesses were present in the methodology of the research. The manner in which the calculations of the EXERGIA study were carried out also lacked transparency, thus making verification of these results more complicated.

Due to the ever-increasing political importance of greenhouse-gas emissions from energy sources, the study at hand was commissioned to determine the carbon footprint[2] (CF) of natural gas from its production phases to its distribution in central Europe (Central EU)[3]. The study in addition to public available statistical data also uses best available industry data and considers the requirements of the life cycle assessment (LCA) as set out by DIN EN ISO 14040 [6] and DIN CEN ISO TS 14067 [7]. It includes the four principle components of a life cycle assessment: goal and scope definition, life cycle inventory analysis, life cycle impact assessment, and interpretation. Full ISO conformity can be achieved as soon as a critical review by a third party is conducted.

The goal of the present study is the determination of the carbon footprint of natural gas distributed in Central EU based on best available data, and the comparison of the results with those of the EXERGIA study. This is explored in greater detail in Chapter 2. Research of current best available data is focused on the major supplying countries for Central Europe: The Netherlands, Norway and Russia. Moreover, Germany as the main consumer and an important transit country of natural gas will be considered. The input data, which is relevant for those countries and necessary for the calculation of the CF, will be described in Chapter 3. Moreover, Chapter 3 includes a description of the greenhouse gas (GHG) emissions, which occur on the life cycle stages production, processing, transport, storage and distribution of natural gas. In the course of the impact assessment the effects on climate change (the only impact category) is presented in Chapter 4. In Chapter 5, results will be interpreted and evaluated.

The project was commissioned and coordinated by Zukunft ERDGAS GmbH and carried out by DBI Gas- und Umwelttechnik GmbH Leipzig.

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[1] JEC is a cooperation of three organizations: **J**oint Research Centre of the European Commission (Institut für Energie und Transport), **E**UCAR (European Council for Automotive Research and Development) und **C**ONCAWE (Oil Companies' European Organisation for Environment, Health and Safety) [60].

[2] The CF is the "Sum of greenhouse gas emissions (…) in a product system, expressed as CO_2 equivalents and based on a life cycle assessment using the single impact category of climate change." [7, p. 13]

[3] According to Exergia the region "Central EU" comprises: Austria, Belgium, Czech Republic, Estonia, Germany, Hungary, Latvia, Lithuania, Luxemburg, The Netherlands, Poland, Slovakia [1, p. 322].

2. Goal of the Project and Scope Definition

2.1 Goal of the Project

2.1.1 Intended Application

The goal of the CF study is „…to calculate the potential contribution of a product to global warming expressed as CO_2 equivalent (CO_2e) by quantifying all significant GHG emissions and removals over the product's life cycle.“ [7, p. 35].

This study in particular aims to determine the carbon footprint of natural gas from the source to a defined point of use. The resulting carbon footprint will, therefore, be based on the latest and most reliable data available. The assessment of the carbon footprint is carried out according to the DIN EN ISO 14040 [6] and the DIN CEN ISO TS 14067 [7]. A report will be created which outlines greenhouse gas emissions resulting from production, processing, transport/transmission, storage and distribution in the region Central Europe (Central EU)[4].

This study will enable a comparative evaluation of carbon footprint research with other similar studies such as the EXERGIA study. The study will also contribute to an improvement of the available data.

2.1.2 Reasons for Carrying out the CF Study

The EXERGIA study reaches greatly different conclusions regarding the ecological evaluation of natural gas than previous studies (e.g. JEC study from 2013 [2]). These discrepancies are due to the use of different calculation models and assumptions made, different basic data, and, on occasion, different system boundaries. It is unclear whether existing studies consider international standards for CF studies and life cycle assessments, and if so, to what extent. This analysis should compare it´s results with the results of the EXERGIA study, should identify and correct weaknesses, and, thereby, improve the public available database for further research.

2.1.3 CF Communication

The results of the study will be communicated to the European Commission (in particular to the Directorate General Energy, Directorate General Climate Action and Directorate General Mobility and Transport). Further interested parties include related trade professionals, political community, and organisations taking part in the project.

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[4] Explanation in section 2.2.3.

2.2 Scope of the Study

2.2.1 Definition of Product System

As required by the ISO, the product system is roughly explained in this section. A detailed description of the system boundaries is given in 2.2.3. The product system comprises the individual stages of the natural gas value chain.

Natural Gas Production

Natural gas can occur in connection with oil fields or in separate gas fields. If natural gas reserves are discovered during exploratory drilling, production drilling is carried out which allows the natural gas to be extracted. The effort for the extraction of natural gas depends on the type of natural gas (conventional or unconventional such as shale gas) and on the location of the field (onshore or offshore).

Natural Gas Processing

Natural Gas consists of different components (methane, propane, carbon dioxide (CO_2), hydrogen sulphide, water, etc.) Some of these components (especially hydrogen sulphide and water) need to be separated to avoid operational problems (e.g. the degradation of pipelines) [8]. Other components (e.g. CO_2) are separated to create a certain calorific value of the gas. The calorific value is important for the function of end user appliances. Different processes, for instance dehydration or separation of condensates, are applied for gas processing.

Natural Gas Transport

The transport of natural gas from production locations is normally carried out with high-pressure pipelines, or as liquefied natural gas (LNG). As a result of friction, the pressure of the gas within the pipeline will gradually decrease. To reverse this decrease, compressor stations are placed along the pipeline at intervals of approximately 100 to 150 km.

Natural Gas Storage

In order to counteract seasonal or peak-load fluctuations, natural gas can be stored in underground storage facilities. These facilities can be divided into two categories: porous storage and salt cavern storage. In porous storage the natural gas is stored within a porous rock formation. Surrounding impermeable rock stops the stored gas from escaping. Depleted gas reservoirs and natural aquifers are often utilised for this purpose. In cavern storage an impermeable space is created within the salt rock and filled with natural gas. Additionally to underground storage there is also above ground storage.

Natural Gas Distribution

In contrast to compressors, gas pressure regulating (and metering) stations (GPR(M)S) reduce pressure in the pipeline. This is necessary for the withdrawal of the gas by the end-user. Further functions of GPR(M)S are the volume measurement, the preheating and odourisation of natural gas. When pressure of natural gas is reduced, the gas temperature decreases (Joule-Thompson Effect), therefore preheating units increase the temperature of the gas again. Odourisation is necessary because natural gas is odourless and only with adding an odorant it is possible to detect leaks. At a municipal level, natural gas is distributed via high-, medium- and low-pressure pipelines. It is primarily used in the heating market (heat generation for domestic use, and process heating for industry), for electricity generation and (to a minor degree) in the transport sector. In addition to power plants and domestic customers, it is therefore necessary to supply filling stations with natural gas as well.

2.2.2 Definition of Functional Unit

In the following, one gigajoule natural gas distributed at a regional level will be considered to be the functional unit. This shows that fuel dispensing will not be taken into account. The reasons for this are explained in the following passage: 2.2.3.

2.2.3 Definition of System Boundaries

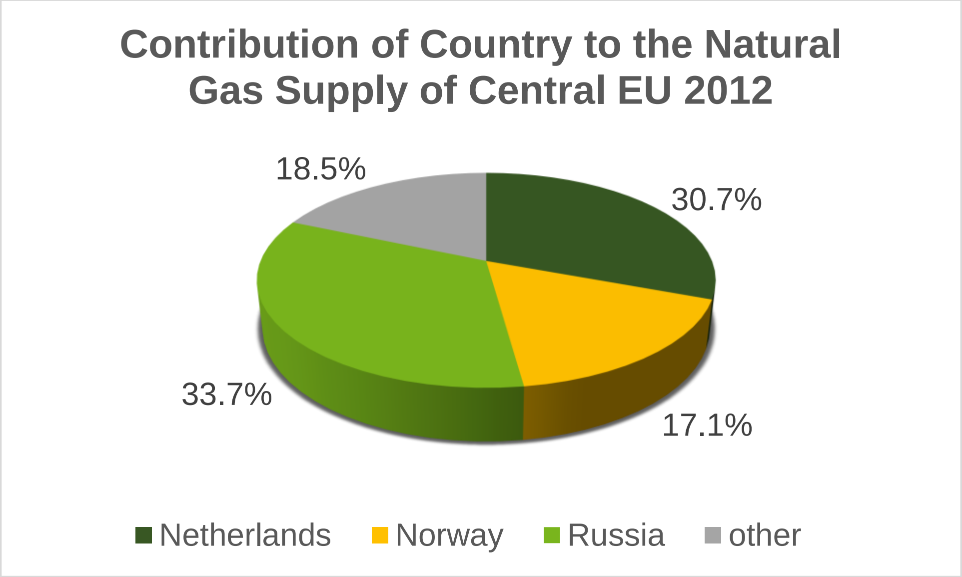
The EXERGIA study distinguishes four regions in Europe: Central EU, North EU, South-West EU and South East-EU. This study only focusses on the Central EU region. The definition corresponds to that of the EXERGIA study. It includes the following countries:

- Belgium
- Germany
- Estonia
- Latvia
- Lithuania
- Luxembourg
- Netherlands
- Austria
- Poland
- Slovakia
- Czech Republic
- Hungary

As part of this study, the input data for the calculation of the carbon footprint for natural gas from the main supplier countries to the Central EU region (Netherlands, Norway, Russia), as well as the data for Germany as the major consuming an important transit country, will be re-analysed because those data have the highest impact on the final result (see Figure 1).

For the following calculations, two different systems are relevant: “natural gas distributed in Central EU” and “natural gas distributed in Germany”.

Figure 1: Contribution of different countries to the natural gas supply of Central EU in 2012



Source: Own illustration DBI based on [9]

The data for all other supplying and consuming countries of Central EU as well as the data relating to LNG, which is necessary for the calculation of the carbon footprint, will be taken from the EXERGIA study as they are included in the GHGenius[5] model.

2.2.3.1 System “Natural Gas Distributed in Central EU”

For the calculation of the CF, the system “natural gas distributed in Central EU” is considered (Figure 2).

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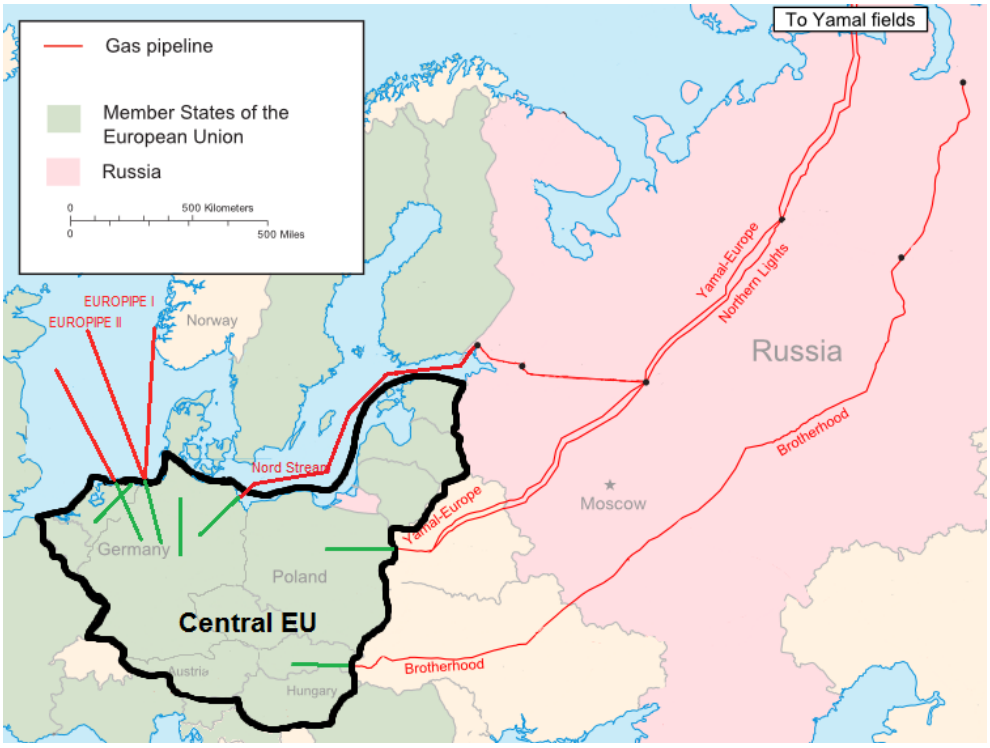
[5] The model is explained in section 2.2.4.

Figure 2: System "Natural Gas Distributed in Central EU"



Source: Own illustration DBI based on [10]

The system comprises the following life cycle stages:

1.) Production and processing of natural gas
2.) Transport to the Central EU border
3.) Transmission, storage and distribution within Central EU

The life cycle stages are explained in detail in the following:

1.) Production and processing of natural gas

This study particularly updated and inquired data for the main supplying countries of Central EU (The Netherlands, Norway, and Russia) as well as for Germany. For all other countries, which produce gas for Central EU, the data set from the EXERGIA study was taken as included in the GHGenius model[6]. Unconventional gas was not considered as part of this research study as there is for the considered timeframe no exploration and production of it in Central EU.

GHG emissions are released in the context of combustion processes for the utilisation of auxiliary energy (mainly CO_2) and as fugitive[7] emissions (CH_4 and CO_2). Auxiliary energy is mainly used in the form of natural gas and electricity for compressors in the gas production and transmission stages.

Furthermore, emissions (mainly CO_2) occur during the flaring of natural gas, which is done when the gas is not usable from the perspective of cost efficiency. Emissions caused by flaring are in analogy to the approach in the EXERGIA study considered as contribution to the energy demand. That means the amount of flared natural gas is collected and this amount is included to the amount of gas necessary for the production of natural gas.

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[6] In the version and with data as used for the EXERGIA study (see section 2.2.5).

[7] The meaning of "fugitive emissions" is different in the literature. In this study, the definition of the IPCC guidelines [61, p. 4.32] is applied which defines fugitive emissions as all emissions, which are not emitted in combustion processes.

Production of natural gas causes fugitive methane (CH_4) emissions because of minor leaks on the used machines and pipelines.

For the gas processing various processes (e.g. gas dehydration, separation of condensates) are used which on one hand use energy and on the other hand lead to fugitive CH_4 and to fugitive CO_2 emissions.

As a source of fugitive CO_2 emissions, the acid gas processing has to be named. At the acid gas processing, hydrogen sulphide is separated from the natural gas and converted to elemental sulphur. The elemental sulphur is then available as saleable product. During the process, emerging CO_2 is also separated and released into the atmosphere.

2.) Transport to the External Border of Central EU

As already described in section 2.2.1 natural gas can be transported via pipelines or in form of LNG. Within this study, only data for the transport via pipelines is investigated. For LNG, data remain as it is contained in the model GHGenius in original state[6], because this provision was not subject of the project. The field LNG is investigated more precisely in following studies (e.g. NGVA[8] study „Greenhouse Gas Intensity Study on Natural Gas“).

Analogous to the EXERGIA study the transport from a country of production to the EU external border and the transmission within Europe is considered separately.

At gas transport, GHG emissions occur because of energy demand and fugitive methane emissions. Energy has to be spent for the compressors, which are located at distances of approximately 100 to 150 km on the pipelines to increase the pressure that decreases because of the pipe friction. The drives of the compressors are mostly directly driven by natural gas from the pipelines but they can also be electrically driven. Fugitive methane emissions particularly occur on the sealing system of the compressors as well as on the valve stations on the pipelines. At repair works, a planned blow down of the pipelines is undertaken. This procedure is necessary to guarantee safety at repair works.

Some pipelines, for example Nord-Stream and also all Norwegian export pipelines run offshore and have no interim compressor stations along the pipeline. The gas is fed with sufficient high pressure in the pipeline; therefore, no additional compression to reach the European border is necessary.

3.) Transport, Storage and Distribution within Central EU

The transport within Central EU is realised the same way as outside. Sources for GHG emissions are also the same.

Storage of natural gas in the considered system only takes place within Central Europe. In the transmission grid, storage is done in underground storage facilities. For injection, the gas is compressed to pressures up to 200 bar. GHG emissions occur especially because of the drive of the compressors and also by fugitive methane emissions on the compressor sealings.

In the distribution network storage facilities also exist in some countries (e.g. Germany). These are mainly above ground storage facilities with low pressures (approximately 10-20 bar). They also can cause fugitive methane emissions.

Furthermore, the gas distribution network predominantly consists of pipelines made of different materials, which show significantly lower pressure rates than the transport pipes (20 mbar to 25 bar). To reduce the pressure, gas pressure regulating and metering stations (GPR(M)S) are used. The

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[8] NGVA = Natural & bio Gas Vehicle Association.

pipelines as well as the facilities of the gas distribution grid are sources for fugitive methane emissions.

The energy demand in the distribution grid predominantly exists for the preheating systems that are partly included in the GPR(M)S and which are necessary to heat gas before it cools down due to pressure reduction (Joule-Thompson Effect). It is assumed that the preheating energy of GPR(M)S has no significant part on the whole carbon footprint and the provision of proper representative data is coupled with a very high effort. The energy demand of GPR(M)S is therefore defined as cut-off criteria.

4.) Fuel Dispensing

Supply of natural gas at natural gas filling stations is not considered in the present study because only 0.4 % of the natural gas used in Europe[9] is used in the transport sector [11]. Other applications, such as the heat- or electricity market are of much greater importance. Because natural gas for these applications is taken either from the transport grid or the distribution grid the system boundary for the system „Natural gas distributed in Central EU“ already ends at the above mentioned point 3.).

2.2.3.2 System „Natural gas distributed in Germany“

The system „Natural gas distributed in Germany“ consists of the same production stages as the system „Natural gas distributed in Central EU“. However, the specific supply structure in Germany as well as the German electricity mix and the relevant efficiency of power generation for Germany is assumed at the calculation of CF to specifically show the natural gas supply in Germany. The electricity mix and the efficiency of power generation are assumed for this purpose as contained in GHGenius. In this field modifications are necessary that reflect the present circumstances. This will be subject of following projects. Figure 3 presents the system “Natural Gas Distributed in Germany” graphically with a map excerpt.

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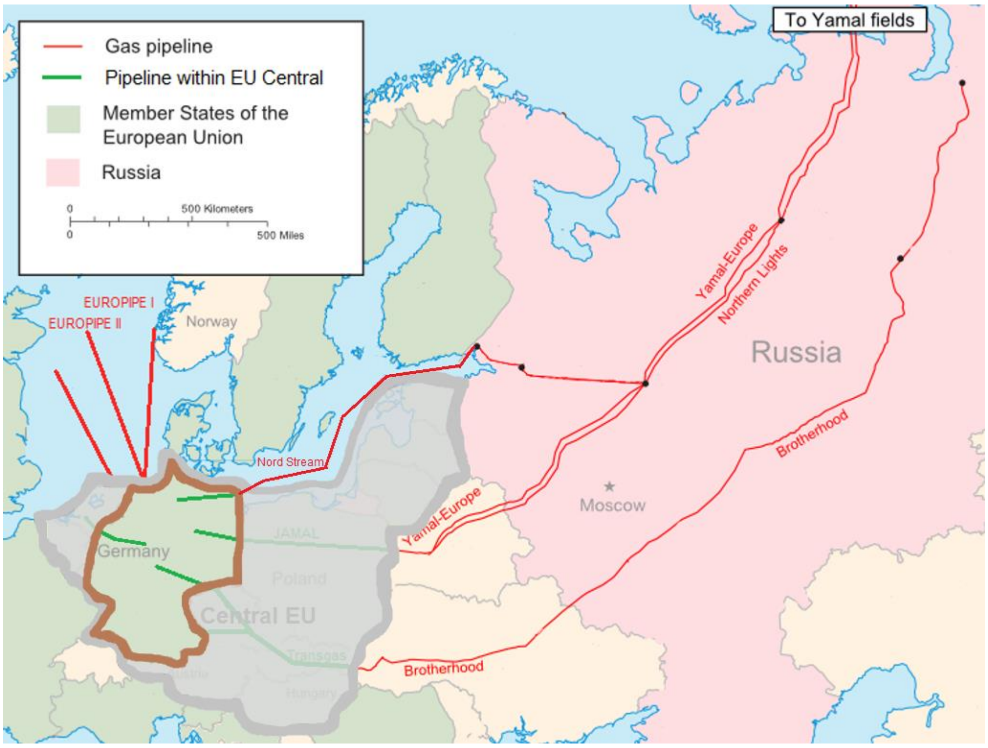
[9] Information for the year 2014 for the EU-28, Turkey and Switzerland.

Figure 3: System "Natural Gas Distributed in Germany“



Source: Own illustration DBI based on [10]

2.2.4 Allocation Procedures

The allocation procedure for a life cycle assessment is a classification procedure that becomes necessary as soon as different usable products are created by one process. However, not all of these products are considered within the life cycle assessment system of a certain product. Allocation procedures, therefore, allow us to focus our approach based on specific criteria. This approach corresponds to the ISO-norm and is widely accepted. [12, p. 11]

In order to determine the proportion of natural gas production comparative to total oil and natural gas production, the allocation process is based on energy content.

2.2.5 Impact Categories, Impact Assessment and Evaluation Method

2.2.5.1 Impact Categories

Different life cycles can have different environmental effects. These effects must be considered in the impact assessment when evaluating the pollutants. The goal of this impact assessment is to examine of specific impact categories (the environmental impact of the collected data). This information is included in the evaluation.

According to DIN CEN ISO TS 14067, the only relevant impact category for the creation of a carbon footprint analysis is climate change. [7, p. 74]

Table 1: Impact Category, Impact Assessment Model, and Impact Category Indicator

Impact Categories	Impact Assessment Model	Impact Category Indicator
Climate Change	Values from the 4th Assessment Report of the Intergovernmental Panel on Climate Change (IPCC)	g CO_2-equivalent (gCO_2e)

2.2.5.2 Impact Assessment Methods

The carbon footprint will be determined with the help of the GHGenius model, which is freely available online (http://www.ghgenius.ca/). Since the model was created for Canada, it has been adapted in the framework of the EXERGIA study.

The adapted version is not freely available but was provided in the framework of a consultancy agreement with the developers (S&T) ^{2}-Consultants. This way, the version GHGenius 4.03 was used for this study - the same, which was applied in the EXERGIA study.

The study at hand uses other designations than the designations defined in GHGenius for the different life cycle steps. An allocation of the used designations to these of GHGenius is in Annex 1.

2.2.5.3 Evaluation Method

The evaluation will take place according to the requirements of ISO TS 14067 paragraph 6.6 [7, p. 62]. This includes:

- Identification of the significant issues based on the results of the quantification of the CF according to life cycle inventory analysis (LCI) and the life cycle impact assessment (LCIA) phases
- An evaluation that considers completeness, sensitivity and consistency checks
- Conclusions, limitations, and recommendations

For the purposes of evaluation, a table will be created including the resulting values for the carbon footprint of natural gas. The years 2012-2014[10] will be considered for Germany and for the region Central EU. This enables a direct comparison with the EXERGIA study.

