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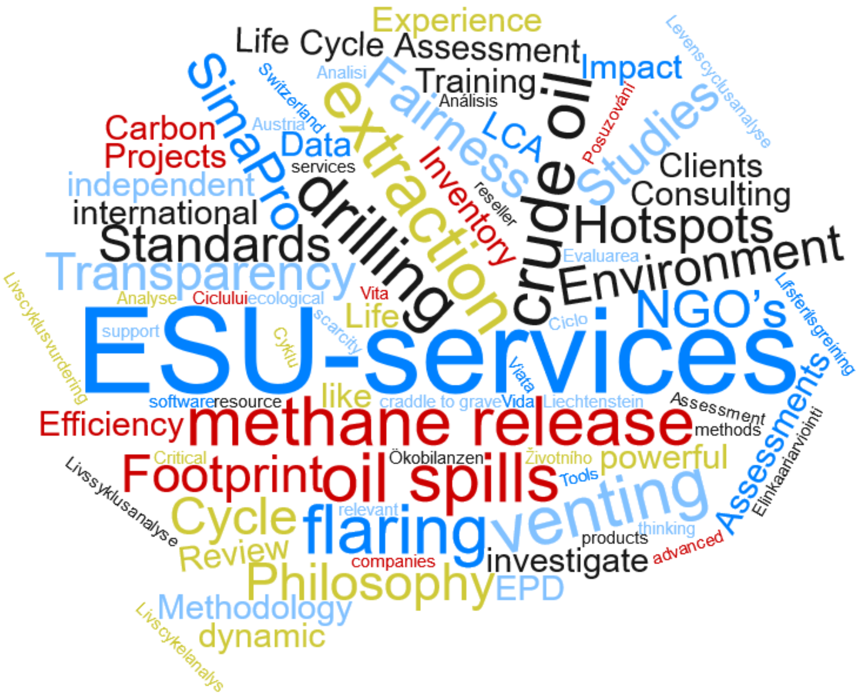
Life cycle inventories for long-distance transport and distribution of natural gas



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Life cycle inventories for long-distance transport and distribution of natural gas

Report

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Abstract

Natural gas is an important fossil fuel for the energy supply in several countries. Fossil fuels cause environmental problems, particularly regarding climate change. Frequently, the environmental impacts of gaseous and liquid fuels and their use are compared, considering the upstream process chain.

A prerequisite for such a comparison is the use of current and consistent LCI data. Data on gas production and its transport to several countries were last fully updated in 2022 for ecoinvent 3.9. These data should now be updated and extended for the upcoming in the ecoinvent release.

Therefore, in this and two related reports (Meili et al. 2023a, b) data on global oil and natural gas production and the supply of its products to Europe, North America and worldwide are documented for the reference year 2021.

Contents

Abbreviations

µg	Microgram: 10-9 kg
AE	United Arab Emirates
AZ	Azerbaijan
BE	Belgium
BR	Brazil
C/H	Hydrocarbons
CA	Canada
CFC	Chlorofluorocarbon
CH	Switzerland
CN	China
CO	Colombia
DE	Germany
DIN	Deutsches Institut für Normung e.V.
DVGW	Deutsche Vereinigung des Gas- und Wasserfaches
DZ	Algeria
EC	Ecuador
EIA	U.S. Energy Information Administration
ES	Spain
FR	France
GB	United Kingdom
GCV	Gross calorific value
HDPE	High density polyethylene
H-gas	High calorific natural gas
HP	High-pressure
ID	Indonesia
IQ	Iraq
IT	Italy
IR	Iran
K	Degree Kelvin
kBq	Kilobecquerel
KZ	Kazakhstan
KW	Kuwait
LCA	Life Cycle Assessment
LCI	Life Cycle Inventory Analysis
LCIA	Life Cycle Impact Assessment
LDPE	Low density polyethylene
L-gas	Low-calorific natural gas
LNG	Liquid Natural Gas
LY	Libyan Arab Jamahiriya
m3	Cubic metre
MWI	Municipal Waste Incinerator
MX	Mexico
MY	Malaysia
NAC	North African Countries
NCS	Norwegian Continental Shelf
NCV	Net calorific value
NG	Nigeria
NGL	Natural gas liquids: mixture of ethane, propane, butane and pentane
NL	The Netherlands
Nm3	Normal cubic meter

NMVOC	Non-methane volatile organic compounds
NO	Norway
o.e.	Oil equivalent: 1 Nm3 oil = 1 Nm3 o.e., 1'000 Nm3 mnatural gas = 1 Nm3 o.e. resp. 0.84 kg o.e., 1 kg o.e. = 42.3 MJ (NCV).
PAHs	Polycyclic aromatic hydrocarbons
PE	Polyethylene
PJ	Petajoule : 1015 Joule
QA	Qatar
RER	Region Europe
RME	Region Middle East
RNA	Region North America
RO	Romania
RU	Russian Federation
SA	Saudi Arabia
SDg2	Square of the geometric standard deviation
SVGW	Swiss Association of gas and water (Schweizerischer Verein des Gas- und Wasserfaches)
TJ	Terajoule : 1e12 Joule
TR	Turkey
UCTE	Union for the Co-ordination of Transmission of Electricity
US	United States of America
VE	Venezuela
VOC	Volatile organic compound
VSG	Association of the Swiss gas industry (Verband der Schweizerischen Gasindustrie)

1 Introduction

This document is based on former reports for the life cycle inventory data for natural gas (Bussa et al. 2021, 2022_ENREF_4) extending the regional scope to Asia. Bussa et al. 2021 is an update of the life cycle inventory data provided by Schori et al. 2012 and considered also updates made for the ecoinvent v3 data (Faist-Emmenegger et al. 2015). The approach for the modelling of the life cycle inventory analysis is based on a generic archetype model for the oil and gas production chains (Meili & Jungbluth 2019a, b).

The goal of the report is to document the data as they are provided for the ecoinvent database for the reference year 2021.

In general, only subchapters on process steps that are assessed as relevant in the former LCIA results (ecological scarcity 2013) were kept or updated in this report.

If the figures did not change considerably or no new figures were available, the former text was kept for this report to provide this relevant information.

The data documented in this report are provided to the commissioner in XML format. They are also integrated in the ESU-database (ESU-services 2023). For the integration in ecoinvent data v3.10 further changes and extensions have been applied which are documented in a change report (Moreno Ruiz et al. 2022).

The following chapters analyse the transport and distribution of natural gas for various destination countries and regions.

Energy requirements and emissions are inventoried for pipeline and LNG-Transport. Transport routes from the most relevant countries of origin to destination countries and regions are investigated and supply mixes are calculated based on trade statistics. These data are used to prepare life cycle inventories for pipeline and LNG transport as well as for high- and low-pressure distribution.

2 Market situation for supplies to individual countries and regions

In this study both country-specific and regional consumption mixes are of interest. Country-specific consumption mixes are provided for CA, MX, US, CN, JP, KR, TR, BE, FR, DE, IT, NL, ES, GB and CH. Regional consumption mixes are calculated for RNA, EU-28 and GLO. The EU-28 mix is labelled in the datasets with the country code “RER”. In the framework of the LCA methodology the original country for the natural gas extraction is of interest. Therefore, by using trade and extraction statistics the activities of trading countries are traced back to assess the amount of natural gas extracted for final consumption in the destination countries and regions.

In this study, all natural-gas producing countries which contributed with at least 0.5%$_{vol}$ to the North American, EU-28 and global supply mix were considered. In addition, the natural gas extraction was also modelled for relevant oil supply countries, as often a combined production is conducted. Additionally, smaller production countries, which were modelled in Meili et al. 2023b are included as well. In total, 48 countries of origin are investigated.