2.2.6 Data Requirements and Initial Data Quality Requirements

Central requirements for all data sources are resilience, up-to-dateness and transparency. The data quality is evaluated through quantitative and qualitative aspects in compliance with the requirements of the DIN CEN ISO TS 14067 [7, pp. 41, 42]:

a) **Time-related coverage**: The latest available data[11] should be used and in so doing, it should be possible to compare the results with the EXERGIA study.

b) **Geographical coverage**: The datasets should be completely available for the geographical system boundaries (Germany, Netherlands, Norway, and Russia). Only pipeline streams,

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[10] The year 2015 has not been considered, because many data sources have published data up to 2014 only and therefore the data situation for 2015 is very fragmental.

[11] See section 2.2.7.2 data availability.

which deliver natural gas to Central EU resp. Germany should be considered (relates especially to Russia).

c) **Technology coverage**: The researched data should have its origin in the industry and therefore represent not just one representative technology but all technologies in the field.

d) **Precision**: A high precision of the data and calculations is required. This could be fulfilled, if the clamed completeness, representativeness, consistency and reproducibility are satisfied. Additionally, accurately defined system boundaries should enhance the precision.

e) **Completeness**: A complete consideration of all stages of the life cycle should be done. Nevertheless, there could be some limitations, see chapter 2.2.7. For all considered years, the supplier countries and for all stages of life cycle the database should be complete. If it is not possible, requirements must be determined and specified.

f) **Representativeness**: The study is seeking for a high representativeness. The used data should be examined, if possible, with data from other sources. The consideration of three consecutive years is also ensuring the representativeness.

g) **Consistency**: The determination of the CF should be made with use of a consistent methodology.

h) **Reproducibility**: The results of the study should be reproducible by third parties. For this reason, the exposition of the results should be as transparent as possible so that a third party can reproduce the results. This becomes possible by a detailed description of the determination of the CF. A few data sets are confidential. This causes limitations of the claim for reproducibility. However, most data sets are freely available.

i) **Sources of the data**: The used data sources should be mainly primary data from the industry, national energy balances, National Inventory Reports (NIR) (prepared as reporting for the United Nations Framework Convention on Climate Change (UNFCCC)) and national statistics. Only if no other data is available the data from the GHGenius-model or the EXERGIA study should be used.

j) **Uncertainty of the information**: The estimation of GHG emissions generally causes uncertainties, because of the model character of the estimation. Often the estimation of emissions is just modelled with use of equations and not measured directly. For this reason, only approximations to reality are possible. In addition the inventories of all sources for GHG emissions are not always completely given.

2.2.7 Assumptions and Limitations

2.2.7.1 Assumptions

All assumptions made for the calculation of the carbon footprint are described in detail in the relevant sections.

2.2.7.2 Limitations

Focus on a Single Environmental Issue:

The study considers climate change to be the single impact category. Further environmental impacts are not evaluated.

Limited Appraisal of the Different Product Stages:

Natural Gas Transport to the Border and within Central EU

This research did not collect data on GHG emissions occurring from the production of transmission pipelines. The GHGenius model considers this aspect based on the data from a Dutch study (see [13]). However, this aspect was not further considered by the EXERGIA study. It can be assumed that the results are of limited significance for the determination of the carbon footprint. This is due to the long lifetime of the pipelines. The manufacture of compressors and other facilities in the gas grid are also not considered.

Gas Distribution within Central EU

As in the EXERGIA study, the energy demands of gas pressure regulating and measuring stations are not considered by this study. This information is of limited relevance to the final results.

Data Availability

The study shall be based on the newest available data. Since the national inventory report (NIR) used for the United Nations Framework Convention on Climate Change in 2015 will not be published until 2017, and since several important data sources continue to use data from 2014, it was decided that the latest year for all calculations in this study would be 2014.

2.2.8 Type of Critical Review

Due to time limitation, a critical review was not carried out as part of this project. However, the report is prepared to be reviewed after the project.

3. Inventory Analysis

3.1 Data Collection

3.1.1 General Remarks

An excel spreadsheet had been prepared for the collection of primary data from the operator companies. The data sheet had to be filled out with all necessary input data needed for GHGenius. Because not all operators were able to provide data in the required format, additional data sources were used and prepared as input data for the model. Detailed information about these can be found in Section 3.1.2 to 3.1.5.

The following companies or associations supported the project by completing the excel spreadsheet or providing data in other formats, finding the right contact persons and alternative data sources and giving expert advice:

- Bundesverband Erdgas, Erdöl und Geoenergie e.V. (BVEG)
- E.ON
- ExxonMobil
- Fernleitungsnetzbetreiber Gas e. V. (FNB Gas) and the German TSO
- Gassco
- Gasunie
- Gazprom
- International Association of Oil & Gas Producers (IOGP)
- Naftogaz
- Norwegian Oil and Gas Association (NOROG)
- OMV
- Shell
- Statoil
- Uniper
- Wingas
- Wintershall

Separate analysis of oil and gas production is often a challenge. A lot of the data on energy demands and emissions is not collected separately for gas production, but is rather recorded as a summary of oil and gas production. In order to achieve independent data for gas production, an allocation according to energy content is, where necessary, undertaken (see Chapter 2.2.4).

As certain data sources are provided using other data units, the original data is, in part, converted so as to be compatible with the GHGenius model. The conversion of the country-specific data is carried out using certain country-specific key values (e.g. upper heating value, or gas pressure). These key values are specified in Annex 2.

Data collection is explained in further detail in 3.1.2 using the example of Germany to describe the basic approach. For the data collection from the Netherlands, Norway, and Russia (section 3.1.3 to 3.1.5 only the differences in data sources or approach will be explored further.

3.1.2 Germany

3.1.2.1 Production

Data for natural gas production in Germany was taken from the annual national energy balances from 2012 to 2014 [14]. These reports include information on the domestic production of natural gas, flaring, and energy consumption for oil and gas extraction. Since the following study focuses solely on natural gas production, it is necessary to make an assumption in order to determine the share of energy consumed in the natural gas production process. This assumption was reached by determining the amounts of natural gas, oil, and liquid natural gas for the years in question, and then calculating their energy shares of the total production. These energy shares were applied to the total oil and gas production to determine the share of energy demand which should be allocated to the natural gas production (=allocation based on energy content, ref. 2.2.4).

The data for consumption of diesel, natural gas, and flare gas (in PJ) in the production of natural gas is based on net calorific values (lower heating values) and is then re-calculated to determine the gross calorific value (upper heating value). For diesel the ratio 1.07[12] is used, and for natural gas 1.108[13]. In order to enable direct comparison with the EXERGIA study, the data has to be re-calculated from the unit used in the data source PJ into the unit used in the EXERGIA study kJ/t. To achieve this, the natural gas production as part of the annual energy balances for the years 2012-2014 was determined and the given units (MJ) were then re-calculated into tons. Flaring volumes, as in the EXERGIA study, are considered as natural gas consumption and not calculated separately.

$$Specific\ Energy\ Consumption\ Gas\ Production = \frac{Energy\ Consumption\ Gas\ Production}{Amount\ of\ Gas\ Produced} \cdot Share\ of\ Production \tag{3.1}$$

$Specific\ Energy\ Consumption\ Gas\ Production\ [kJ/t]$
$Energy\ Consumption\ Gas\ Production\ [kJ]$
$Amount\ of\ Gas\ Produced\ [t]$
$Share\ of\ Production\ [-]$

Specific methane emissions for production could be taken from the annual reports of the Federal Gas, Oil, and Geothermal Energy Association (BVEG) [15]. The data is reported in tCH_4/natural gas were, with the densities of methane and natural gas, re-calculated into m^3 and subsequently into a percentage. An overview of all input data for production is provided below in Table 2:

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[12] The value is taken from the GHGenius model.

[13] The “AG Energiebilanzen” suggests to use a value of 0.90238 for conversion of values from the net calorific value to the gross calorific value [62]. This equals to a value of 1.108 when multiplied instead of divided (1 / 0.90238 = 1.108).

Table 2: Input Data Gas Production - Germany

Germany	Gas Production									
	Crude oil	**Diesel fuel**	**Residual fuel**	**Natural gas**	**Coal**	**Electricity**	**Gasoline**	**Coke**	**Total**	**Gas lost**
	$[kJ_{consumed}/t_{produced}]$									[%]
2012 DBI	0	582	0	840,702	0	220,418	0	0	1,061,702	0.0225%
2013 DBI	0	500	0	945,830	0	205,766	0	0	1,152,096	0.0216%
2014 DBI	0	2,293	0	1,120,379	0	251,229	0	0	1,373,901	0.0189%

Source: Own calculation DBI based on [14], [15]

According to the BVEG, methane emissions in Germany are low due to the high environmental standards, sustainable approaches, and the technical integrity of facilities. For many years Germany has invested in innovative technologies. A further reason for the low emissions values is the general avoidance of flaring in oil and natural gas production. As a result German flare gas volumes account for only 0.1 % of total natural gas production. [15]

3.1.2.2 Processing

For the energy consumption of gas processing data from the BVEG are used (Table 3). It shows the amount of natural gas (in kWh) which is necessary to process 1,000 m³ of natural gas.

Table 3: Energy Consumption Gas Processing

Year	Specific Energy Demands for Gas Processing $[kWh_{NG}/1000m^3_{NG}]$
2012	197*
2013	197
2014	164
* For 2012 the figure from 2013 has been used as no data was available for this year.	

Source: BVEG [16]

Multiple products are created during gas processing (processed natural gas as well as elementary sulphur[14]). It is therefore practical to use an allocation process in this case. According to the recommendations of the BVEG, 1/6 of the energy demand for gas processing should be assigned to sulphur production, and 5/6 should be assigned to the processing of natural gas [16]. The resulting values are displayed in Table 4. This table also displays the data in kJ/t: the unit required for utilization by GHGenius.

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[14] During Acid gas processing H_2S is separated and converted to elementary sulphur, which can be sold afterwards.

Table 4: Energy Consumption Gas Processing – Germany – adapted and converted

Year	Specific Energy Consumption of Gas Processing [kWh/1000m³$_{NG}$]	Specific Energy Consumption of Gas Processing [kJ$_{konsumiert}$/t$_{produziert}$]
2012	164*	788,000
2013	164	788,000
2014	137	656,000
* For 2012 the figure from 2013 has been used as no data was available for this year.		

Source: Own calculation DBI based on [16]

For the electricity demands for gas processing the data (30,000 kJ/t natural gas) has been taken from the EXERGIA study as this data has thus far neither been verified nor corrected.

Gas losses during gas processing are determined using the NIR 2016 [17]. In the NIR methane emissions are given as an absolute value in Gg. By using the density of CH_4, it is possible to convert this data into m^3. The specific methane emissions or the gas losses as a percentage are calculated using the total amount of natural gas produced. This calculation has already been used in section 3.1.2.1. The formula in 3.2 shows the relationship between these factors. The total amount of natural gas produced is also converted into m^3 using the gross calorific value.

$$Specific\ Methane\ Emissions = \frac{Methane\ Emissions}{Production\ Volume} \tag{3.2}$$

Specific Methane Emissions [%]
Methane Emissions [m^3CH_4]
Production Volume [m^3NG]

An overview of the input data for gas processing is provided in Table 5.

Table 5: Input Data Gas Processing – Germany

Germany	Gas Processing									
	Crude oil	Diesel fuel	Residual fuel	Natural gas	Coal	Electricity	Gasoline	Coke	Total	Gas lost
	[kJ$_{consumed}$/t$_{produced}$]									[%]
2012 DBI	0	0	0	788,000	0	30,000	0	0	818,000	0.016
2013 DBI	0	0	0	788,000	0	30,000	0	0	818,000	0.016
2014 DBI	0	0	0	656,000	0	30,000	0	0	686,000	0.016

Source: [1] and own calculation DBI based on [16], [18]

Vented CO_2 emissions are relevant for gas processing, too. In particular the CO_2 emissions occurring during acid gas processing are of relevance. According to the BVEG the CO_2 emissions resulting from acid gas processing in 2012 were 0.3597 $t_{CO2}/t_{acid\ gas}$ or converted to a percentage related to the total amount of natural gas produced[15] in Germany 5.81% were acid gas. However, the BVEG

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[15] Calculation in Annex 4.

recommends that only 5/6 of the emissions from acid gas processing shall be attributed to natural gas[16]. The resulting values are displayed in Table 6.

Table 6: Vented CO_2 Emissions - Germany

Year	Vented CO_2 [%]
2012	4.84
2013	5.56
2014	4.41

Source: Own calculation DBI based on [15]

3.1.2.3 Transmission, Storage and Distribution

For gas transmission, data from the German transmission system operators (TSO) is used. Data was made available by all TSO. In this study weighted mean values are provided.

Energy demands for gas transport are, as in the EXERGIA study, stated in $J_{consumed}/J_{transported}\cdot km$. The TSO provided data for the absolute energy demands of gas transport. This was converted into a specific demand using the transported gas volume (also provided by the TSO) and an average transport distance of 300 km[17].

$$\mathit{Specific\ Energy\ Demands\ Gas\ Transmission} = \frac{\mathit{Absolute\ Energy\ Demands\ for\ Gas\ Transport}}{\mathit{Transported\ Gas\ Volume} \cdot \mathit{Transport\ Distance}} \qquad (3.3)$$

Specific Energy Demands for Gas Transmission $[J_{consumed}/J_{transported}\cdot km]$
Absolute Energy Demands for Gas Transmission [J]
Transported Gas Volume [J]
Transport Distance [km]

The data for methane emissions during gas transport was also provided by the TSO. This was then converted using the transport gas volume (Formula 3.4).

$$\mathit{Specific\ Methane\ Emissions\ Gas\ Transmission} = \frac{\mathit{Absolute\ Methane\ Emissions\ for\ Gas\ Transmission}}{\mathit{Transported\ Gas\ Volume}} \qquad (3.4)$$

Specific Methane Emissions for Gas Transmission[-]
Absolute Methane Emissions for Gas Transmission[J]
Transported Gas Volume [J]

The methane emissions data provided by the TSO only includes planned gas release for repair or maintenance work. Gas release through leakage of pipelines, their associated facilities, and compressors is not included. The data in Table 7 has, therefore, been marked up by 30 %. This mark-up was is concurrent with the Russian data, which separates planned gas release and gas release as a result of leakage. This approach was approved by the TSO but was viewed by them as a conservative estimate.

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[16] Explanation in Section 3.1.2.1

[17] This data is based on the average transport distance from the gas entry point to the distribution network. This approach, as well as the values, are taken from the EXERGIA study. [1, p. 190].

$$Mark - Up = (Emissions_{Transport\ Pipelines} + Emissions_{Compressors}) \cdot 0{,}3 \tag{3.5}$$

$$Fugitive\ Emissions = Emissions_{Transport\ Pipelines} + Emissions_{Compressors} + Mark - Up \tag{3.6}$$

TSO also provided data for the electrical energy required to power the compressors each year. It is therefore possible to determine which part of gas transport energy takes place electrically.

Data for gas distribution was taken from the NIR 2016 for the years 2012 - 2014 [17]. The conversion of this data occurs in the same manner as described for gas processing in 3.1.2. The underlying natural gas consumption data was taken from the annual energy balances for Germany [14].

$$Specific\ Methane\ Emissions\ for\ Gas\ Distribution = \frac{Absolute\ Methane\ Emissions\ for\ Gas\ Distribution}{Gas\ Consumption}$$

(3.7)

Specific Methane Emissions Gas Distribution [-]
Absolute Methane Emissions Gas Distribution [$m^3 CH_4$]
Gas Consumption [m^3NG]

The input data for natural gas transport and distribution is provided in Table 7.

Table 7: Input Data Gas Transmission and Distribution - Germany

Germany	Gas Distribution	Gas Transmission			
	Loss Rate	Transmission Energy	Distance	% electric[18]	Loss Rate
	[-]	[$J_{consumed}/J_{transported}\cdot km$]	[km]	[%]	[-]
2012 DBI	0.00143	0.000010	300	1.91	0.000095
2013 DBI	0.00137	0.000010	300	2.19	0.000054
2014 DBI	0.00156	0.000009	300	1.22	0.000058

Source: [1] and own calculation DBI based on [14], [17], [19], [20]

3.1.3 Netherlands

The input data for calculation of carbon footprint which is relevant for the Netherlands is described in the following sections. A tabular overview is provided in Annex 5 to Annex 7. Information on the conversion of data is provided in Annex 2.

3.1.3.1 Production

Data for natural gas production in the Netherlands and for the energy demands of natural gas production for the years 2012 – 2014 was taken from the national energy balances [21].

The CH_4 emissions for the years 2012 - 2014 was taken from the Dutch NIR 2016 [22]. The data for oil and gas production are provided in an aggregated form. An allocation according to energy content was, therefore, carried out. A percentage was calculated from the absolute data based on the gas volume produced (Formula 3.8).

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[18] This is the term of GHGenius, which means the share of compressors, which are driven electrically.

$$Specific\ Methane\ Emissions\ Gas\ Production = \frac{Methane\ Emissions\ for\ Gas\ Production}{Production\ Volume} \cdot Share\ of\ Production \quad (3.8)$$

$Specific\ Methane\ Emissions\ for\ Gas\ Production\ [\%]$
$Methane\ Emissions\ for\ Gas\ Production\ [m^3]$
$Production\ Volume\ Natural\ Gas\ [m^3]$
$Share\ of\ Production\ Natural\ Gas\ [\%]$

The calculation for Dutch gas production follows the same approach as described for the German calculation.

3.1.3.2 Processing

The Dutch gas industry provided values for electrical energy demands for gas transmission in the Netherlands in the years 2012 – 2014 [23]. These values include the energy demands for the production of nitrogen, which is necessary for the conditioning of natural gas. As a result, these values should be allocated to gas processing. This approach is described in 3.1.3.3.

The absolute value was determined based on the volume of gas produced as recorded in the energy balance (see 3.1.3.1) and then converted into the required units.

Gas losses from gas processing are assumed to be nil. This conclusion was drawn since the losses were not separately recorded in the NIR. It is, therefore, assumed that these losses have been included in the production losses.

The vented CO_2 emissions are derived from the NIR 2016 [22] and, as with methane emissions for production, were converted into a percentage based on the volume of gas produced (Formula 3.9).

$$Specific\ CO2 - Emissions\ for\ Gas\ Processing = \frac{CO2\text{−}Emissions\ for\ Gas\ Processing}{Production\ Volume} \cdot Share\ of\ Production \quad (3.9)$$

$Specific\ CO2 - Emissions\ for\ Gas\ Processing\ [\%]$
$CO2 - Emissions\ for\ Gas\ Processing\ [m^3]$
$Production\ Volume\ Natural\ Gas\ [m^3]$
$Share\ of\ Production\ Natural\ Gas\ [\%]$

3.1.3.3 Transmission, Storage and Distribution

Information on the energy demands for gas transmission was taken from the annual reports of the Dutch gas industry [24, pp. 27, 55] [25, pp. 26, 33] [26, pp. 17, 31]. Energy demands for transmission are made up from gas consumption, and electricity consumption. This data is provided separate from one another in the annual reports of the Dutch gas industry. These values also include the energy demands for the production of nitrogen, for the liquefaction and the storage of natural gas, and also for the energy for facility operation. The individual proportions for this are not public available. However, as part of the research for this study, the share of energy demands for gas transmission for one year became known. According to the Dutch operators, 230,000 MWh_{el} were necessary in 2015 for the gas transport and this value is seen to be representative for the years 2013 and 2014, too [27]. This proportion of the energy demands was assigned to the share for gas transmission, all outstanding demands were assigned to gas processing. The liquefaction of gas, however, is not within the remit of this study, and it is unclear which proportion of the energy used for facility operation can be assigned to the product natural gas. The evaluation of these aspects would not have fit within the time-frame, or general scope of this project. As a result, a conservative approach has been taken, which includes the entire energy demands.

Energy consumption for gas transport per kilometre is determined by the average transport distance (as by EXERGIA), and by the ratio of energy demand to transported volume of gas (Formula 3.3).

The annual reports of the Dutch gas industry also include data on methane emissions. This was converted into a percentage based on the transported volume of gas. The formula used is the same as that used for Germany (3.4).

Methane emissions for gas distribution were taken from the NIR 2016. The conversion was carried out using Formula 3.7.

3.1.4 Norway

The input data for calculation of CF which is relevant for the Norway is described in the following sections. A tabular overview is provided in Annex 8 to Annex 10. All relevant conversion data are displayed in Annex 2.

3.1.4.1 Production

Data on the energy demands for natural gas production are taken from the Norwegian national energy balance [28]. The calculation methodology is identical to that already described for Germany.

The methane emissions for the years 2012 – 2013 were taken from the NIR 2016 [29] and, as with the EXERGIA study, divided equally: half for gas production, and half for gas processing. For 2014, the data published in [30, p. 1] are used due to an update in the calculation method.

The Norwegian emissions data for oil and gas production has also been recorded in aggregated form. Here too, an allocation procedure is used.

3.1.4.2 Processing and Transport to the Borders of Central EU

When accessing the available sources for Norwegian data, it is extremely difficult to differentiate between gas transport and gas processing. This is because the gas compression necessary for gas transport already occurs within the gas processing facilities. In addition there are no values for gas processing in its entirety, only for the individual processing facilities. These facilities also produce other products (e.g. condensate) in addition to natural gas. Data for gas transport has already been made available for this study by the Norwegian gas industry. However, this data could not be used without first adjusting it to also consider gas processing. This task was beyond the time-frame provided for this study. In conclusion it was decided to use the values provided in the EXERGIA study for 2012 [1, p. 216][19] for all the years considered by this study, both for gas transport and gas processing. The data provided by the Norwegian gas industry shall be used in following projects.

The determination of gas losses during gas processing has already been described for gas production (see 3.1.4.1). The methane emissions for gas transport are also included in the emissions for gas production. It can also be assumed that there will only be minimal losses along the gas

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[19] The EXERGIA-Study states a value of von 0.00001 J/J·km [1, p. 216] According to the agents, a value of 0.000015 J/J·km has been separated from the gas processing data to determine the energy consumption of gas processing [71]. Hence, the gas processing data are only correct in connection with the value of 0.000015 J/J·km. The available comparing data are similar (section 3.2.3).

transport pipelines in the export corridor as these pipelines are located under water and have no interim compressor stations.

Data for gas processing were, as well as the data for gas production, allocated according to the energy content.

Vented CO_2 emissions were taken from the NIR 2016 [29] and determined according to Formula 3.9.

3.1.5 Russia

The relevant input data for the calculation of the CF, which are relevant for Russia, can be found in tabular form in Annex 11 to Annex 13. Information on conversion data can be found in Annex 2.

For the natural gas supply of Central EU, three different export corridors are considered:

1. The “Ukrainian Corridor” or Russia 1, consisting of the pipelines “Urengoy – Uzhgorod”, ”Elets – Kremenchug – Krivoy Rog” and “Progress” (GIS Sudzha)
2. The “Belarussian Corridor” or Russia 2, consisting of the pipeline “Yamal – Europe” (GIS Kondratki)
3. The “Northern Corridor” or Russia 3, representing the gas transmission within the corridor from Bovanenkovo till Greifswald, including the “Nord-Stream Pipeline”.

A weighted average (Russia 4) is created from the values for the three corridors considering the distribution of the amount of gas exported.

Data is available for all years considered in this study.

3.1.5.1 Production and Processing

The energy consumption during gas production in Russia is presented for the years 2013-2015 at the “State report on energy-saving and on improvement of energy efficiency in the Russian Federation in 2015” which is publicly available from the Ministry of Energy of Russia [31]. For this report, additional explanation and data from the Russian operators were provided upon request to relate the energy consumption of the gas production to the three considered export corridors. The specific energy consumption of gas production was determined according to formula 3.1, whereas a conversion of the primary data was done with the conversion data in Annex 2. The necessary primary data for this calculation are shown in Annex 14, the flared amount of gas was considered as energy consumption, as done for all other countries, too.

Energy demands and gas losses during gas processing in Russia have been assumed as nil since these are already included in data for gas production.

Since methane is classified as a pollutant in Russia (see list of pollutants under state control, No. 33 [32]), methane emissions need to be recorded and reported to the authorities. The methane emissions are estimated with the annual federal statistical data sheet № 2-TP (air) (ref. [33]). The completed forms must be sent to the Russian Federal State Statistic Service. This published data forms the basis to charge an environmental tax to the responsible polluter. The completed forms and charged environmental tax are checked by the Russian Federal Supervisory Natural Resources Management Service (ref. [34]) during regular inspections and audits. On the website of the Russian Federal State Statistics Service the hydrocarbon emissions of different sectors are published regularly (ref. [35]). Although methane emissions of Russian gas industry are available on this website, feedback was needed from the Russian operators in order to have the granularity for this study. Data collected with the questionnaire for gas production and transport (ref. section 3.1.1) is shown in Annex 14. Data derived from this questionnaire and used as input data for GHGenius is presented in Annex 11.

Vented CO_2 emissions are determined using data from the national inventory report [36]. The approach used has already been described in section 3.1.3.2.

All input data for GHGenius relevant for the Russian gas production and processing are shown in Annex 11 and Annex 12.

3.1.5.2 Transport to the Central EU Borders

Data for the specific energy demands of gas transport are also available in the "State report on energy-saving and on improvement of energy efficiency in the Russian Federation in 2015" [31]. Again, additional information and data from the Russian gas grid operators was provided to relate the data to the three different corridors. The original data is shown in Annex 14. It needs to be converted from the original unit [$m^3/(10^6 m^3 \cdot km)$] to the unit used in GHGenius [$J_{consumed}/(J_{transported} \cdot km)$] (Annex 13). The data was validated, among others, by data which is publicly available from the Ministry of Energy of Russia (see section 3.2.3).

The data on methane emissions of the gas transport system are determined in analogy to the data of gas production (section 3.1.5.1) and are presented in Annex 14.

The methane emissions are transformed into a percentage with formula 3.4 using the total exported gas volume in the individual years. The amount of exported gas is measured by different gas metering stations which are located at the export corridors considered in this study (Table 8).

Table 8: Amount of Gas Transported to Europe

Metering station	Amount of gas transported [$10^9 m^3/a$]			In this study related to
	2012	2013	2014	
Sudzha	62.98	62.41	42.92	Ukrainian Corridor (Russia 1)
Kontratki	29.02	34.69	34.64	Belarussian Corridor (Russia 2)
Portovaya	11.86	23.77	35.55	Northern Corridor (Russia 3)

Source: [37]

In order to correctly determine the carbon footprint of Russian gas in Central EU, the losses in Belarus and Ukraine (which are outside of Central EU) need to be taken into account. The data for Belarus is already included in [37]. However, for Ukraine, there was no suitable data available[20] for the determination of GHG emissions caused by the gas transport across Ukraine. For this reason, the emissions were estimated with the Russian data. It was assumed, that the energy consumption for gas transport and the loss rate of gas transport were comparable with those of Russia. For this

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[20] The Ukrainian grid operators submitted data upon request but this data was on a high level of aggregation and could, therefore, not be used as input data for this study. It is, however, used for comparison and presented in section 3.2.3.

reason the values of the specific energy consumption of the gas transport for Russia (Annex 13) were taken into account.

The calculation of gas losses was preformed based on a coefficient, determined from the Russian data (see Annex 16).

The precise lengths of the three export corridors were also provided by the Russian grid operators and shown in Annex 14. As the length of the transport pipelines in the Ukrainian Corridor is not included in the statistics, this corridor is prolonged by 1,160 km [38] to consider the transport distance to the border of Central EU.

In order to determine the carbon footprint for the system of „Natural Gas distributed in Germany“, it is necessary to adjust the lengths of the Russian pipelines and to extend these distances to include countries in Central EU between Russia and Germany. The lengths of the pipelines in these countries were researched on the internet and using the VGE pipeline map [39]:

- Poland: 684 km [40]
- Slovakia: 410 km [39]
- Czech Republic: 350 km [39]

3.1.6 Natural Gas Supply Structure

In order to allocate consumed natural gas in Central Europe to its corresponding producers and, therefore to its corresponding carbon footprint, the differing origins of the total consumed natural gas were calculated. The data basis for this is data from the International Energy Agency (IEA), which was derived from the Annual Gas Statistics database of the IEA/OECD.

For the years 2013 and 2014, the data was taken from the latest report from the IEA [9]. Data for 2012 was downloaded from the OECD Library [41].

To calculate the supply structure, the amount of imports and domestic production for each individual country considered in the study are combined. This total amount (imports + domestic production) is then used to determine the percentage of natural gas derived from each individual source country. The percentages in these national gas mixes are then multiplied by the total annual natural gas consumption of the country. By now combining the resulting absolute consumption figures for each country within the central Europe region, we are able to determine the source countries and their individual contribution to the central European gas mix.

In order to calculate the amount of Russian natural gas entering Germany via different routes, the proportional volume of the gas trade flow at the different border crossings into Germany in the years 2012-2014 is calculated. This data was taken from the IEA database “Gas Trade Flows in Europe” [42].

The proportional energy consumption for the countries of the central Europe region and the allocated countries of origin are displayed in Annex 17.

The calculation of the individual energy consumption as a proportion of the total energy consumption in central Europe is also derived from data from the IEA [9, pp. II.8-II.9]. The input data for these parameters is displayed in Annex 18.

3.2 Data Validation

In order to validate the data collected for the individual countries as displayed in 3.1, this data is subsequently compared with data from other sources and evaluated. The data from the EXERGIA study will also be compared in this manner in order to analyse differences. Where the same data has been used as in the EXERGIA study, it is generally recognised that minor discrepancies may arise as a result of different calculation methods. Conversion calculations in this study are made according to the country-specific information as displayed in Appendix 1. The EXERGIA study does not explicitly describe which net/gross calorific heating values, densities etc. was used to convert data.

The values used to determine the carbon footprint of natural gas, which were previously introduced in 3.1, are shown in bold in the tables.

3.2.1 Germany

3.2.1.1 Production

Table 9 shows the comparable data for gas production in Germany. The data for energy demands of the gas production is almost identical to the data in the EXERGIA study. The minor discrepancies can be accounted for by the differing calculation methods, as mentioned above.

Greater differences can be observed in the gas losses during gas production. A possible reason for this is that gas losses in the EXERGIA study were based on the volume of natural gas consumed. In the study at hand, gas losses are based on the volume of natural gas produced.

The EXERGIA study also used data sourced from the NIR. When using this data in relation to production (rather than consumption, as was the case in the EXERGIA study), the values are similar to those calculated by BVEG.

Table 9: Comparison of Data for Gas Production – Germany

Germany	**Gas Production**									
	Crude oil	**Diesel fuel**	**Residual fuel**	**Natural gas**	**Coal**	**Electricity**	**Gasoline**	**Coke**	**Total**	**Gas lost**
	[kJ$_{consumed}$/t$_{produced}$]									[%]
2012 GHGenius	0	596	0	880,055	0	227,756	0	0	1,108,407	0.3400
2012 EXERGIA report	0	596	0	880,055	0	227,756	0	0	1,108,407	0.0030
2012 DBI	**0**	**582**	**0**	**840,702**	**0**	**220,418**	**0**	**0**	**1,061,702**	**0.0225**
2013 DBI	**0**	**500**	**0**	**945,830**	**0**	**205,766**	**0**	**0**	**1,152,096**	**0.0216**
2014 DBI	**0**	**2,293**	**0**	**1,120,379**	**0**	**251,229**	**0**	**0**	**1,373,901**	**0.0189**

Source: [1], [43] and own calculation DBI based on [14], [15]

3.2.1.2 Processing

The input data for the calculations as displayed in Table 10 and Table 11 is collected from various sources. Minor differences can be observed in the energy demands for gas processing. These values were only estimated in the EXERGIA study. The information on natural gas demands in this study was based on data from BVEG. BVEG did not provide data on electricity demand and, as a result, the values displayed in the EXERGIA study were used.

Gas losses during gas processing were determined using the NIR 2016. The EXERGIA study collected this data from the NIR 2014. The NIR 2014 did not yet differentiate between gas production and gas processing and, as a consequence, the gas losses during gas processing were recorded as nil in the EXERGIA study. The carbon footprint of natural gas as ascertained by the EXERGIA study was, in this point, based on a value of 0.2 %. This appears to be a typing error.

Table 10: Comparison of Data for Gas Processing – Germany

Germany	Gas Processing									
	Crude oil	Diesel fuel	Residual fuel	Natural gas	Coal	Electricity	Gasoline	Coke	Total	Gas lost
	[kJ$_{consumed}$/t$_{produced}$]									[%]
2012 GHGenius	0	0	0	1,000,000	0	30,000	0	0	1,030,000	0.200
2012 EXERGIA report	0	0	0	1,000,000	0	30,000	0	0	1,000,000	0.000
2012 DBI	**0**	**0**	**0**	**788,000**	**0**	**30,000**	**0**	**0**	**818,000**	**0.016**
2013 DBI	**0**	**0**	**0**	**788,000**	**0**	**30,000**	**0**	**0**	**818,000**	**0.016**
2014 DBI	**0**	**0**	**0**	**656,000**	**0**	**30,000**	**0**	**0**	**686,000**	**0.016**

Source: [1], [43] and own calculation DBI based on [15], [17]

In order to calculate vented CO_2 emissions in 2012, the EXERGIA study uses information from the NIR 2014. For the determination of CO_2 emissions during acid gas processing, an emission factor of 0.23 $tCO_2/1000m^3$ natural gas [44, p. 266] from Austria is used since the acid gas processing facilities in Austria and Germany are comparable.

The conversion of the BVEG value of 0.3597 tCO2/t acid gas (after subtracting the 1/6 share of the value assigned to sulphur production) results in an emission factor of 0.24 $tCO_2/1000m^3$. This value is comparable to the value used in the Germany NIR. Accordingly, the input value for 2012 as used by this study is comparable to the values used by the EXERGIA study.

Table 11: Comparison of Data for Vented CO_2– Germany

Germany	Vented CO_2
	[%]
2012 GHGenius	5.30
2012 EXERGIA report	5.30
2012 DBI (source BVEG)	**4.84**
2013 DBI (source BVEG)	**5.56**
2014 DBI (source BVEG)	**4.41**

Source: [1], [43] and own calculation DBI based on [18]

3.2.1.3 Transmission, Storage and Distribution

Table 12 shows the comparative data for gas transmission and distribution in Germany. The input data for the energy demands of gas transmission in the EXERGIA study is very similar to the data calculated by DBI based on the NIR. However, this data is very different from the data provided by the TSO. The main cause of discrepancy is that the data used by EXERGIA and in the NIR is based on the consumed volume of gas in Germany. In comparison the data from the TSO is based on the total amount of gas transported. Since Germany is an important gas transit land, the amount of gas transported is considerably higher than the amount consumed. Even the EXERGIA study recognised that calculations based on the amount of gas consumed would, therefore, lead to higher values [1, p. 190].

Data on gas losses during gas transport is also recorded as far higher in the EXERGIA study than is recorded by the TSO. This is, in part, due to the data being based on total consumption volume, rather than total transport volume, as previously stated. However, the TSO also record considerably less gas loss than is recorded in the NIR. Data from TSO only includes losses from planned gas release. Nonetheless, by reviewing other data sources (3.1.2.3), it can be presumed that planned gas release is responsible for the majority of gas losses. In addition, the data from TSO was further adapted by a conservative 30 % increase. As a consequence, this data is generally considered to be more representative than the data used in the NIR.

Further validation of the data from the TSO also showed that neither methane emissions nor energy demand of gas storage were included. This is because the TSO are not generally responsible for the storage of natural gas in underground storage facilities. This is normally the responsibility of the storage operators. The data from the TSO does not cover the system parameters for gas storage as defined in section 2.2.3. Since the storage phase of the life cycle is of limited relevance to the final carbon footprint for natural gas distributed in Germany and Central EU[21], no further data was collected.

No data on the demand for electrical energy for gas transport is provided in the NIR. As a result the EXERGIA study listed this value as nil. This shortcoming could be filled using data from the TSO.

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[21] The Norwegian Oil and Gas Association reports in its environmental report of the year 2015 that the methane emissions of gas storage contribute 1 % to the overall methane emissions of the oil and gas industry [63, p. 35]. A sample calculation for validation of the significance of storage on the CF result is given in Annex 3.

The EXERGIA study used the NIR 2014 for data on gas distribution, while this study uses the 2016 version of the NIR. The NIR 2016 represents a change in methodology to previous reports. Among other things, updated emission factors are used to determine data for gas distribution. These emission factors are based on newly developed research into the damage frequency of pipelines. As a result, the values for 2012, as calculated by the NIR 2016 are considerably lower than the values calculated by the NIR 2014.

The data for methane emissions from the German NIR contains also information about methane emissions of natural gas refuelling stations. These refuelling stations are not considered in this study. A separation of the data was not adequate because of the limited timeframe and the certainly marginal influence on the result.

Table 12: Comparison of Data for Gas Transmission and Distribution – Germany

Germany	Gas Distribution	Gas Transmission			
	Loss Rate	Transmission Energy	Distance	% electric[22]	Loss Rate
	[-]	[$J_{consumed}/J_{transported} \cdot km$]	[km]	[%]	[-]
2012 GHGenius	0.00378	0.000025	300	0	0.000254
2012 EXERGIA report	0.00378	0.000025	300	0	0.000254
2012 DBI (NIR 2014)	0.00299	0.000023	300	0	0.000257
2012 DBI (NIR 2016)	0.00143	0.000023	300	0	0.001209
2013 DBI (NIR 2016)	0.00137	0.000026	300	0	0.001172
2014 DBI (NIR 2016)	0.00156	0.000024	300	0	0.001349
2012 DBI	**0.00143**	**0.000010**	**300**	**1.91**	**0.000095**
2013 DBI	**0.00137**	**0.000010**	**300**	**2.19**	**0.000054**
2014 DBI	**0.00156**	**0.000009**	**300**	**1.22**	**0.000058**

Source: [1], [43] and own calculation DBI based on [14], [17], [19]

3.2.2 Netherlands

A tabular overview of the input and comparative data required for the calculation from further sources is provided in Annex 5 to Annex 7.

The NIR 2014 was used in order to compare the data quality. The values for 2012 as recorded in the NIR 2014 are identical, or differ only slightly, to the same data in the NIR 2016.

Minor differences can be observed for the energy demands for gas production as the data from the energy balance has been updated since the EXERGIA study.

The value for gas loss during gas production as recorded in the EXERGIA study differs from the same value recorded by GHGenius by a factor of 10. Due to the dimension of the reference data, it seems likely that the value in the report is correct and the value in the model is distorted by a typing error. On enquiry with (S&T)²-Consultants it has been confirmed that the input data in the model have not been correct at this point and the later versions of GHGenius have been adapted in this regard.

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[22] This is the term of GHGenius, which means the share of compressors, which are driven electrically.

Considerable discrepancy can be observed in the energy demands for gas transmission. The values in both the EXERGIA study and the DBI study are based on data by the Dutch gas industry. However, the EXERGIA study uses the NIR values for the total volume of gas transported. In this study the values were taken from the Dutch gas industry. Furthermore, the EXERGIA study did not divide the industry data between gas transport and gas processing. This division was carried out with the DBI data, which also explains the discrepancies in the data for gas processing.

Major differences are visible in relation to gas distribution. According to NIR 2016 [22, pp. 116, 118], new measurements were conducted on the natural gas pipelines. These new measurements resulted in lower emission factors. Consequently the methane emissions recorded in the NIR 2016 are less since lower emission factors were applied.

3.2.3 Norway

The input data applied for Norway (provided in Annex 8 to Annex 10) is largely the same as in the EXERGIA study since both studies used the same data sources[23]. Nonetheless a modification has been made regarding the calculation for gas transport. The results calculated by EXERGIA for the CF of natural gas include a value of $3.0 \cdot 10^{-5}$ $J_{consumed}/J_{transported} \cdot km$ for the energy demand during gas transport from Norway. However, in the report this value is stated as $1.0 \cdot 10^{-5}$ $J_{consumed}/J_{transported} \cdot km$ [1, p. 216].

Upon further questioning it was explained that no value had been recorded for energy demands for gas transport. Therefore, a value of $1.5 \cdot 10^{-5}$ $J_{consumed}/J_{transported} \cdot km$ was assumed and subtracted from the aggregated energy demands for gas transport and gas processing. As a result the reported data is only correct in relation to the value of $1.5 \cdot 10^{-5}$ $J_{consumed}/J_{transported} \cdot km$. Thus, this value was used in the calculations for this project. However, the data provided by the Norwegian gas grid operators implies that this value is too high. Furthermore, NOROG provided data from the EEH database (ref. [45]). This database includes, at least, data for the Norpipe. Since no data was available for the transported amount of gas, the design capacity (32 million m^3/d) [46] and a length of 443 km [46] was used to determine the specific transport energy consumption of the pipeline according to formula 3.3. It amounts to $1.05 \cdot 10^{-5} J_{consumed}/J_{transported} \cdot km$[24]. However, this could be too low, because the actual amount of gas transported is presumed to be lower than the design capacity.

The limited time-frame of this project did not allow for the collection of new data on gas processing and, therefore, the data of the EXERGIA-Study was used for the calculations in this study. This data is, as stated above, only correct with the transport energy of $1.5 \cdot 10^{-5}$ $J_{consumed}/J_{transported} \cdot km$, which could be too high as other data indicates. Further research is needed in this field.

The data for emissions from Norwegian oil and natural gas production was calculated in the NIR on the basis of emission factors from 1992. For the balance year 2014, the new emission factors for methane gas release for oil and natural gas production (as published in [30, p. 1]) were applied. These values are considered more robust than the values used in the NIR 2016 as the methodology was considered insufficient according to [47] because the pre-defined sources do not include all relevant sources and are somewhat inaccurate. The emissions were calculated in part by a newly-developed method, and in part using already-published modern methods. The recalculated

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[23] Note the utilization of the same input data as in section 3.1.4.

[24] The database states a diesel consumption of 91.72 t and a natural gas consumption of 53,983,948.26 m³ for the ýear 2012. For the conversion, a gross calorific value of 42.7 MJ/kg for diesel and of 40 MJ/m³ for natural gas was applied [42], [61].

emissions are based on a more comprehensive list of potential emissions sources as well as more accurate and up-to-date quantification methods.

3.2.4 Russia

An overview of the relevant comparative data is provided in Annex 11 to Annex 13.

A fundamental difference between the EXERGIA data on Russia and the data used in this study is that the EXERGIA study only generated a single data set because the applied data basis (the NIR) did not differentiate between the existing export corridors. Since the infrastructure differs considerably between the export corridors, this study considers three different transport routes (which reflects reality). In order to facilitate comparison with the data from the EXERGIA study, a fourth data set is created for each input value. This fourth data set constitutes a weighted average of the other three data sets.

Russian Gas Production – Energy Consumption

The Ministry of Energy of Russia publishes data on the “specific consumption of fuel and energy resources for production of goods, services” in its “State report of power saving and improving energy efficiency in Russian Federation” (ref. [31]). This report includes information of the specific energy consumption of gas production (Table 13)

Table 13: Specific Consumption of Fuel and Energy Resources for Production of Goods, Services in ton of coal equivalent/ ($10^3 m^3$)

Indicator	Specific consumption of fuel and energy resources for production of goods, services		
Unit	Ton of coal equivalent/ ($10^3 m^3$)		
Sector	Oil and gas		
Year	2013	2014	2015
Value	0.0176	0.0176	0.0177

Source: [31, p. 123]

The data from Table 13 can be converted[25] to the unit kJ/t so that it is comparable with the data used within this study (Table 14).

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[25] Numbers are converted using the following conversion factors taken from [64]: 1 kg coal equals 29.3 MJ and 1 t oil equals 41.868 GJ. Therefore, 1 t oil equivalent equals to 1.42894 t coal equivalent. 1 GJ correlates to 26.8 m^3 natural gas according to [64].

Table 14: **Specific Consumption of Fuel and Energy Resources for Production of Goods, Services in kJ/t**

Indicator	Specific consumption of fuel and energy resources for production of goods, services		
Unit	kJ/t natural gas		
Sector	Oil and gas		
Year	2013	2014	2015
Value	706,411	706,411	710,425

Source: Own calculations DBI based on [31, p. 123]

The values of Table 14 are in line with the input data used for GHGenius in this study.

Russian Gas Transport – Energy Consumption

Significant differences can be observed in the energy demand for natural gas transport outside of Central EU. The EXERGIA study applied a relatively high value of $4.5 \cdot 10^{-5}$ J/(J·km) and verifies this, among others, with a high compression ratio (1.45). This compression ratio was correct some years ago but decreased over time due to system improvements. Today, however, it is ranges between 1.3 – 1.36 according to latest data [48]. The Institute for Energy and Environmental Research (ifeu), in comparison, uses a value of $3.0 \cdot 10^{-5}$ J/(J·km) for the energy demand for gas transport. According to ifeu, this value is based on measurements by the Wuppertal Institute in 2003 [5]. The values applied in this study are between $2.05 \cdot 10^{-5}$ J/(J·km) (Northern Corridor 2014) and $3.03 \cdot 10^{-5}$ J/(J·km) (Ukrainian und Belarussian Corridor 2012). These values appear to be representative due to continually employed energy-saving measures by the Russian gas grid operators (see [49] and Figure 4). Moreover in the, “State report of power saving and improving energy efficiency in Russian Federation” from the Ministry of Energy in Russia data for the transportation of gas, oil and petroleum products is presented (Table 15). However, this data also includes transmission pipelines within Russia, not only designated export pipelines.

Table 15: **Specific Consumption of Fuel and Energy Resources for Production of Goods, Services in ton of coal equivalent/ (10^6m³·km)**

Indicator	Specific consumption of fuel and energy resources for production of goods, services		
Unit	ton of coal equivalent/ (10^6m³·km)		
Sector	transportation of gas, oil and petroleum products		
Year	2013	2014	2015
Value	0.0303	0.0268	0.0264

Source: [31, p. 123]

The data from Table 15 was converted[26] to the unit m³/(10⁶m³·km), so that they are comparable with the data used within this study (Table 16).

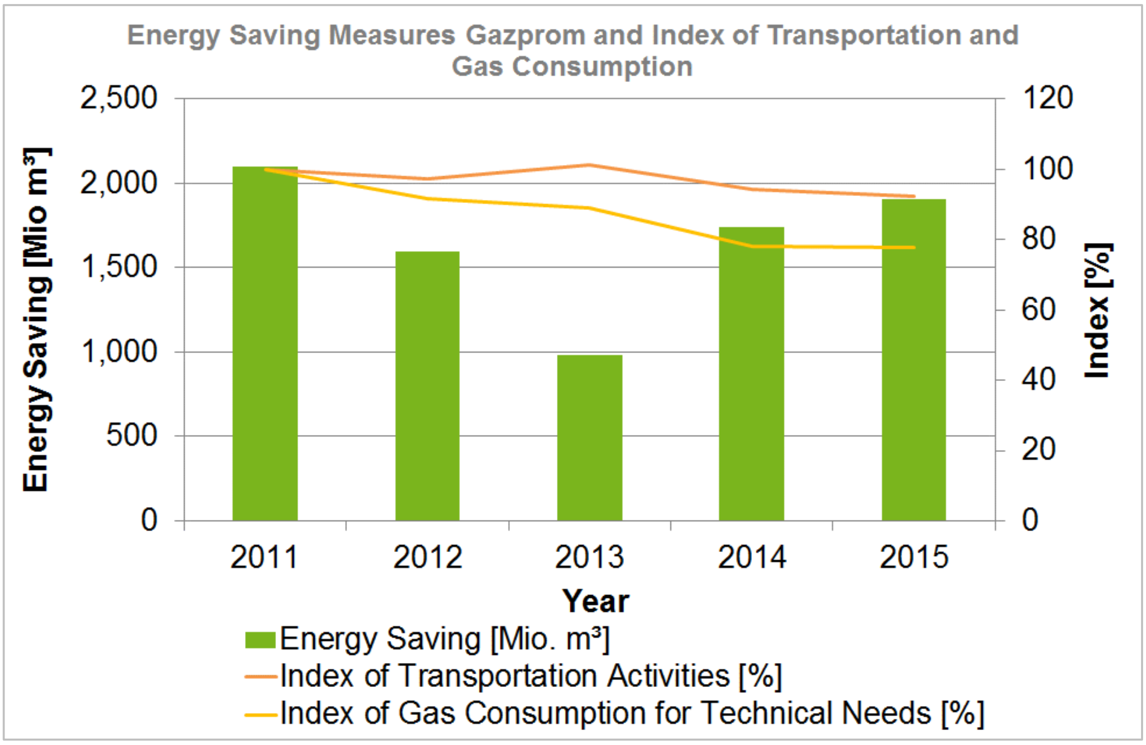
Table 16: **Specific Consumption of Fuel and Energy Resources for Production of Goods, Services in [m³/(10⁶m³·km)] and [J/(J·km)]**

Indicator	Specific consumption of fuel and energy resources for production of goods, services – Sector transportation of gas, oil and petroleum products	
Unit	m³/(10⁶m³·km)	J/(J·km)
2013	23.79	0.0000238
2014	21.04	0.0000210
2015	20.73	0.0000207

Source: Own calculations DBI based on [31, p. 123]

Like the public available data, the input data used in this study shows a clear reduction in the energy demands for transport from 2013 to 2015. A possible explanation for this is the reduction in the volume of gas transported. This leads to an improved efficiency (less losses due to reduced pipe friction).

Figure 4: **Energy Saving Measures of Russian Gas Operators**



Source: Own illustration DBI based on [49] and [50].

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[26] Numbers are converted using the following conversion factors taken from [64]: 1 kg coal equals 29.3 MJ and 1 t oil equals 41.868 GJ. Therefore, 1 t oil equivalent equals to 1.42894 t coal equivalent. 1 GJ correlates to 26.8 m³ natural gas according to [64].

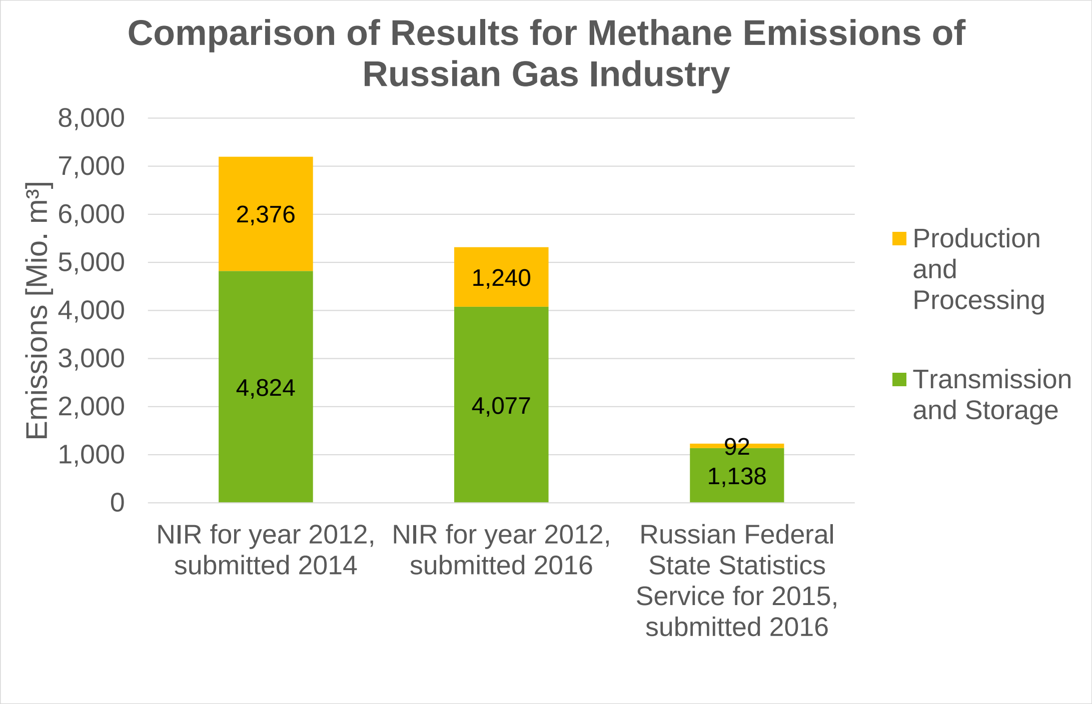
Russian Gas Production and Transport – Methane Emissions

The EXERGIA study used the Russian NIR to determine methane losses of gas production and gas transport from Russia. However, no actual data is used for the creation of emission estimation in the Russian NIR. Instead "default values" for developing countries are applied.

The Russian Federal State Statistics Service published hydrocarbon emissions of different sectors on its website. In the case of gas transport and gas production, these emissions are primarily methane emissions. In 2015, they amounted to 1,138 kt for the sector "pipeline transport of gas and the products of its processing" and to 92 kt for the sector "production of natural gas and gas condensates" [35]. Although the base year is not the same, these figures can be compared with those of the Russian NIR submitted in 2014 and the one submitted in 2016 to show the general differences (Figure 5).

The NIR submitted in 2016 shows significantly lower emissions than the NIR submitted in 2014 although both reports are for the base year 2012. This is due to a methodological change in the preparation of the NIR and indicates that emissions were estimated to high in the EXERGIA-Study. Moreover, the NIR 2016 states that further improvements are planned in the sector natural gas to update emission factors [51, p. 90]. The values of the Russian Federal State Statistics Service are significantly lower than the values in both NIRs.

Figure 5: **Comparison of information from different sources about the methane emissions in the Russian gas industry**



Source: Own illustration DBI based on [35], [52] and [53]

With the information from the NIR 2014 and equation 3.8 a value of 0.56 %[27] could be determined for the vented methane emissions of the gas production in Russia [52]. However, with the information of the NIR 2016 the share would account for 0.29 % [53] and in case of the usage of information from the Russian Federal State Statistic Service it amounts to 0.02 % [35], assuming that always the same produced amount of natural gas from the NIR 2014 was used as reference base. The last value is in line with the input data for gas production considered in this study.

The same approach has been used for methane emissions of gas transport. With the information from the NIR 2014 and the equation 3.4 a value of 0.97 %[28] could be determined for the vented methane emissions of the gas transport in Russia [52]. However, with the information of the NIR 2016 the share would account for 0.82 % [53] and in case of the usage of information from the Russian Federal State Statistic Service it amounts to 0.32 % [35], assuming that always the same transported amount of natural gas from the NIR 2014 was used as reference base.

This value of 0.32 % is well comparable with the values used for this study. However, as already described in the EXERGIA study, the values of the NIR and also of the Russian Federal State Statistics Service account only for the gas transport within Russia and not for the exports beyond the Russian border [1, p. 211].

Ukranian Gas Transport – Methane Emissions

As mentioned in section 3.1.5.2, the emissions of the Ukrainian are determined based on extrapolation used from Russian data. Data from the Ukrainian grid operators are also available, however, due to their high aggregation level, it was not possible to use the data as input data for GHGenius, and the data can only be used for comparison (Figure 6)[29]. The operators' data is higher than the data used in this study, because the data set includes several Ukrainian transmission pipelines and storages, which are used for natural gas consumed in Ukraine or which is transported to countries not part of Central EU (e.g. Romania). This study considers only a part of the Ukraine (Ukrainian corridor – Russia 1). Furthermore, it was unclear which sources of methane emissions were considered within the Ukrainian industry data and how they exactly were estimated. However, for both data sets the order of magnitude is consistent and in the operators' data the general trend (decreasing total emissions between 2012 and 2014) is visible, as well.

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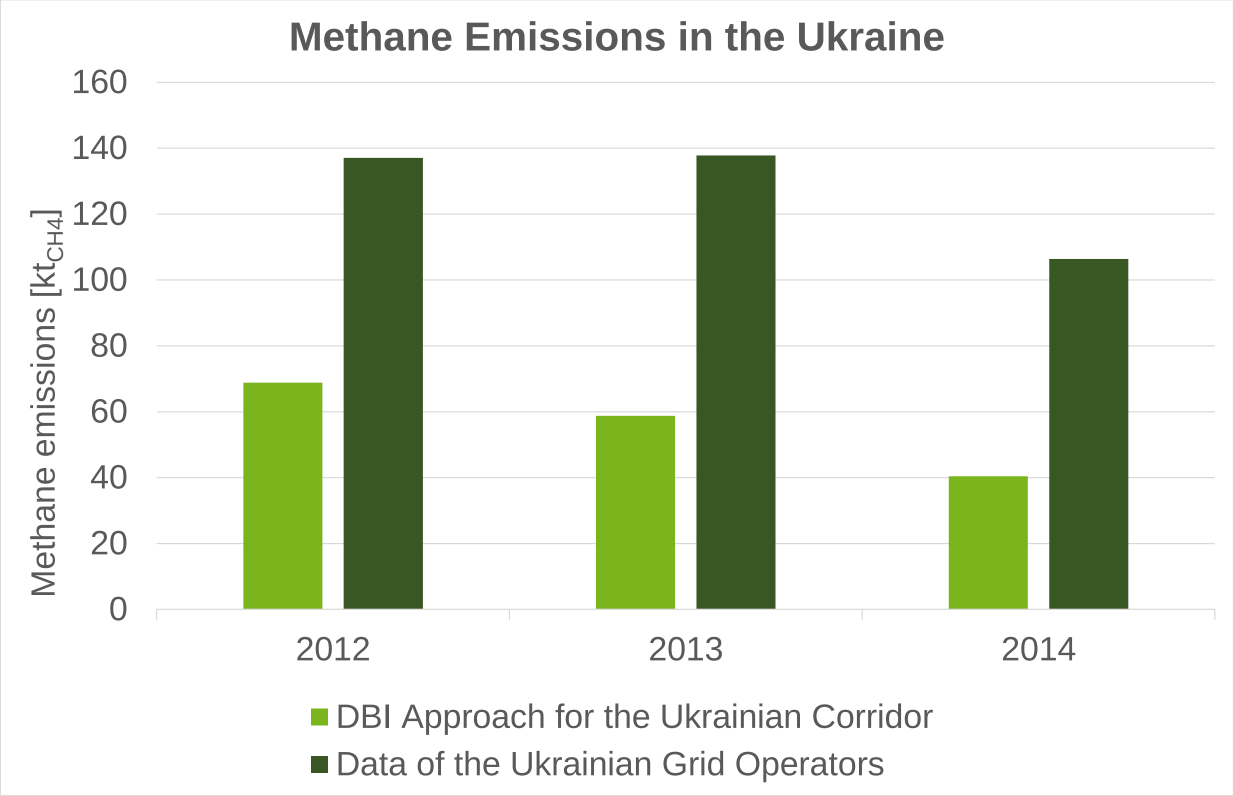
[27] In the EXERGIA study a value of 0.5 % is stated [1, p. 211]. The small deviation is caused by the usage of a different density for natural gas, which is necessary for the conversion.

[28] In the EXERGIA study a value of 1.02 % is stated [1, p. 211]. The small deviation is caused by the usage of a different density for natural gas, which is necessary for the conversion.

[29] Data listed in tabular form see Annex 16, Table 29.

Figure 6: **Comparison of methane emissions for the Ukrainian corridor with data of Ukrainian grid operators**



Source: Own illustration DBI based on [54]

3.2.5 Natural Gas Supply Structure

Since the IEA is an international organisation of the OECD countries with extensive experience in the field of energy statistics, their data sets are considered reliable and are plausible in relation to one another since the energy balances (import + production = consumption + export) are largely comparable with only slight statistical deviation.

However, the IEA data is commercial data, i.e. the import volume to Germany is bought by Germany, but not necessarily consumed in Germany. The method used treats domestically-produced natural gas in the same way as imported gas. This does not necessarily reflect reality, however, with the data available, no other evaluation option is possible.

3.3 Data Calculation

In the first step GHG emissions are presented. These emissions were determined using the GHGenius model (see 2.2.5.2) and the input data described in 3.1. These results are then divided according to the systems introduced in section 2.2.3 “Natural Gas distributed in Central EU”, and “Natural Gas distributed in Germany”. In section 4.2 the results are then displayed as a carbon footprint, which means they are converted to CO_2 equivalents to express their climate impact.

3.3.1 Natural Gas Distributed in Central EU

The emissions for natural gas distributed within Central EU will be determined using real supply structures. This means that all relevant providers for the Central EU region will be considered. After this, the emissions of the selected countries of origin will also be analysed.

3.3.1.1 All Natural Gas Producers

The following GHG amounts were derived from the natural gas distributed in Central EU (Table 17). These results were achieved based on the natural gas supply structure for Central EU as described in 3.1.6, and the input data as described in section 3.1.

Table 17: **GHG Emissions of Natural Gas which is distributed in Central-EU**

	2012				2013				2014			
	CO_2	CH_4	N_2O	CO	CO_2	CH_4	N_2O	CO	CO_2	CH_4	N_2O	CO
	[g/GJ]											
Transmission, storage and distribution in Central EU	149.0	64.4	0.0	0.1	145.0	63.0	0.0	0.1	141.6	66.8	0.0	0.0
Gas processing	249.1	2.9	0.0	0.2	214.8	2.8	0.0	0.2	200.5	2.4	0.0	0.2
Gas transport[30]	3,717.0	43.9	0.0	1.5	3,566.0	43.6	0.0	1.4	2,896.3	38.5	0.0	1.1
Gas production	1,153.7	24.3	0.1	1.8	1,192.2	23.9	0.1	1.8	1,203.9	23.5	0.1	1.8
CO_2, H_2S removed from NG	259.0	0.0	0.0	0.0	210.0	0.0	0.0	0.0	188.4	0.0	0.0	0.0
Total	**5,527.8**	**135.5**	**0.1**	**3.5**	**5,328.0**	**133.3**	**0.1**	**3.5**	**4,630.7**	**131.3**	**0.1**	**3.2**

Source: Own calculation DBI

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[30] Gas transport to Central EU border (in the case of Norway and Russia) or another county in Central EU (in the case of Germany and the Netherlands, because they are situated in Central EU).

3.3.1.2 Specific Natural Gas Producers

In order to determine the GHG emissions for a specific county of origin, the natural gas supply structure in GHGenius is modified so as to assume that the country under consideration was the only supplier to the region. Table 18 shows the GHG emissions for natural gas distributed in central EU but produced in Germany, Netherlands, Norway, or Russia as an Example for the year 2014. The results for the remaining years are displayed in Annex 19 to Annex 22.

Table 18: GHG Emissions from Natural Gas produced in Germany, Netherlands, Norway, or Russia in 2014

2014	Germany				Netherlands				Norway				Russia (weighted aver.)			
	CO_2	**CH_4**	**N_2O**	**CO**	**CO_2**	**CH_4**	**N_2O**	**CO**	**CO_2**	**CH_4**	**N_2O**	**CO**	**CO_2**	**CH_4**	**N_2O**	**CO**
	[g/GJ]															
Transmission, storage and distribution in Central EU	134.7	66.8	0.0	0.0	127.3	66.8	0.0	0.0	131.3	66.8	0.0	0.0	146.2	66.8	0.0	0.0
Gas processing	819.5	6.1	0.0	0.6	24.2	0.0	0.0	0.0	269.3	1.7	0.0	0.2	0.0	0.0	0.0	0.0
Gas transport[31]	0.0	0.0	0.0	0.0	1.1	6.0	0.0	0.0	1,576.4	1.9	0.0	0.6	11,791.9	69.2	0.1	4.5
Gas production	2,005.2	18.1	0.1	2.5	924.0	11.0	0.0	1.2	1,438.1	15.4	0.1	2.6	856.5	11.7	0.0	1.4
CO_2, H_2S removed from NG	2,172.3	0.0	0.0	0.0	0.8	0.0	0.0	0.0	16.8	0.0	0.0	0.0	2.4	0.0	0.0	0.0
Total	**5,131.8**	**90.9**	**0.1**	**3.2**	**1,077.5**	**83.8**	**0.0**	**1.3**	**3,431.8**	**85.9**	**0.2**	**3.4**	**12,797.0**	**147.7**	**0.1**	**6.0**

Source: Own calculation DBI

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[31] Gas transport to Central EU border (in the case of Norway and Russia) or another county in Central EU (in the case of Germany and the Netherlands, because they are situated in Central EU).

3.3.2 Natural Gas Distributed in Germany

In order to estimate the CF of natural gas distributed in Germany, the region “Central EU” is once again selected in the GHGenius. The input-data basis and settings are therefore identical to those used for the results in 3.3.1. However, several adjustments are applied in the GHGenius model:

1. The natural gas supply structure of central EU is replaced with the corresponding structure for Germany (see Annex 17)
2. The electricity mix of central EU is replaced with the corresponding mix for Germany (Annex 23)
3. The efficiency calculation for electricity production in central EU is replaced with the corresponding data for Germany (see Annex 24)
4. Germany will be selected within the model as the sole consumer of natural gas in central EU.
5. The transport distances should be adjusted, so that the distance until the German border is used and not just the distance to the EU border (see Annex 15).

For the aforementioned adjustments, the following amounts of GHGs for natural gas distributed in Germany are determined (Table 19).

Table 19: GHG Emissions of Natural Gas which is distributed in Germany

	2012				2013				2014			
	CO_2	**CH_4**	**N_2O**	**CO**	**CO_2**	**CH_4**	**N_2O**	**CO**	**CO_2**	**CH_4**	**N_2O**	**CO**
	[g/GJ]											
Transmission, storage and distribution in Central EU	85.9	29.3	0.0	0.0	87.0	27.3	0.0	0.0	74.8	31.0	0.0	0.0
Gas processing	219.3	3.2	0.0	0.2	193.7	3.2	0.0	0.2	159.6	2.3	0.0	0.1
Gas transport[32]	3,466.2	37.8	0.0	1.3	3,457.6	42.4	0.0	1.3	2,858.7	35.7	0.0	1.1
Gas production	1,140.4	20.5	0.1	1.8	1,171.4	21.5	0.1	1.8	1,164.5	18.8	0.1	1.8
CO_2, H_2S removed from NG	364.5	0.0	0.0	0.0	366.5	0.0	0.0	0.0	249.8	0.0	0.0	0.0
Total	**5,276.3**	**90.8**	**0.1**	**3.3**	**5,276.2**	**94.4**	**0.1**	**3.3**	**4,507.4**	**87.8**	**0.1**	**3.0**

Source: Own calculation DBI

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[32] Gas transport to another county in Central EU.

4. Impact Assessment

This chapter evaluates the potential effects of each greenhouse gas on climate change. This is achieved by the conversion of the calculated greenhouse gas emissions into CO_2-equivalents, and, therefore, expressing the carbon footprint [7, p. 62].

4.1 Global Warming Potential

In order to calculate the CO_2-equivalent values of greenhouse gases, a factor for "Global Warming Potential" (GWP) is applied to the greenhouse gas emissions. As is called for DIN CEN ISO TS 14067 [7, p. 62] the global warming potential over a time-span of 100 years (GWP_{100} value) is applied. These values change considerably over time due to the development of scientific knowledge and its probable effect on the expected global warming.

The GWP utilised in this study are taken from the Fourth Assessment Report (AR4) of the Intergovernmental Panel on Climate Change [55, p. 212]. This report has been selected as a source for the applied global warming potential values for two reasons in particular. Firstly, it has been fixed as a binding source for the National Inventory Reports since the United Nations Climate Change Conference in Warsaw in 2013 [56, p. 2]. In addition, the carbon footprints calculated by the EXERGIA study were also based on the GWP from the Fourth Assessment Report. This increases the comparability of the results of this study with the results of the EXERGIA study.

The latest GWP_{100} values were, however, released in the Fifth Assessment Report (AR5) of the IPCC. For example, the GWP_{100} for methane is now listed as 34 in contrast to 25 in the Fourth Assessment Report, including climate carbon feedback (CCFB) [57, p. 714]. In order to consider these latest developments, a sensitivity analysis including the latest GWP_{100} values from the Fifth Assessment Report of the IPCC is carried out.

The GWP values entered in the GHGenius model and applied in this study are displayed in Table 20.

In GHGenius, indirect GHGs carbon monoxide (CO) and volatile organic compounds (VOC) are considered, too. It is presumed that these gases are completely oxidized to CO_2, therefore, they are multiplied with an equivalent factor (Table 21). This procedure is carried out in accordance with the Guidelines of the IPCC [58, p. 7.6].

Table 20: Overview of GWPs Applied in This Study

	2007 (100 Years)	**2013 with ccfb (100 Years)**
Source	AR4 [55, p. 212]	AR5 [57, p. 714; 731]
CO_2	1	1
CH_4	25	34
N_2O	298	298
CFC-12	10900	10200
HFC-134a	1430	1550
SF6	22800	23500

Source: [55], [57]

Table 21: Overview of Equivalence Factors for Indirect Greenhouse Gases in This Study

	Carbon-weighted option
CO	1.57
VOC	2.99

Source: [43]

4.2 Conversion of Results in CO_2-equivalents

The model GHGenius automatically converts the calculated emissions into CO_2-equivalents. Consequently, the procedure to determine the results is described in section 3.3. The only difference is that the amount of the emitted gases is converted into CO_2-equivalents using the global warming potential described in section 4.1.

4.2.1 Natural Gas Consumed in Central EU

At first, the system “natural gas consumed in Central EU” is considered. All results are presented for the actual natural gas supply structure, meaning, all producers and consumers of natural gas relevant for the region are taken into account. Afterwards, the CF of natural gas of specific countries of origin is shown.

4.2.1.1 All Natural Gas Producers

Taking into account all producing and consuming countries for Central EU the results in Table 22 are calculated for the CF of natural gas distributed in Central EU.

Table 22: Carbon Footprint of Natural Gas Distributed in Central EU

	2012	2013	2014
	[gCO_2e/GJ]		
Transmission, storage and distribution in Central EU	1,760	1,720	1,813
Gas processing	323	287	262
Gas transport[33]	4,822	4,667	3,867
Gas production	1,781	1,813	1,813
CO_2, H_2S removed from NG	235	247	184
Total	**8,922**	**8,734**	**7,939**

Source: Own calculation DBI

The calculated results in CO_2-equivalents can be compared with the results of the EXERGIA study. For that purpose, the results for the step “dispensing” have to be excluded from the EXERGIA

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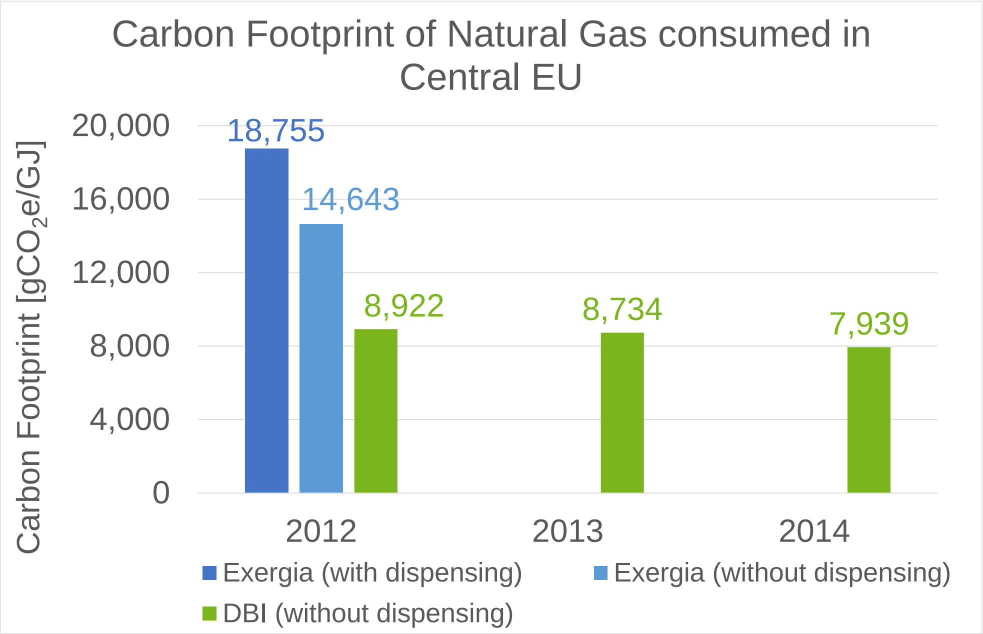
[33] Gas transport to Central EU border (in the case of Norway and Russia) or another county in Central EU (in the case of Germany and the Netherlands, because they are situated in Central EU).

results[34]. Figure 7 shows the result of Exergy for the CF of natural gas dispensed in Central EU at the natural gas filling station, in comparison to the result of EXERGIA without the life cycle step “dispensing” and the results obtained in this study for the carbon footprint of natural gas distributed in Central EU.

The carbon footprint for natural gas distributed in Central EU was calculated at 8,922 gCO2e/GJ in 2012 (cf. EXERGIA: 14,643 gCO2e/GJ) and 7,939 gCO_2e/GJ in the year 2014. The input data for pipeline gas from Germany, the Netherlands, Norway, and Russia was updated. All other data remained the same as used in the EXERGIA study.

Figure 7: Carbon Footprint of Natural Gas Distributed in Central EU [gCO_2e/GJ]



Source: Own illustration DBI

The differences between the results of this study and the EXERGIA study are due to updated input data which have been discussed individually in section 3.2.

The largest reduction of the result is caused by updated data for gas transport to the border of Central EU. Reduced values also occur in the steps transport, storage and distribution inside Central EU. They have been achieved for example by new measurements and subsequent updates of the NIR for the gas distribution network of The Netherlands, which now show significant less methane emissions than former releases.

For some applications of natural gas, the CF is preferred in a different unit. Figure 8 shows the results of Figure 7 in gCO_2e/kWh[35].

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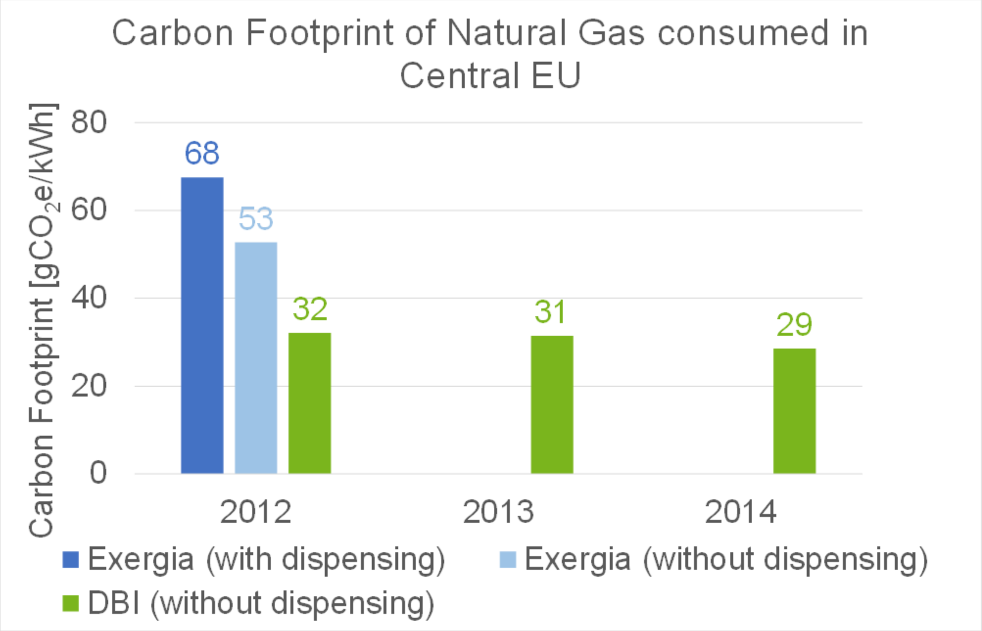
[34] The exclusion of fuel dispensing is justified in section 2.2.3.1.

[35] The results are converted by dividing the values in Figure 7 by 277.778 (=conversion of GJ into kWh).

Figure 8: **Carbon Footprint of Natural Gas Distributed in Central EU [gCO_2e/kWh]**



Source: Own illustration DBI

4.2.1.2 Specific Natural Gas Producers

The CF, which is valid for a specific producer country, is determined in analogy to the procedure described in section 3.3.1.1. Table 23 shows the results exemplary for the year 2014. The detailed results for all years are provided in Annex 25 for natural gas produced in Germany, in Annex 26 for natural gas produced in The Netherlands, in Annex 27 for natural gas produced in Norway and in Annex 28 for natural gas produced in Russia.

Table 23: **Carbon Footprint of Natural Gas Distributed in Central EU, by Producer Country (Example for 2014)**

	2014			
	Germany	**Netherlands**	**Norway**	**Russia**
	[gCO_2e/GJ]			
Transmission, storage and distribution in Central EU	1,805	1,797	1,801	1,810
Gas processing	977	26	315	0
Gas transport[36]	0	151	1,629	9,248
Gas production	2,483	1,210	1,867	1,179
CO_2, H_2S removed from NG	2,172	1	17	2
Total [gCO_2e/GJ]	**7,437**	**3,185**	**5,629**	**12,239**

Source: Own calculation DBI

Again, these results can be compared with the results of the EXERGIA study (Figure 9 to Figure 12).

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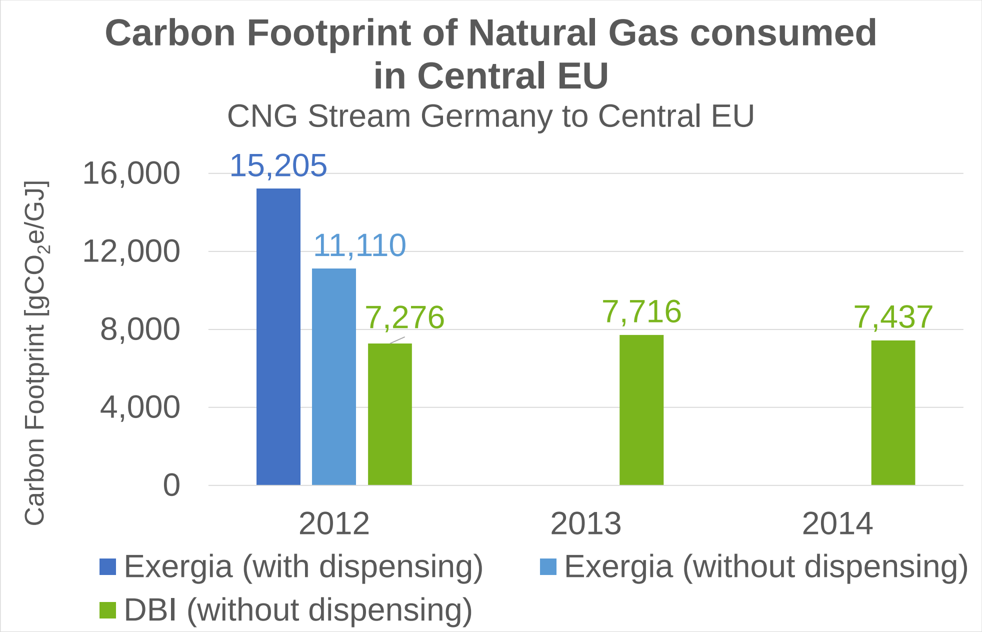
[36] Gas transport to Central EU border (in the case of Norway and Russia) or another county in Central EU (in the case of Germany and the Netherlands, because they are situated in Central EU).

Figure 9 shows the results for natural gas produced in Germany and distributed in Central EU. For this reason, solely the input data for Germany is relevant for the life cycle steps gas production and gas processing. Thus, for the steps gas transmission, storage and distribution the result is influenced by the data of all countries within Central EU.

In comparison with the EXERGIA study, the differences mainly result from the updated input data for the loss rate in the sections gas production and gas processing in Germany and the transmission energy and the loss rates for transmission and distribution within Germany (section 3.2.1.3 and Annex 25).

Figure 9: Carbon Footprint of Natural Gas Produced in Germany and Distributed in Central EU

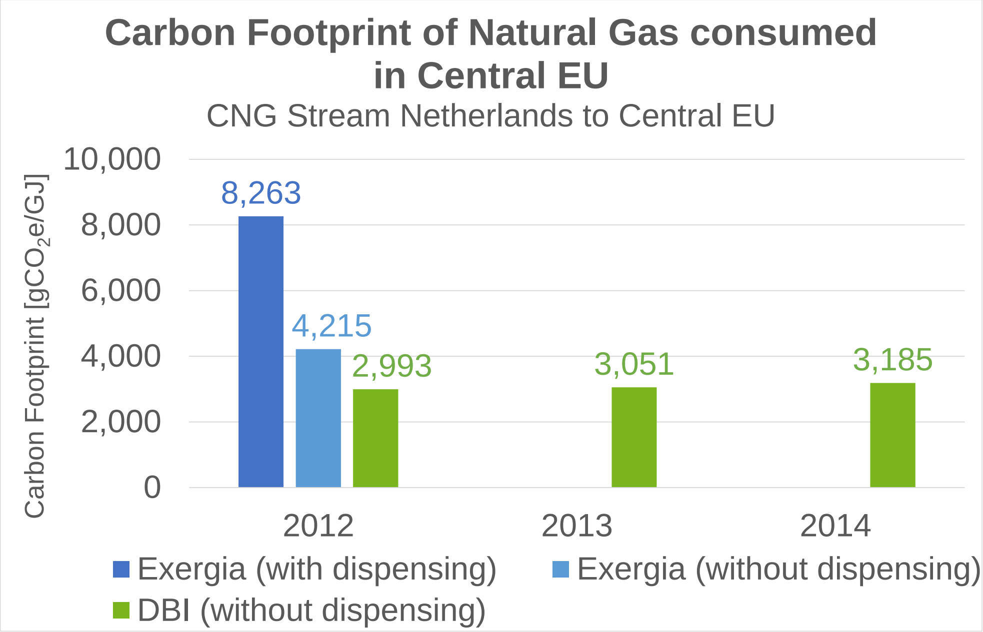


Source: Own illustration DBI

Figure 10 shows the results for natural gas produced in the Netherlands and distributed in Central EU. For this reason, solely the input data for the Netherlands is relevant for the life cycle steps gas production and gas processing. Thus, for the steps gas transmission, storage and distribution the result is influenced by the data of all countries within Central EU.

In comparison with the EXERGIA study, the differences mainly result from gas transport within EU, storage and distribution (section 3.2.2 and Annex 26).

Figure 10: **Carbon Footprint of Natural Gas Produced in the Netherlands and Distributed in Central EU**

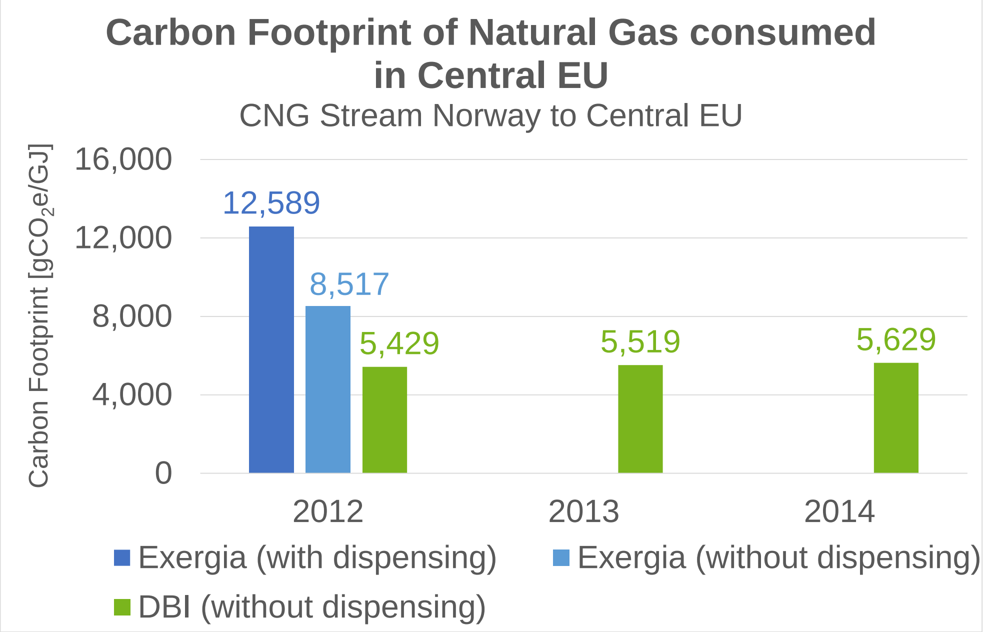


Source: Own illustration DBI

Figure 11 shows the results for natural gas produced in Norway and distributed in Central EU. For this reason, solely the input data for Norway is relevant for the life cycle steps gas production and gas processing. Thus, for the steps gas transmission, storage and distribution the result is influenced by the data of all countries within Central EU.

The main differences to the EXERGIA study reveal in the life cycle steps “transport until EU border” and “CO_2, H_2S removed from NG” (section 3.2.2 and Annex 27). Further differences to EXERGIA emerge in the step “gas transport within EU, storage and distribution”, not because of updates in the Norwegian data but updated data from Germany and the Netherlands.

Figure 11: **Carbon Footprint of Natural Gas Produced in Norway and Distributed in Central EU**

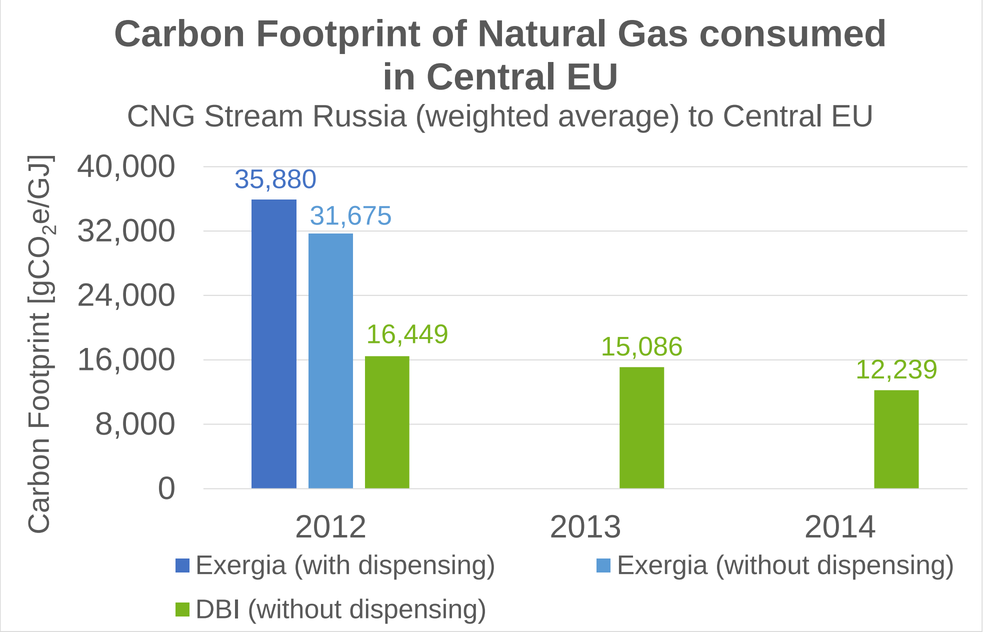


Source: Own illustration DBI

Figure 12 shows the results for natural gas produced in Russia and distributed in Central EU. For this reason, solely the input data for Russia is relevant for the life cycle steps gas production and gas processing. Thus, for the steps gas transmission, storage and distribution the result is influenced by the data of all countries within Central EU.

In comparison with the EXERGIA study, the main differences appear on the step transport until the EU border (section 3.2.3 and Annex 28). Further differences occur in gas production and gas processing. The dropped Carbon Footprint for “gas transport within EU, storage and distribution” results from updating the input data for Germany and for The Netherlands.

Figure 12: Carbon Footprint of Natural Gas produced in Russia and Distributed in Central EU



Source: Own illustration DBI

4.2.2 Natural Gas Consumed in Germany

With the procedure described in section 3.3.2 the CF of natural gas distributed in Germany can also be determined. Table 24 shows the results.

Table 24: Carbon Footprint of Natural Gas Distributed in Germany (with Adjusted Lengths)

System Germany	2012	2013	2014
	[CO_2e/GJ]		
Transmission, storage and distribution in Central EU	818	771	851
Gas processing	300	276	219
Gas transport[37]	4,905	4,988	4,074
Gas production	1,675	1,731	1,655
CO_2, H_2S removed from NG	364	366	250
Total [CO_2e/GJ]	**8,064**	**8,132**	**7,050**

Source: Own calculation DBI

The results compare to EXERGIA as follows (Figure 13): The authors of EXERGIA study did not conduct the adjustment of the transport distances for the representation of the system “Natural gas distributed in Germany” as discussed in section 3.3.2 bullet 5. Therefore, only transport distances to the outer border of Central EU have been considered. For the sake of comparison, a result without

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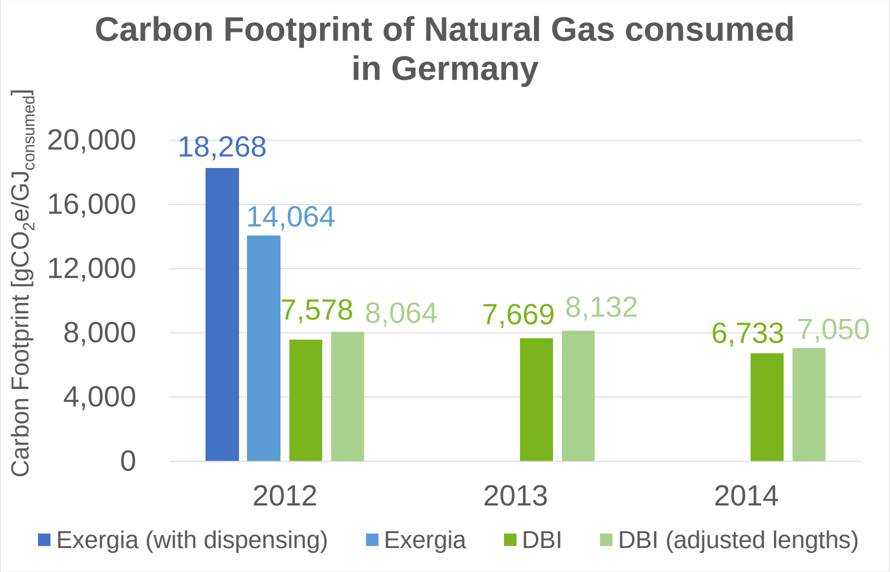
[37] Gas transport to another county in Central EU.

adjusted transport distances has been calculated and is presented in Figure 13 (dark green column). The value with the adjusted transport distances (light green column) is more resilient as it represents actual conditions. For the system “Natural Gas distributed in Germany” a CF of 8,064 gCO_2e/GJ has been calculated for the year 2012 (ref. EXERGIA: 14,064 gCO_2e/GJ) and 7,050 gCO_2e/GJ for 2014.

Figure 13: Carbon Footprint of Natural Gas Distributed in Germany (with Adjusted Lengths)



Source: Own illustration DBI

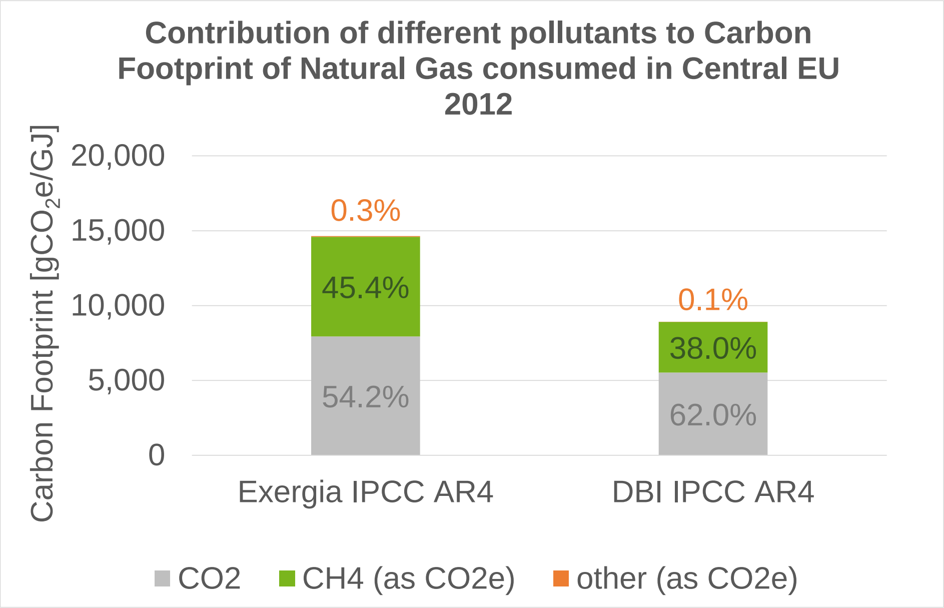
5. Interpretation and evaluation

5.1 Identification of Significant Issues

5.1.1 Contribution of Different Greenhouse Gases to the Carbon Footprint of Natural Gas Distributed within Central EU

The overview of GHG emissions of natural gas distributed within Central EU (section 3.3.1) shows that primarily CO_2 emissions arise in the individual stages of the life cycle. However, CH_4 emissions are gaining in importance as they have a 25-times higher global warming potential than CO_2 [55, p. 212]. However, the overall share of the total CF that is contributed by CH_4 as shown in this research, is lower than the share of CO_2 (Figure 14).

Figure 14: Contribution of Different GHG to the Total Carbon Footprint



Source: Own illustration DBI

5.1.2 Effect of the Updated Data on the Total Carbon Footprint in Comparison with the Results of the EXERGIA study

The following section shows, exemplary for the year 2012, the effects of the update of individual parameters on the CF. In this manner it is possible to identify the parameters, which have most influence on the result. The following figures always represent the results for natural gas produced for Central EU and distributed within Central EU, meaning that the data of all suppliers (Annex 17) and all consumers (Annex 18) in Central EU is relevant.

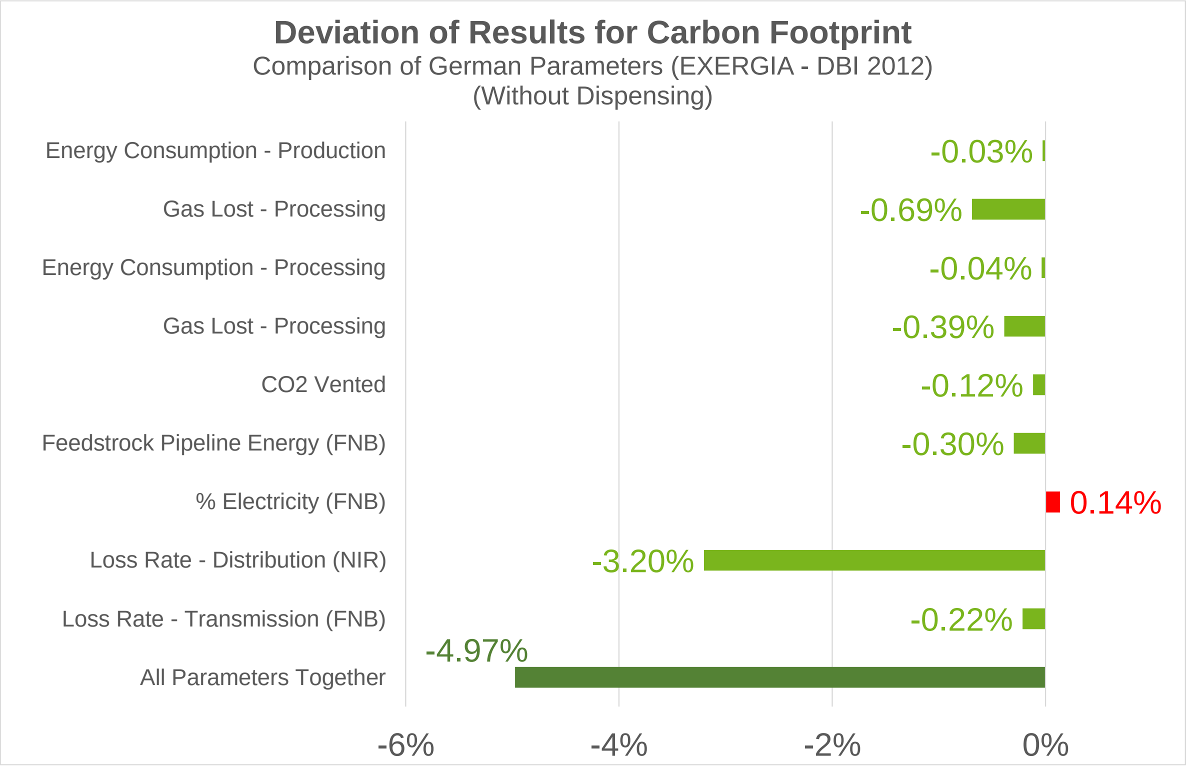
General explanation for all following figures in this section: green bars show a lower result than in the EXERGIA study, because of the updating, whereas red bars indicate a higher result. Grey tagged percentages display the case without deviation.

The total deviation shown in the figures is not necessarily the same as the sum of the single parameters. The reason for this is, that some changes also influence other areas of the GHGenius model (e.g. the electricity production with natural gas). Thus, there is a certain interaction of several parameters which influences the overall result slightly.

5.1.2.1 Germany

The total deviation of the CF resulting from the present study, in comparison with the result of the EXERGIA study, is – 4.97 % (Figure 15). For the German data the greatest influence results from the update of the “Loss Rate – Distribution”, which is based on data from the NIR. The EXERGIA study also used the NIR as a data source. The difference is that in the year 2015, methodological changes occurred, which also applied to 2012. One example is the usage of new emission factors for the gas distribution grid, based on new knowledge. An explanation for the differences between the values of the EXERGIA study and the study at hand is already given in section 3.2.1.

Figure 15: Effect of Different Parameters on the Carbon Footprint of Natural Gas Produced in Germany and Distributed within Central EU

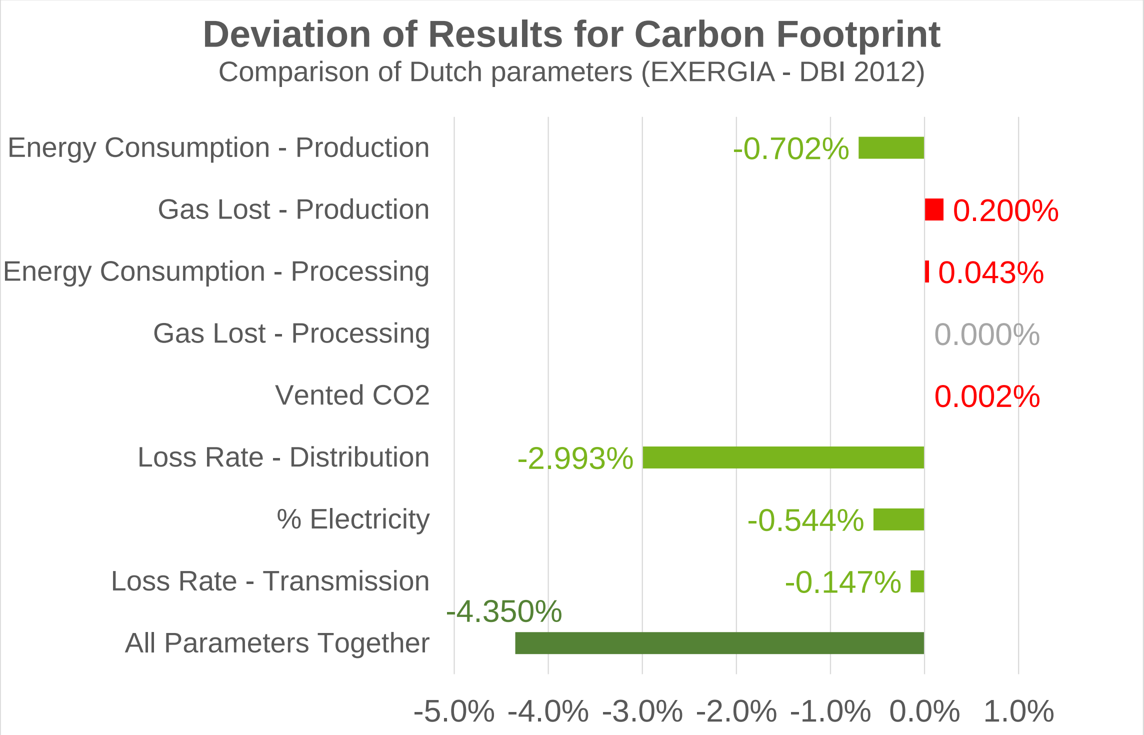


Source: Own illustration DBI

5.1.2.2 The Netherlands

From the update of all Dutch parameters results a total deviation of -4.35 %. The crucial parameter for this result is the “Loss Rate – Distribution”, which causes a decrease of the CF, when compared with the result of the EXERGIA study, of approximately - 3.0 % (Figure 16). The reasons were already explained in section 3.2.2.

Figure 16: **Effect of Different Parameters on the Carbon Footprint of Natural Gas Produced in the Netherlands and Distributed within Central EU**

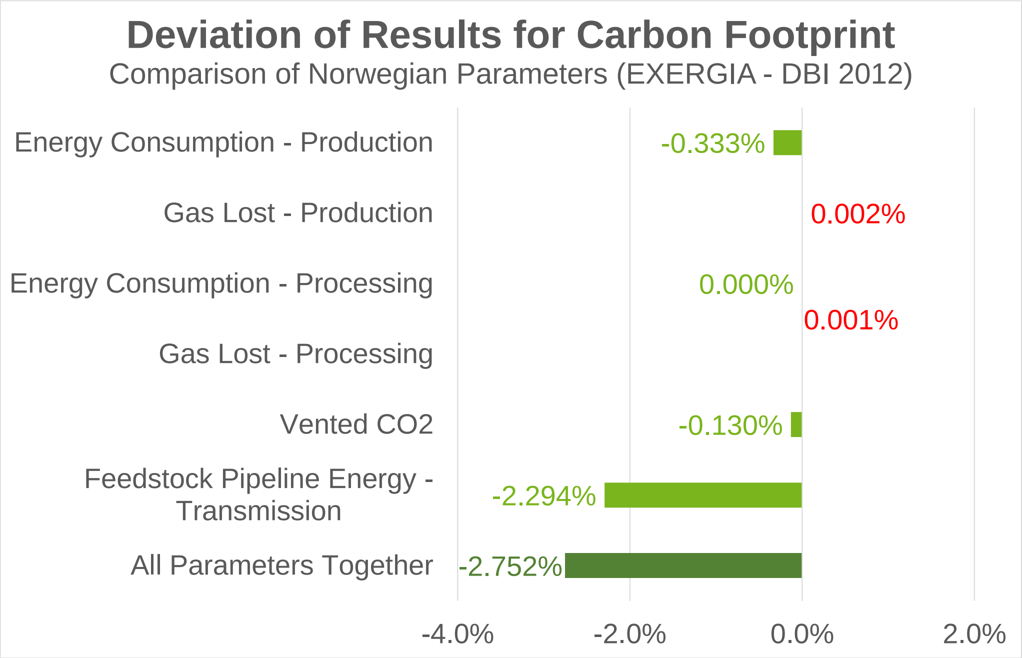


Source: Own illustration DBI

5.1.2.3 Norway

The update of the Norwegian parameters leads to a total deviation of - 2.75 %. The most important parameter is the “Feedstock Pipeline Energy – Transmission”, which causes a decrease of the CF, when compared with the result of the EXERGIA study, of approximately - 2.3 % (Figure 17). An evaluation of the differences between the input data is presented in section 3.2.3.

Figure 17: **Effect of Different Parameters on the Carbon Footprint of Natural Gas Produced in Norway and Distributed within Central EU**

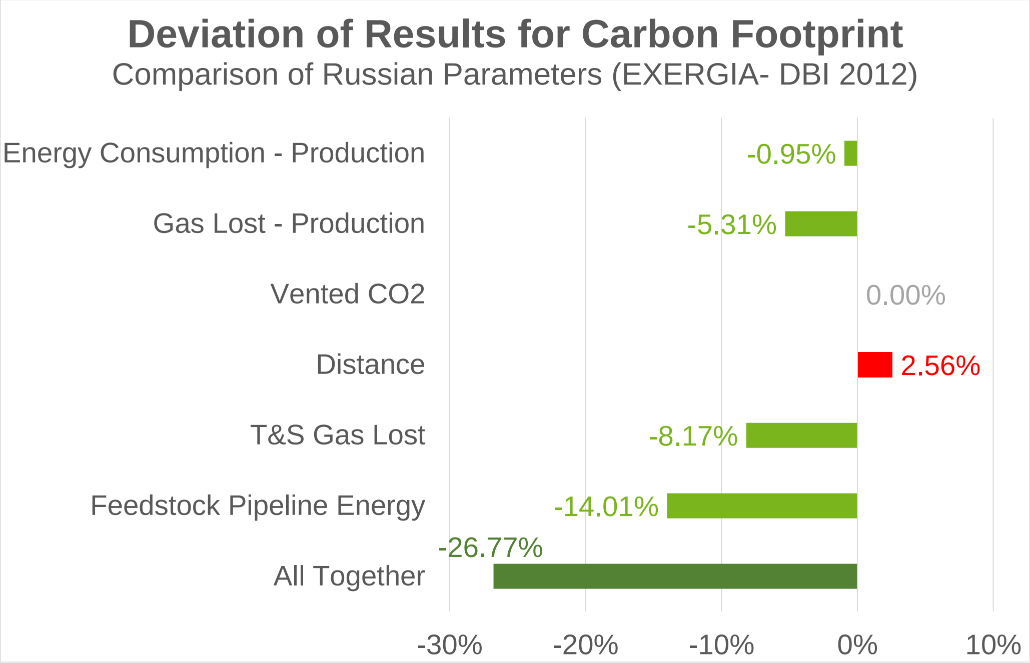


Source: Own illustration DBI

5.1.2.4 Russia

The update of the Russian parameters accounts to a total deviation of - 26.7 %. The main parameters, identified to contribute to this deviation, are the “Feedstock Pipeline Energy – Transmission” and the “T&S Gas Lost” (T&S = transport and storage) (Figure 18). The differences between the input data were evaluated in section 3.2.3.

Figure 18: **Effect of Different Parameters on the Carbon Footprint of Natural Gas Produced in Russia and Distributed in Central EU**



Source: Own illustration DBI

5.1.3 Effect of the GWP on the Total Carbon Footprint

For the assessment of the effect of the GWP values on the results of the CF of natural gas, a sensitivity analysis was realised. With the usage of the latest GWP_{100} from the fifth assessment report of the IPCC (AR5)[38] [57], the following results were observed (see Figure 19).

When using the GWP values of the IPCC AR5 the carbon footprint of natural gas distributed in Central EU, increases by about 14 % in 2012 (from 8,922 to 10,141 gCO_2e/GJ) in comparison with the CF which occurs by using the GWP values of the IPCC AR4 [55].

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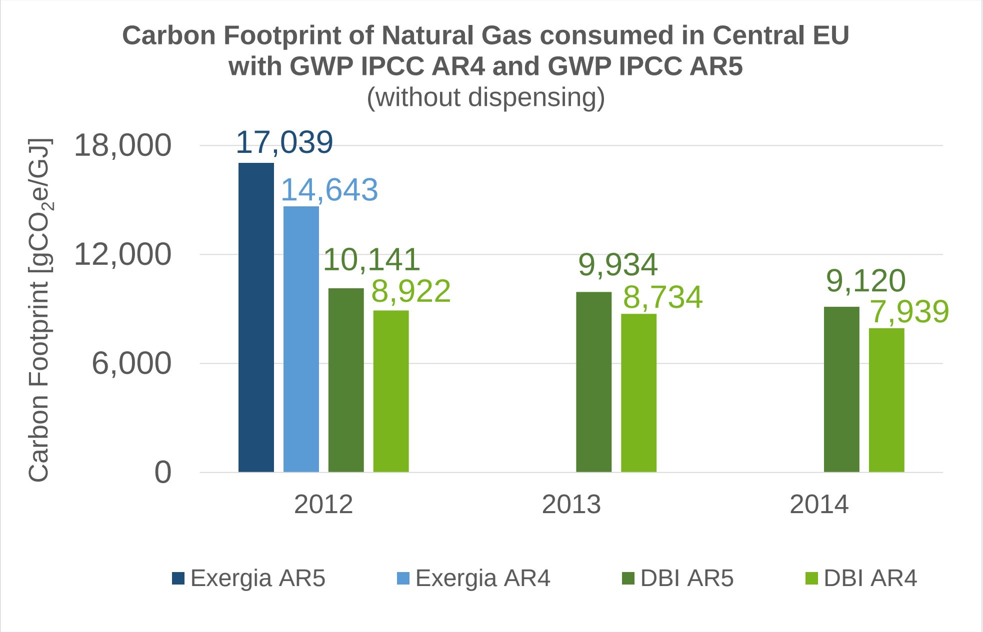
[38] E.g. 34 for CH_4

Figure 19: **Effect of Different GWP_{100}-Values from the IPCC AR5 on the Carbon Footprint of Natural Gas Distributed within Central EU**



Source: Own illustration DBI based on [57]

5.2 Final Assessment of the Applied Data

Up-to-Dateness and Completeness

For the years 2012, 2013 and 2014, a detailed consideration was possible because sufficient data was available. For the year 2015, the data is not yet completely recorded, aggregated, examined and published, and therefore some necessary information was missing. For this reason, the year 2015 was not included in this study.

Precision

A high precision of the data and the calculations was achieved. However, it was necessary to make some allocations because often only aggregated data was available (especially with regard to gas production).

Representativeness

To examine the representativeness of the data, a comparison and assessment of the used data with data from other sources took place. In order to increase the representativeness, the study considered not just one base year but three consecutive years.

Reproducibility

During preparation of the study, the reproducibility by third parties has always been kept in mind. For this reason, within the presentation of the results we tried to be as comprehensible and transparent as possible. A detailed description of the input data necessary for determining the CF is in section 3.1. For the input data a source is always provided. Unfortunately, not every source is publicly available and therefore the reproducibility is limited. The reason for this is that the data from the transmission system operators is subject to confidentiality agreements and not open to the public. Nevertheless, the majority of the data is freely available in the internet.

Uncertainty

The uncertainty of the information should be minimised. However, significant uncertainties exist particularly in the field of methane emissions. These uncertainties are unavoidable because there are many elements which cause emissions and not every element can realistically be part of measurements. For emission estimation often equations are used. With these equations only an approximation of the reality is possible.

Consistency

In calculating the carbon footprint, the model GHGenius 4.03 was always used. In consequence, all calculations were performed consistently.

In Table 25 the data quality assessment is summarised for the different countries and the individual life cycle steps. It represents a highlighting of important insights from the data validation (section 3.2). In general, it could be stated that the goal of the study (section 2.1) was reached. Anyhow it is possible to enhance the data base still more, because it was partly necessary to work with allocations or assumptions.

Table 25: Summary Evaluation of Data Quality

Sector	**Country**	**Remark about Data Quality**
Production	Germany	Current, complete and representative data from the national energy balances and the BVEG was used.
	Netherlands	Current, complete and representative data from the national energy balances and the NIR was used.
	Norway	The used data was obtained from the national energy balances and the NIR. For methane emissions in 2014 a value from [30] was used, based on an updated calculation method for emission factors. For this reason, the value is more reliable and precise.
	Russia	Current, complete and representative industry data which is also used for state reporting ([31], [35]) was used.
Processing	Germany	Removal of the information about energy consumption from the EXERGIA study, because no other data was available. Determination of gas consumption and vented CO_2 emissions based on data from BVEG, which is actual and representative. Fugitive methane emissions were taken from the NIR.
	Netherlands	Current and complete industry data was used, but this data was aggregated for transport, storage and processing and a breakdown was just partly possible. The data base even contains of information (e.g. energy consumption for liquefaction of natural gas) which does not belong to the defined product system boundaries. However, it is assumed that the influence for the result is not significant.

Sector	Country	Remark about Data Quality
Processing	Norway	Data from the EXERGIA study was used, because it was not possible to process the public available data within the timeframe of this study. It is recommended to enhance the data basis for this part.
	Russia	The energy consumption and gas lost were contained in the data of gas production. Hence, current, complete and representative industry data which is also used for state reporting ([31], [35]) was used. The data for vented CO_2 emissions was taken from the NIR.
Transport and Storage	Germany	Current and representative industry data was used. The information about methane emissions of the gas transport was not complete, because only intended gas venting was covered. For the consideration of further gas lost (gas leakages) a surcharge was made. This surcharge is seen to be conservative by the German TSO. The data for storage is not complete. However, comparative data shows that the influence on the final result is not significant. It is recommended to enhance the data basis with the help of new measurements of leaks and the collection of data from storage system operators.
	Netherlands	Current, complete and representative industry data was used.
	Norway	Data from the EXERGIA study was used, because it was not possible to process the public available data within the timeframe of this study. It is recommended to enhance the data basis for this part.
	Russia	Current, complete and representative industry data which is also used for state reporting ([31], [35]) was used for the gas transport in Russia and Belarus. For the gas transport in Ukraine there was no detailed enough data, thus a factor was determined with help of the Russian data. This approach was judged as adequate for the compliance of the goal of this study. However, the data basis should be improved in the future.
Distribution	Germany	Usage of current information about methane emissions from the NIR. However, the data of the NIR contains additionally information about methane emissions of natural gas filling stations because in Germany these stations are part of the distribution grid.
	Netherlands	Usage of current information about methane emissions from the NIR.
	Norway	Not considered in this study, since not part of the system boundaries.
	Russia	Not considered in this study, since not part of the system boundaries.

6. Summary and Outlook

The goal of this study was to determine the carbon footprint of the natural gas distributed in Germany and in Central EU. Emissions resulting from the production, processing, transport, storage, and distribution of natural gas were considered. The utilization of the best data available and the transparency of the calculations were of paramount importance to the project.

The reason for the execution of this project was a study carried out by the consulting firm EXERGIA on behalf of the European Commission entitled “Study on Actual GHG Data for Diesel, Petrol, Kerosene, and Natural Gas” (hereafter referred to as the EXERGIA study). The EXERGIA study came to the conclusion that emissions for the production, processing, transport, storage and distribution of natural gas had long been underestimated. However, an initial analysis of the EXERGIA study showed that it had, in part, been based on obsolete data. It was assumed that by utilising the latest data considerably improved results for the carbon footprint would be achieved. Consequently, the latest data was researched, checked, verified and employed for the purposes of this study. In addition, certain sections of the EXERGIA study were not transparent and, as a result, lacked clarity. The authors of this study were determined to present all input data and calculations transparently in order to allow for them to be examined by third parties. Furthermore, certain elements of the gas infrastructure were considered more sophisticated as in the EXERGIA study so as to more accurately illustrate the real infrastructure and its operation.

In order to make the results comparable with the EXERGIA study, the model GHGenius 4.03 was used to determine the carbon footprint - the same version of the model as was used by the EXERGIA study. An inspection and evaluation of the model itself were not within the scope of this study. In addition this study used the same system parameters as previously used in the EXERGIA study.

In general, the use of updated best available data allowed a determination of clearly lower results compared to the EXERGIA study. A carbon footprint of 8,922 gCO2e/GJ was determined for the year 2012 (compared to the EXERGIA value of 14,643 gCO2e/GJ), and 7,939 gCO2e/GJ for 2014. Only the input data for pipeline gas from Germany, the Netherlands, Norway, and Russia was adapted. All other data remained the same as used in the EXERGIA study. It seems likely that the results of the carbon footprint could be reduced further still if other input data were also updated.

The greatest reduction in the results was achieved through the use of updated best available data for gas transport to the borders of Central EU. However, clear improvements were also possible in the areas of transport, storage, and distribution within Central EU. This can be attributed, among other factors, to the new measurements and the resulting update of the NIR for the gas distribution network in the Netherlands, which now reports considerably lower methane emissions than before.

Due to the limited time-frame of this study, only data that would have a notable influence on the final results was reviewed. Certain input data, such as that for LNG, was utilized in the form it was provided by the GHGenius model without any adjustments. Moreover, no adjustments were made to the electricity mixes of the individual countries, or to the greenhouse gas emissions from electricity generation. It can be expected that the further adjustment of this data would lead to a further reduction in the results of the carbon footprint.

The evaluation of fuel dispensing (not considered in this study due to its limited relevance[39] to the research objectives) will be addressed in a separate project, which will consider the whole of Europe.

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[39] Fuel dispensing was not considered by this study since only approximately 0.4 % of the natural gas consumed in Europe is used by the transport sector [11].

As part of the cooperation with this project, coordinated by the NGVA and conducted by Thinkstep, the data collected as part of this study will be made available for further evaluation. It is expected that this further evaluation within the NGVA/Thinkstep project will lead to a further decrease of the calculated CF.

It can, therefore, be concluded that the public availability and transparency of data have a strong influence on the outcomes of such study results. The availability of this data can, therefore, be seen to have a direct influence on decision-making at a European level since it cannot always be assumed that representatives of the natural gas industry are part of studies (as for example the EXERGIA study) conducted to estimate the carbon footprint.

The following recommendations are made:

- Immediate distribution of the results of this study to ensure that the results of the EXERGIA study, which are currently available at the European Commission, can be updated. Moreover, this study, along with the expected results of the NGVA/Thinkstep study, shall lead to a general review of data and research methods in this field incorporating the natural gas industry.
- In the medium and long-term it is necessary to substantially review and improve the data basis for the input data used in the calculation of the carbon footprint. This review shall occur on a Europe-wide level and include the collection, processing and publication of data. A possible concept for such a review has already been created by GERG[40]. It is, however, important that the ever-increasing transparency practice within the industry continues on its current course. This improved communication is important so as to correctly quantify and record the measures currently being undertaken by the industry (e.g. the application of new technologies and new materials for pipeline construction) to reduce emissions. These measures have already resulted in a considerable reduction in emissions, from approximately 8 % for the total volume of natural gas produced in the mid-1980s, to approximately 2 % by 2010 [59, p. 91].

These measures are considered essential both for the short-term reaction to the current situation, and for the long-term strategic positioning of the industry.

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Annex

Annex 1: Explanation of terms used in GHGenius

Designation in GHGenius	Designation in this Study
Fuel distribution and storage	Transmission, storage and distribution within a country in Central EU.
Fuel production	Gas processing
Feedstock transmission	Gas transport to Central EU border (in the case of Norway and Russia) or another county in Central EU (in the case of Germany and the Netherlands, because they are situated in Central EU).
Feedstock recovery	Gas production
CO_2, H_2S removed from NG	CO_2, H_2S removed from NG (partial step of gas processing, which is considered separately in GHGenius)
% electric	The share of compressors, which are driven electrically.
T&S gas lost	Gas lost within the life cycle steps transport and storage.

Annex 2: Overview on characteristic gas values used

		Germany	**The Netherlands**	**Norway**	**Russia**
Net calorific value	[MJ/m³]	33.85	31.66	36.23	36.10
Gross calorific value	[MJ/m³]	37.51	35.09	40.00	40.04
Density natural gas	[kg/m³]	0.75[41]	0.83	0.84	0.73
Density CO_2	[kg/m³]	1.98	1.98	1.98	1.98
Density CH_4	[kg/m³]	0.72	0.72	0.72	0.72

Source: Germany [20], The Netherlands [60, p. 31], Norway [61], Russia [62], Density of CO_2 and CH_4 [63, pp. 38, 54]

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[41] BVEG uses a natural gas density of 0.8 kg/m³. For that reason, BVEG-data has been converted using this density.

Annex 3: Calculation Example for Validation of the Relevance of the Storage of Natural Gas concerning the German Gas Transport

For the year 2012 it is determined exemplary, how an increase of methane losses and energy consumption for the German gas transport influences the result for the Carbon Footprint of natural gas distributed in Central EU and natural gas distributed in Germany, respectively.

In case of an increase of both parameter for 10 % each, the input data presented in Table 26 is resulting.

Table 26: Calculation Example for Validation of the Relevance of the Storage of Natural Gas concerning the Result for the CF of Natural Gas

Germany	**Transport**			
	Transmission Energy	**Distance**	**% electric**	**Loss Rate**
	[$J_{consumed}/J_{transported}\cdot km$]	[km]	[%]	[-]
2012	0.000011	300	1.91	0.0001045

Source: [1] and own calculation DBI based on [20]

By usage of the input data from Table 26 the result for the Carbon Footprint of natural gas distributed in Central EU in 2012 increases from 8,922 gCO_2e/GJ to 8,926 gCO_2e/GJ. The result for the Carbon Footprint of natural gas distributed in Germany in the year 2012 raises from 8,064 gCO_2e/GJ to 8,076 gCO_2e/GJ. In both cases the deviation is less than 0.15 % and thus, insignificant.

Annex 4: Calculation of Vented CO_2 Emissions of Gas Processing in Germany

In the year 2012 CO_2 emissions from acid gas processing accounted for 0.3597 $t_{CO2}/t_{acid\ gas}$ after the BVEG [64, p. 71]. By his own admission, the BVEG uses for calculation a density of natural gas at 0.8 kg/m³. The density of CO_2 is 1.98 kg/m³. Thus, the value 0.3597 $t_{CO2}/t_{acid\ gas}$ corresponds to 0.1453 $m^3_{CO2}/m^3_{acid\ gas}$ or 14.53 %. Because 40 % of the produced natural gas is acid gas [44, p. 265], the vented CO_2 amounts to a share of 5.81 % (=14.53·0.4) related to the total amount of produced natural gas in Germany. In case of the other years, the procedure was the same.

Table 27: Conversion of the BVEG Data about Emissions of Acid Gas Processing Into the Input Data Necessary for GHGenius

	CO_2 emissions of acid gas processing after BVEG [$t_{CO2}/t_{acid\ gas}$]	Vented Cos emissions of gas processing after DBI [%]
2012	0.3597	4.84
2013	0.4125	5.56
2014	0.3272	4.41

Source: Own calculation DBI based on [15], [64]

Annex 5: Input and Reference Data Gas Production - The Netherlands

	Gas Production									
The Netherlands	**Crude oil**	**Diesel fuel**	**Residual fuel**	**Natural gas**	**Coal**	**Electricity**	**Gasoline**	**Coke**	**Total**	**Gas lost**
	[$kJ_{consumed}/t_{produced}$]									[%]
2012 GHGenius	599	3,592	0	655,414	0	127,093	0	0	786,698	0.003
2012 EXERGIA	599	3,592	0	655,414	0	127,093	0	0	786,698	0.030
2012 DBI	**3,284**	**0**	**0**	**487,312**	**0**	**101,180**	**0**	**0**	**591,776**	**0.026**
2013 DBI	**3,056**	**0**	**0**	**492,179**	**0**	**139,812**	**0**	**0**	**635,048**	**0.021**
2014 DBI	**3,284**	**0**	**0**	**514,217**	**0**	**133,475**	**0**	**0**	**650,976**	**0.026**

Source: [1], [43] and own calculation DBI based on [21], [22]

Values in bold have been used as input data in the model.

Annex 6: Input and Reference Data Gas Processing - The Netherlands

	Gas Processing										**Vented CO_2**
The Netherlands	**Crude oil**	**Diesel fuel**	**Residual fuel**	**Natural gas**	**Coal**	**Electricity**	**Gasoline**	**Coke**	**Total**	**Gas lost**	
	[$kJ_{consumed}/t_{produced}$]									[%]	[%]
2012 GHGenius	0	0	0	1	0	0	0	0	1	0	0.0020
2012 EXERGIA	0	0	0	1	0	0	0	0	1	0	0.0020
2012 DBI	**0**	**0**	**0**	**1**	**0**	**8,681**	**0**	**0**	**8,682**	**0**	**0.0016**
2013 DBI	**0**	**0**	**0**	**1**	**0**	**11,178**	**0**	**0**	**11,179**	**0**	**0.0013**
2014 DBI	**0**	**0**	**0**	**1**	**0**	**13,124**	**0**	**0**	**13,125**	**0**	**0.0017**

Source: [1], [43] and own calculation DBI based on [23]

Values in bold have been used as input data in the model

Annex 7: Input and Reference Data Gas Transport - The Netherlands

	Gas Distribution	**Gas Transmission**			
The Netherlands	**Loss Rate**	**Transmission Energy**	**Distance**	**% electric**	**Loss Rate**
	[-]	[$J_{consumed}/J_{transported}\cdot km$]	[km]	[%]	[-]
2012 GHGenius	0.004300	0.0000270	150	25.0	0.000280
2012 EXERGIA	0.000430	0.0000270	150	10.6	0.000280
2012 DBI (NIR 2014)	0.000407	-	-	-	-
2012 DBI	**0.000194**	**0.0000072**	**150**	**10.6**	**0.000088**
2013 DBI	**0.000188**	**0.0000074**	**150**	**10.6**	**0.000114**
2014 DBI	**0.000213**	**0.0000060**	**150**	**10.6**	**0.000114**

Source: [1], [43] and own calculation DBI based on [22], [24], [25], [26]

Values in bold have been used as input data in the model

Annex 8: Input and Reference Data Gas Production - Norway

	Gas Production									
Norway	**Crude oil**	**Diesel fuel**	**Residual fuel**	**Natural gas**	**Coal**	**Electricity**	**Gasoline**	**Coke**	**Total**	**Gas lost**
	$[kJ_{consumed}/t_{produced}]$									[%]
2012 GHGenius	0	116,801	0	1,133,244	0	153,755	0	0	1,403,800	0.0050
2012 EXERGIA	0	116,801	0	1,133,244	0	153,755	0	0	1,403,800	0.0050
2012 DBI	**0**	**105,677**	**0**	**1,014,021**	**0**	**126,197**	**0**	**0**	**1,245,895**	**0.0053**
2013 DBI	**0**	**129,722**	**0**	**1,059,905**	**0**	**127,009**	**0**	**0**	**1,316,636**	**0.0061**
2014 DBI	**0**	**110,458**	**0**	**1,104,218**	**0**	**137,642**	**0**	**0**	**1,352,318**	**0.0048**
2014 DBI (NIR 2016)	0	110,458	0	1,104,218	0	137,642	0	0	1,352,318	0.0080

Source: [1], [43] and own calculation DBI based on [28], [29], [30], [65]

Values in bold have been used as input data in the model

Annex 9: Input and Reference Data Gas Processing - Norway

	Gas Processing										Vented CO_2
Norway	**Crude oil**	**Diesel fuel**	**Residual fuel**	**Natural gas**	**Coal**	**Electricity**	**Gasoline**	**Coke**	**Total**	**Gas lost**	
	[$kJ_{consumed}/t_{produced}$]									[%]	[%]
2012 GHGenius	0	97	0	157,198	0	51,242	0	0	208,537	0.0050	0.230
2012 EXERGIA	0	97	0	157,187	0	51,242	0	0	208,526	0.0050	0.230
2012 DBI (NIR 2014)	0	97	0	157,187	0	51,242	0	0	208,526	0.0053	0.031
2012 DBI	**0**	**97**	**0**	**157,187**	**0**	**51,242**	**0**	**0**	**208,526**	**0.0053**	**0.029**
2013 DBI	**0**	**97**	**0**	**157,187**	**0**	**51,242**	**0**	**0**	**208,526**	**0.0061**	**0.025**
2014 DBI	**0**	**97**	**0**	**157,187**	**0**	**51,242**	**0**	**0**	**208,526**	**0.0048**	**0.034**
2014 DBI (NIR 2016)	0	97	0	157,187	0	51,242	0	0	208,526	0.0080	0.034

Source: [1], [43] and own calculation DBI based on [29], [30]

Values in bold have been used as input data in the model

Annex 10: Input and Reference Data Gas Transport - Norway

	Transmission			
Norway	**Distance**	**T&S Gas Lost**	**Feedstock Pipeline Energy**	**Pipeline Electricity Fraction**
	[km to Central EU]	[%]	[$J_{consumed}/J_{transported} \cdot km$]	
2012 GHGenius	1,400	0	0.000030	0
2012 EXERGIA	1,400	0	0.000010	0
2012 DBI	**1,400**	**0**	**0.000015**	**0**
2013 DBI	**1,400**	**0**	**0.000015**	**0**
2014 DBI	**1,400**	**0**	**0.000015**	**0**

Source: [1] and [43]

Values in bold have been used as input data in the model

Annex 11: Input and Reference Data Gas Production - Russia

Russia		**Gas Production**									
		Crude oil	**Diesel fuel**	**Residual fuel**	**Natural gas**	**Coal**	**Electricity**	**Gasoline**	**Coke**	**Total**	**Gas lost**
		[kJ$_{consumed}$/t$_{produced}$]									[%]
	2012 GHGenius	0	0	0	1,012,300	0	12,229	0	0	1,024,529	0.500
	2012 EXERGIA	0	0	0	1,012,300	0	12,229	0	0	1,024,529	0.500
2012 DBI	**Russia 1 *(Ukrainian)***	**0**	**0**	**0**	**722,502**	**0**	**12,483**	**0**	**0**	**734,985**	**0.016**
	Russia 2 *(Belarussian)*	**0**	**0**	**0**	**807,865**	**0**	**13,950**	**0**	**0**	**821,815**	**0.017**
	Russia 3 *(Northern)*	**0**	**0**	**0**	**767,584**	**0**	**13,269**	**0**	**0**	**780,853**	**0.017**
	Russia 4 *(weighted)*	**0**	**0**	**0**	**751,502**	**0**	**12,983**	**0**	**0**	**764,485**	**0.016**
2013 DBI	**Russia 1**	**0**	**0**	**0**	**798,406**	**0**	**13,733**	**0**	**0**	**812,140**	**0.015**
	Russia 2	**0**	**0**	**0**	**812,453**	**0**	**13,978**	**0**	**0**	**826,431**	**0.015**
	Russia 3	**0**	**0**	**0**	**770,797**	**0**	**13,263**	**0**	**0**	**784,060**	**0.014**
	Russia 4	**0**	**0**	**0**	**797,007**	**0**	**13,711**	**0**	**0**	**810,718**	**0.015**
2014 DBI	**Russia 1**	**0**	**0**	**0**	**764,558**	**0**	**15,042**	**0**	**0**	**779,600**	**0.016**
	Russia 2	**0**	**0**	**0**	**770,779**	**0**	**15,165**	**0**	**0**	**785,944**	**0.016**
	Russia 3	**0**	**0**	**0**	**748,008**	**0**	**14,715**	**0**	**0**	**762,722**	**0.015**
	Russia 4	**0**	**0**	**0**	**761,261**	**0**	**14,977**	**0**	**0**	**776,238**	**0.016**

Source: [1], [43] and own calculation DBI based on [37]

Values in bold have been used as input data in the model

Annex 12: Input and Reference Data Gas Processing - Russia

Russia		**Gas Processing**										**Vented CO_2**
		Crude oil	**Diesel fuel**	**Residual fuel**	**Natural gas**	**Coal**	**Electricity**	**Gasoline**	**Coke**	**Total**	**Gas lost**	
		$[kJ_{consumed}/t_{produced}]$									[%]	[%]
	2012 GHGenius	0	0	0	135,700	0	3,653	0	0	139,353	0	0.006
	2012 EXERGIA	0	0	0	135,700	0	3,653	0	0	139,353	0	0.006
2012 DBI	**Russia 1 *(Ukrainian)***	**0**	**0**	**0**	**1**	**0**	**0**	**0**	**0**	**0**	**0**	**0.006**
	Russia 2 *(Belarussian)*	**0**	**0**	**0**	**1**	**0**	**0**	**0**	**0**	**0**	**0**	**0.006**
	Russia 3 *(Northern)*	**0**	**0**	**0**	**1**	**0**	**0**	**0**	**0**	**0**	**0**	**0.006**
	Russia 4 *(weighted)*	**0**	**0**	**0**	**1**	**0**	**0**	**0**	**0**	**0**	**0**	**0.006**
2013 DBI	**Russia 1**	**0**	**0**	**0**	**1**	**0**	**0**	**0**	**0**	**0**	**0**	**0.005**
	Russia 2	**0**	**0**	**0**	**1**	**0**	**0**	**0**	**0**	**0**	**0**	**0.005**
	Russia 3	**0**	**0**	**0**	**1**	**0**	**0**	**0**	**0**	**0**	**0**	**0.005**
	Russia 4	**0**	**0**	**0**	**1**	**0**	**0**	**0**	**0**	**0**	**0**	**0.005**
2014 DBI	**Russia 1**	**0**	**0**	**0**	**1**	**0**	**0**	**0**	**0**	**0**	**0**	**0.005**
	Russia 2	**0**	**0**	**0**	**1**	**0**	**0**	**0**	**0**	**0**	**0**	**0.005**
	Russia 3	**0**	**0**	**0**	**1**	**0**	**0**	**0**	**0**	**0**	**0**	**0.005**
	Russia 4	**0**	**0**	**0**	**1**	**0**	**0**	**0**	**0**	**0**	**0**	**0.005**

Source: [1], [43] and own calculation DBI based on [37]

Values in bold have been used as input data in the model

Annex 13: Input and Reference Data Gas Transport - Russia

Russia		**Transmission**				**Supply Structure**	
		Distance	**Feedstock Pipeline Energy**	**Pipeline Length to Germany**	**T&S Gas Lost**	**Export Gas**	**Share**
		[km to Central EU]	$[J_{consumed}/J_{transported} \cdot km]$	[km]	[%]	[bcm]	[-]
	2012 GHGenius	4,200	0.0000450	-	1.00	-	-
	2012 EXERGIA	4,200	0.0000450	-	1.00	-	-
2012 DBI	**Russia 1 *(Ukrainian)***	**4,725**	**0.0000303**	**5,485**	**0.45**	**62.98**	**0.606**
	Russia 2 *(Belarussian)*	**4,236**	**0.0000303**	**4,920**	**0.36**	**29.02**	**0.279**
	Russia 3 *(Northern)*	**3,624**	**0.0000205**	**3,624**	**0.18**	**11.86**	**0.114**
	Russia 4 *(weighted)*	**4,463**	**0.0000291**	**-**	**0.37**	**103.86**	**-**
2013 DBI	**Russia 1**	**4,733**	**0.0000295**	**5,493**	**0.38**	**62.41**	**0.516**
	Russia 2	**4,243**	**0.0000295**	**4,927**	**0.43**	**34.69**	**0.287**
	Russia 3	**3,243**	**0.0000205**	**3,243**	**0.25**	**23.77**	**0.197**
	Russia 4	**4,300**	**0.0000277**	**-**	**0.32**	**120.87**	**-**
2014 DBI	**Russia 1**	**4,731**	**0.0000242**	**5,491**	**0.38**	**42.92**	**0.379**
	Russia 2	**4,133**	**0.0000242**	**4,817**	**0.38**	**34.64**	**0.306**
	Russia 3	**3,099**	**0.0000205**	**3,099**	**0.22**	**35.55**	**0.314**
	Russia 4	**4,035**	**0.0000231**	**-**	**0.26**	**113.12**	**-**

Source: [1], [43] and own calculation DBI based on [37]

Values in bold have been used as input data in the model

Annex 14: Primary Data Received by Russian gas operators according to Questionnaire

	Dimension	Ukrainian corridor (Russia 1)			Belarussian corridor (Russia 2)			Northern corridor (Russia 3)		
		2012	**2013**	**2014**	**2012**	**2013**	**2014**	**2012**	**2013**	**2014**
Production and Processing										
Raw Gas Produced per Year (allocated to Corridor)	10^9 m^3/a	63.83	63.35	43.54	29.46	35.22	35.14	12.03	24.12	36.05
Energy Consumption Gas Production/ Gas Processing (Natural Gas)	10^6 m^3/a	724.94	776.50	530.90	374.10	439.30	432.00	145.20	285.40	430.10
Flaring	10^6 m^3/a	121.67	151.94	80.19	62.80	85.96	65.25	24.37	55.85	64.95
Energy Consumption Gas Production/ Gas Processing (Electricity)	10^6 kWh$_{el}$/a	162.67	177.60	133.70	83.90	100.50	108.80	32.60	65.30	108.30
Gas Loss	10^6 m^3/a	9.90	9.26	6.81	5.10	5.24	5.55	2.03	3.45	5.55
Transport										
Length of Corridor	km	3,565	3,573	3,571	4,236	4,243	4,133	3,624	3,243	3,099
Export Volume Gas	10^9 m^3/a	62.98	62.41	42.92	29.02	34.69	34.64	11.86	23.77	35.55
Technological Losses	10^6 m^3/a	34.01	33.70	23.18	15.67	18.73	18.71	6.41	12.84	19.20
CH$_4$ Emissions without Technological Losses	10^6 m^3/a	177.57	147.25	101.26	88.26	130.49	112.29	14.81	45.90	60.02
All CH$_4$ Emissions	10^6 m^3/a	211.58	180.96	124.44	103.93	149.22	131.00	21.22	58.73	79.22
Share Total CH4 Emissions on Export Volume	%	0.34	0.29	0.29	0.36	0.43	0.38	0.18	0.25	0.22
Specific Energy Consumption Gas Transport	m^3/(10^6 m^3·km)	30.25	29.46	24.23	30.25	29.46	24.23	20.50	20.50	20.50

Source: [37]

Annex 15: Adjusted lengths of Russian Corridors

Corridor	**Pipeline Length 2012 [km]**	**Pipeline Length 2013 [km]**	**Pipeline Length 2014 [km]**
Ukrainian Corridor (Russia 1)	3,565 + 1,160 + 410 + 350 = 5,485	3,573 + 1,160 + 410 + 350 = 5,493	3,571 + 1,160 + 410 + 350 = 5,491
Belarussian Corridor (Russia 2)	4,236 + 684 = 4,920	4,243 + 684 = 4,927	4,133 +684 = 4,817
Northern Corridor (Russia 3)	3,624	3,243	3,099

Source: Own calculation DBI based on [40]

The lengths of the corridors were calculated by using actual daily flows of the exported amount of gas from the production field to the exit points, which were aggregated for one year. The calculation was done with a mathematical model based on the network scheme of the Russian gas grid. The transport routes and the corresponding lengths differ in several years because different amounts of gas from various production fields are used and, related to this, the dispatching, the nomination of gas volumes and the transport through the gas grid changes, and thus the actual transported distance.

Annex 16: Calculation and Validation of GHG Emissions during Gas Transport in Ukraine

Because there was no suitable data available[42] for determination of GHG emissions caused by the gas transport across the Ukraine, the emissions were estimated with the Russian data. It was assumed, that the energy consumption for gas transport and the loss rate of gas transport were comparable with those of Russia. For this reason the values of the specific energy consumption of the gas transport, already presented in Annex 14, were assumed. By the help of a coefficient, determined from the Russian data, the calculation of gas losses took place.

For the calculation, we used the absolute losses of the Ukrainian corridor (1) divided by the length of the corridor (2) and determined a value for the relative loss per km pipeline (3). This value was multiplied with the length of the pipelines in the Ukrainian part of the corridor (4), to determine the absolute loss of gas transport within the Ukraine (5). This loss was added to the loss value of the Russian gas transport, resulting in a total loss for the whole corridor (6). In the following, the total loss was divided by the export gas volume (7), to determine the share of losses for the export gas (8).

Table 28: Calculation of GHG emissions during gas transport in Ukraine

Position	Description	Unit	Ukrainian Corridor (Russia 1)			Source
			2012	2013	2014	
(1)	Total CH_4 emissions	10^6 m³/a	211.58	180.96	124.44	[37]
(2)	Length of the corridor	km	3,565	3,573	3,571	[37]
(3)	Relative loss per km pipeline	m³/km·a	59,350	50,645	34,848	DBI
(4)	Length Ukrainian part of the corridor	km	1,160	1,160	1,160	[38]
(5)	Absolute loss Ukrainian part	10^6 m³/a	68.85	58.75	40.42	DBI
(6)	Total loss Russia to Central EU	10^6 m³/a	280.43	239.70	164.87	DBI
(7)	Export gas volume	10^9 m³/a	62.98	62.41	42.92	[37]
(8)	Share of export gas	%	0.45	0.38	0.38	DBI

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[42] In fact, Ukrainian grid operators submitted data but this data was on a high level of aggregation. For this reason, it was not possible to use the data as input data for the calculation but it was used for the validation of the DBI approach.

Table 29: Validation of data for the Ukrainian corridor

	Unit	Year			Source
		2012	2013	2014	
Methane emissions of the Ukrainian corridor (Russia 1)	10^6 m^3/a	68.85	58.75	40.42	[DBI]
Methane emissions of the Ukrainian corridor (Russia 1)[43]	kt/a	51	43	30	[DBI]
Methane emissions from PJSC Uktransgaz	kt/a	137.1	137.8	106.4	[54]

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[43] Conversion of above data with help of a density at 0.735 kg/m^3, which is typical for Russian high caloric gas (see Annex 2).

Annex 17: Natural Gas Supply Structure in Central EU and Germany 2012 to 2014 [Mio. m³]

Table 30: Natural Gas Supply Structure in Central EU and Germany in the years 2012 to 2014 [Mio. m³]

	Producing countries ↓												
Consuming countries ↓	**Germany**	**Den-mark**	**Nether-lands**	**Po-land**	**Norway**	**Norway LNG**	**UK**	**Russia**	**Qatar**	**Hun-gary**	**Other**	**Other LNG**	**Total**
year: 2012													
Belgium	909	0	6,795	0	6,072	0	2,042	0	2,038	0	0	0	17,855
Czech Rep,	0	0	0	0	3	0	0	7,468	0	0	263	0	7,734
Germany	11,060	0	21,930	0	20,688	0	0	27,575	0	0	4,508	0	85,761
Share in Germany	**12.9%**	**0%**	**25.6%**	**0%**	**24.1%**	**0%**	**0%**	**32.2%**	**0%**	**0%**	**5.3%**	**0%**	**100%**
Estonia	0	0	0	0	0	0	0	657	0	0	0	0	657
Latvia	0	0	0	0	0	0	0	1,716	0	0	0	0	1,716
Lithuania	0	0	0	0	0	0	0	3,263	0	0	0	0	3,263
Luxembourg	0	0	14	0	627	0	0	290	0	0	279	0	1,210
Hungary	0	0	0	0	0	0	0	7,797	0	2,175	159	0	10,130
The Netherlands	251	561	34,370	0	6,805	326	1,878	1,257	0	0	0	109	45,558
Austria	0	0	0	0	1,107	0	0	5,001	0	0	2,818	0	8,926
Poland	1,840	0	0	6,158	0	0	0	9,528	0	0	571	0	18,097
Slovakia	0	0	0	150	0	0	0	4,801	0	0	0	0	4,951
Total	14,060	561	63,109	6,308	35,302	326	3,920	69,353	2,038	2,175	8,598	109	205,858
Share in Central EU	**6.8%**	**0.3%**	**30.7%**	**3.1%**	**17.1%**	**0.2%**	**1.9%**	**33.7%**	**1.0%**	**1.1%**	**4.2%**	**0.1%**	**100%**
year: 2013													
Belgium	1,223	0	8,174	0	6,087	0	1,070	0	1,459	0	0	7	18,020
Czech Rep,	0	0	0	0	4	0	0	8,217	0	0	245	0	8,466
Germany	9,745	0	24,699	0	16,154	0	0	31,881	0	0	5,241	0	87,720
Share in Germany	**11.1%**	**0%**	**28.2%**	**0%**	**18.4%**	**0%**	**0%**	**36.3%**	**0%**	**0%**	**6.0%**	**0%**	**100%**
Estonia	0	0	0	0	0	0	0	678	0	0	0	0	678
Latvia	0	0	0	0	0	0	0	1,698	0	0	0	0	1,698
Lithuania	0	0	0	0	0	0	0	2,661	0	0	0	0	2,661
Luxembourg	0	0	0	0	622	0	0	245	0	0	106	1	974

	Producing countries ↓												
Consuming countries ↓	**Germany**	**Den-mark**	**Nether-lands**	**Po-land**	**Norway**	**Norway LNG**	**UK**	**Russia**	**Qatar**	**Hun-gary**	**Other**	**Other LNG**	**Total**
Hungary	0	0	0	0	0	0	0	7,150	0	1,804	377	0	9,331
The Netherlands	349	571	35,085	0	6,270	303	1,647	1,747	0	0	0	101	46,074
Austria	0	0	0	0	1,055	0	0	4,768	0	0	2,771	0	8,594
Poland	2,213	0	0	6,057	0	0	0	9,390	0	0	570	0	18,229
Slovakia	0	0	0	0	0	0	0	5,323	0	0	187	0	5,510
Total	13,530	571	67,958	6,057	30,192	303	2,717	73,757	1,459	1,804	9,497	109	207,955
Share in Central EU	**6.5%**	**0.3%**	**32.7%**	**2.9%**	**14.5%**	**0.1%**	**1.3%**	**35.5%**	**0.7%**	**0.9%**	**4.6%**	**0.1%**	**100%**
year: 2014													
Belgium	336	0	7,485	0	5,178	0	1,565	0	1,217	0	0	3	15,784
Czech Rep,	0	0	0	0	699	0	0	6,550	0	0	259	0	7,508
Germany	7,549	0	22,363	0	16,582	0	0	29,656	0	0	3,062	0	79,212
Share in Germany	**9.5%**	**0%**	**28.2%**	**0%**	**20.9%**	**0%**	**0%**	**37.4%**	**0%**	**0%**	**3.9%**	**0%**	**100%**
Estonia	0	0	0	0	0	0	0	530	0	0	0	0	530
Latvia	0	0	0	0	0	0	0	947	0	0	0	0	947
Lithuania	0	0	0	0	66	0	0	2,614	0	0	0	0	2,680
Luxembourg	0	0	0	0	622	0	0	245	0	0	106	1	974
Hungary	0	0	0	0	0	0	0	6,879	0	1,504	362	0	8,745
The Netherlands	5,20	246	28,426	0	6,468	381	1,486	2,603	0	0	0	127	40,258
Austria	0	0	0	0	971	0	0	4,390	0	0	2,484	0	7,845
Poland	2,332	0	1	6,006	85	0	0	8,826	0	0	409	0	17,658
Slovakia	0	0	0	0	0	0	0	4,757	0	0	100	0	4,857
Total	10,737	246	58,276	6,006	30,672	381	3,051	67,995	1,217	1,504	6,782	131	186,998
Share in Central EU	**5.7%**	**0.1%**	**31.2%**	**3.2%**	**16.4%**	**0.2%**	**1.6%**	**36.4%**	**0.7%**	**0.8%**	**3.6%**	**0.1%**	**100%**

Source: Own calculation DBI based on [9], [41]

Table 31: Contribution of the Russian gas exports to Central EU and Germany in the years 2012-2014

	Share on Russian natural gas stream	Share of total supply	Share in system "Germany"
year: 2012			
Russia 1 (Ukrainian Corridor)	0.606	0.204	0.129
Russia 2 (Belarussian Corridor)	0.279	0.094	0.132
Russia 3 (Northern Corridor)	0.114	0.038	0.060
Total	1.000	0.337	0.322
year: 2013			
Russia 1 (Ukrainian Corridor)	0.516	0.183	0.123
Russia 2 (Belarussian Corridor)	0.287	0.102	0.133
Russia 3 (Northern Corridor)	0.197	0.070	0.107
Total	1.000	0.355	0.363
year: 2014			
Russia 1 (Ukrainian Corridor)	0.379	0.138	0.088
Russia 2 (Belarussian Corridor)	0.306	0.111	0.132
Russia 3 (Northern Corridor)	0.314	0.114	0.154
	1.000	0.364	0.374

Source: Own calculation DBI based on [9], [37], [42], [41]

Annex 18: Fraction of Natural Gas Consumption in the Countries in the Region Central EU of Total Natural Gas Consumption

	EXERGIA	**DBI 2012**	**DBI 2013**	**DBI 2014**
Belgium	0.086	0.086	0.087	0.084
Czech Republic	0.040	0.041	0.041	0.040
Germany	0.414	0.415	0.422	0.424
Estonia	0.003	0.003	0.003	0.003
Latvia	0.007	0.007	0.007	0.007
Lithuania	0.016	0.016	0.013	0.014
Luxembourg	0.006	0.006	0.005	0.005
Hungary	0.049	0.049	0.045	0.047
Netherlands	0.222	0.220	0.222	0.215
Austria	0.044	0.043	0.041	0.042
Poland	0.087	0.088	0.088	0.094
Slovakia	0.026	0.026	0.027	0.024
Central EU	**1.000**	**1.000**	**1.000**	**1.000**

Quelle: Own calculation DBI based on [9], [41]

Annex 19: Greenhouse Gas Emissions of Natural Gas produced in Germany and distributed in Central EU

Stream Germany	**2012**				**2013**				**2014**			
	CO_2	**CH_4**	**N_2O**	**CO**[44]	**CO_2**	**CH_4**	**N_2O**	**CO**[44]	**CO_2**	**CH_4**	**N_2O**	**CO**[44]
	[g/GJ]											
Transmission, storage and distribution in Central EU	137.9	64.4	0.0	0.0	137.8	62.9	0.0	0.0	134.7	66.8	0.0	0.0
Gas processing	972.2	6.7	0.0	0.8	979.1	6.8	0.0	0.8	819.5	6.1	0.0	0.6
Gas transport[45]	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Gas production	1,597.9	15.1	0.1	1.9	1,685.7	16.1	0.1	2.1	2,005.2	18.1	0.1	2.5
CO_2, H_2S removed from NG	2,388.1	0.0	0.0	0.0	2,738.6	0.0	0.0	0.0	2,172.3	0.0	0.0	0.0
Total	**5,096.1**	**86.1**	**0.1**	**2.7**	**5,541.2**	**85.9**	**0.1**	**2.9**	**5,131.8**	**90.9**	**0.1**	**3.2**

Source: Own calculation DBI based on [14], [15], [20]

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[44] CO is not a direct greenhouse gas, however it is considered a „precursor gas“ and is therefore included in the calculations of the Carbon Footprint in GHGenius. It's assumed that CO oxidises completely to CO2 in the atmosphere. For details, refer to section 4.1.

[45] Gas transport to another country in Central EU.

Annex 20: Greenhouse Gas Emissions of Natural Gas produced in The Netherlands and distributed in Central EU

Stream Netherlands	**2012**				**2013**				**2014**			
	CO_2	**CH_4**	**N_2O**	**CO**[44]	**CO_2**	**CH_4**	**N_2O**	**CO**[44]	**CO_2**	**CH_4**	**N_2O**	**CO**[44]
	[g/GJ]											
Transmission, storage and distribution in Central EU	130.1	64.3	0.0	0.0	129.5	62.9	0.0	0.0	127.3	66.8	0.0	0.0
Gas processing	16.0	0.0	0.0	0.0	20.6	0.0	0.0	0.0	24.2	0.0	0.0	0.0
Gas transport[46]	1.1	6.0	0.0	0.0	1.1	6.0	0.0	0.0	1.1	6.0	0.0	0.0
Gas production	811.7	10.5	0.0	1.1	916.1	9.9	0.0	1.2	924.0	11.0	0.0	1.2
CO_2, H_2S removed from NG	0.8	0.0	0.0	0.0	0.6	0.0	0.0	0.0	0.8	0.0	0.0	0.0
Total	**959.8**	**80.9**	**0.0**	**1.2**	**1,068.0**	**78.8**	**0.0**	**1.2**	**1,077.5**	**83.8**	**0.0**	**1.3**

Source: Own calculation DBI based on [21], [22], [23], [24], [25], [26]

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[46] Gas transport to another country in Central EU.

Annex 21: Greenhouse Gas Emissions of Natural Gas produced in Norway and distributed in Central EU

Stream Norway	**2012**				**2013**				**2014**			
	CO_2	**CH_4**	**N_2O**	**CO**[44]	**CO_2**	**CH_4**	**N_2O**	**CO**[44]	**CO_2**	**CH_4**	**N_2O**	**CO**[44]
	[g/GJ]											
Transmission, storage and distribution in Central EU	134.2	64.4	0.0	0.0	133.5	62.9	0.0	0.0	131.3	66.8	0.0	0.0
Gas processing	268.9	1.8	0.0	0.2	269.3	1.9	0.0	0.2	269.3	1.7	0.0	0.2
Gas transport[47]	1,574.8	1.9	0.0	0.6	1,577.7	2.0	0.0	0.6	1,576.4	1.9	0.0	0.6
Gas production	1,328.5	14.3	0.1	2.4	1,422.7	15.1	0.1	2.6	1,438.1	15.4	0.1	2.6
CO_2, H_2S removed from NG	14.5	0.0	0.0	0.0	12.4	0.0	0.0	0.0	16.8	0.0	0.0	0.0
Total	**3,320.9**	**82.4**	**0.1**	**3.2**	**3,415.5**	**82.0**	**0.2**	**3.4**	**3,431.8**	**85.9**	**0.2**	**3.4**

Source: Own calculation DBI based on [28], [29], [30], [65]

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[47] Gas transport to Central EU border.

Annex 22: Greenhouse Gas Emissions of Natural Gas produced in Russia and distributed in Central EU

Stream Russia (weighted average)	**2012**				**2013**				**2014**			
	CO_2	**CH_4**	**N_2O**	**CO[44]**	**CO_2**	**CH_4**	**N_2O**	**CO[44]**	**CO_2**	**CH_4**	**N_2O**	**CO[44]**
	[g/GJ]											
Transmission, storage and distribution in Central EU	148.3	64.4	0.0	0.0	150.0	63.0	0.0	0.0	146.2	66.8	0.0	0.0
Gas processing	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Gas transport[48]	10,891.7	104.3	0.1	4.2	12,456.8	77.0	0.1	4.8	11,791.9	69.2	0.1	4.5
Gas production	874.3	12.1	0.0	1.4	878.1	11.7	0.0	1.4	856.5	11.7	0.0	1.4
CO_2, H_2S removed from NG	3.0	0.0	0.0	0.0	2.4	0.0	0.0	0.0	2.4	0.0	0.0	0.0
Total	**11,917.4**	**180.9**	**0.1**	**5.7**	**13,487.3**	**151.7**	**0.1**	**6.3**	**12,797.0**	**147.7**	**0.1**	**6.0**

Source: Own calculation DBI based on [37]

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[48] Gas transport to Central EU border.

Annex 23: Electricity Mix in Central EU and in Germany

	Coal	Oil	Gas Boiler[49]	Gas Turbine	Nuclear	Wind	Other Carbon	Biomass	Hydro
Central EU	0.39	0.02	0.18	0.00	0.17	0.08	0.03	0.06	0.08
Germany	0.437	0.012	0.123	0.000	0.158	0.122	0.029	0.071	0.044

Source: [43]

Annex 24: Efficiency of Electricity Generation in Central EU and in Germany

	Coal	Oil	Gas Boiler[49]	Gas Turbine	Nuclear	Wind	Other Carbon	Biomass	Hydro
Central EU	0.39	0.69	0.54	0.45	0.35	1.00	0.39	0.37	1.00
Germany	0.398	0.772	0.562	0.450	0.350	1.000	0.398	0.421	1.000

Source: [43]

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[49] This is the term in GHGenius, which actually represents electricity production from natural gas with a single cycle process with a steam turbine. Since publicly available data often do not distinguish the electricity production from natural gas into different technologies, this column represents single cycle and combined cycle plants. The column “gas turbine” is not filled.

Annex 25: CF of Natural Gas produced in Germany and distributed in Central EU

	EXERGIA with dispensing	**EXERGIA without dispensing**	**DBI without dispensing**		
Germany	**2012**	**2012**	**2012**	**2013**	**2014**
	[gCO$_2$e/GJ]				
Fuel dispensing	4,095	Not considered	Not considered	Not considered	Not considered
Transmission, storage and distribution in Central EU	2,791	2,791	1,747	1,712	1,805
Gas processing	2,229	2,229	1,145	1,154	977
Gas transport[50]	0	0	0	0	0
Gas production	3,478	3,478	1,995	2,111	2,483
CO_2, H_2S removed from NG	2,613	2,613	2,388	2,739	2,172
Total [gCO$_2$e/GJ]	**15,205**	**11,110**	**7,276**	**7,716**	**7,437**

Source: Own calculation DBI based on [14], [15], [20]

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[50] Gas transport to another country in Central EU.

Annex 26: CF of Natural Gas produced in The Netherlands and distributed in Central EU

	EXERGIA with dispensing	**EXERGIA without dispensing**	**DBI without dispensing**		
The Netherlands	**2012**	**2012**	**2012**	**2013**	**2014**
	[gCO_2e/GJ]				
Fuel dispensing	4,053	Not considered	Not considered	Not considered	Not considered
Transmission, storage and distribution in Central EU	2,769	2,769	1,739	1,703	1,797
Gas processing	0	0	17	22	26
Gas transport[51]	151	151	151	151	151
Gas production	1,294	1,294	1,086	1,175	1,210
CO_2, H_2S removed from NG	1	1	1	1	1
Total [CO_2e/GJ]	**8,263**	**4,215**	**2,993**	**3,051**	**3,185**

Source: Own calculation DBI based on [21], [22], [23], [24], [25], [26]

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[51] Gas transport to another country in Central EU.

Annex 27: CF of Natural Gas produced in Norway and distributed in Central EU

	EXERGIA with dispensing	**EXERGIA without dispensing**	**DBI without dispensing**		
Norway	**2012**	**2012**	**2012**	**2013**	**2014**
	[gCO_2e/GJ]				
Fuel dispensing	4,071	Not considered	Not considered	Not considered	Not considered
Transmission, storage and distribution in Central EU	2,781	2,781	1,743	1,707	1,801
Gas processing	318	318	317	320	315
Gas transport[52]	3,374	3,374	1,628	1,632	1,629
Gas production	1,930	1,930	1,726	1,847	1,867
CO_2, H_2S removed from NG	113	113	14	12	17
Total [gCO_2e/GJ]	**12,589**	**8,517**	**5,429**	**5,519**	**5,629**

Source: Own calculation DBI based on [28], [29], [30], [65]

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[52] Gas transport to Central EU border.

Annex 28: CF of Natural Gas produced in Russia and distributed in Central EU

	EXERGIA with dispensing	**EXERGIA without dispensing**	**DBI without dispensing**		
	2012	**2012**	**2012**	**2013**	**2014**
	[gCO$_2$e/GJ]				
Fuel dispensing	4,204.7	Not considered	Not considered	Not considered	Not considered
Transmission, storage and distribution in Central EU	2,838.1	2,838.1	1,759.3	1,721.1	1,810.2
Gas processing	180.0	180.0	0.0	0.0	0.0
Gas transport[53]	25,014.1	25,014.1	13,521.5	12,139.8	9,247.5
Gas production	3,639.7	3,639.7	1,164.8	1,223.1	1,179.4
CO$_2$, H$_2$S removed from NG	3.0	3.0	3.0	2.4	2.4
Total [gCO$_2$e/GJ]	**35,880**	**31,675**	**16,449**	**15,086**	**12,239**

Source: Own calculation DBI based on [37]

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[53] Gas transport to Central EU border.