Different data sources could be used to estimate the consumption mix in the destination countries and regions. The ideal data source would have to cover the following information (but is not yet available):

- Reference year 2021 with updates available annually
- Detailed information for all producing countries and all European countries (including Switzerland)
- Clear definition how transit countries and temporary storage are handled
- Consistent modelling for crude oil and natural gas
- Differentiation for trade movements by pipeline and ship (crude oil and LNG)
- Detailed regarding import for own consumption and re-exports to other countries
- Full transparency of data sources

The available data sources have advantages and disadvantages, which makes it difficult to find a perfect solution:

- BP-statistics (2022): Published annually and available with 2021 data. Details for trade by pipeline and LNG. Not all countries covered and thus contains a relevant part of "Other European countries". For Europe, the source differentiates only between EU-countries and non-EU countries.
- Eurostat (2023a, b): Annual data of imports and exports of natural gas by country of production and destination. Full coverage of all EU-27 countries, EFTA-countries, EU candidate countries and potential candidate countries, but Switzerland and the United Kingdom do not deliver data for these statistics. Separate data for LNG are available, but for some countries considerable shares of natural gas imports are classified as "Not further specified" for reasons of confidentiality or lacking information on production countries. Updated annually in January for the penultimate year. Data for 2021 are available at the time of this project.
- Eurostat (2023c, d): Monthly data of imports and exports of natural gas but other than the annual data referring to country entry points and not to production countries. Full coverage of all EU-27 countries, EFTA-countries, EU candidate countries and potential candidate countries, but Switzerland and the United Kingdom do not deliver data for these statistics. However, exports from reporting countries to the United Kingdom and Switzerland are included. Data for 2021 are available.
- IEA statistics (2020a): Full coverage of all European countries including Switzerland. Data for 2019 are available. LNG imports are accounted for separately but without specifying the country of origin. Gas trades are shown for country entry points without any information on the production country.
- VSG (2022): The yearly statistics of the VSG provide data on the natural gas imports of Switzerland and is available for 2021. However, the breakdown into countries of origin is not sufficient for LCI modelling as only data for three producing countries are shown and the remaining imports are aggregated in EU-countries and other countries.
- Department for Business, Energy and Industrial Strategy (2022): The Department for Business, Energy and Industrial Strategy provides data on the natural gas imports and exports of the United Kingdom for 2021. Imports via pipeline and LNG are presented separately.

The chosen modelling approach is described in the following sub-chapters.

2.1 Non-European countries

The consumption mixes for CA, MX, US, CN, JP and KR were calculated based on the production and trade statistics provided in BP (2022) and are summarized in Tab. 2.1.

Tab. 2.1 Natural gas consumption mix in CA, MX, US, CN, JP and KR. Marked in green: Countries modelled in this study

Origin of natural gas	CA	MX	US	CN	JP	KR
	%	%	%	%	%	%
United Arab Emirates	0.0%	0.0%	0.0%	0.3%	1.8%	0.6%
Angola	0.0%	0.0%	0.0%	0.2%	0.0%	0.2%
Australia	0.0%	0.0%	0.0%	11.7%	35.8%	20.2%
Azerbaijan	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Belgium	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Brunei Darussalam	0.0%	0.0%	0.0%	0.2%	5.8%	0.4%
Bolivia	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Brazil	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Canada	78.6%	0.0%	9.1%	0.0%	0.0%	0.0%
Cameroon	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
China	0.0%	0.0%	0.0%	56.3%	0.0%	0.0%
Colombia	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Germany	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Denmark	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Algeria	0.0%	0.0%	0.0%	0.1%	0.0%	0.0%
Ecuador	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Egypt	0.0%	0.0%	0.0%	0.5%	0.3%	0.4%
Spain	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
France	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
United Kingdom	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Equatorial Guinea	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Indonesia	0.0%	0.4%	0.0%	1.8%	2.5%	5.1%
Iraq	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Iran	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Italy	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Japan	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
South Korea	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Kuwait	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Kazakhstan	0.0%	0.0%	0.0%	1.6%	0.0%	0.0%
Libya	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Myanmar	0.0%	0.0%	0.0%	1.1%	0.0%	0.0%
Mexico	0.0%	32.9%	0.0%	0.0%	0.0%	0.0%
Malaysia	0.0%	0.0%	0.0%	3.2%	13.7%	8.3%
Nigeria	0.0%	0.0%	0.0%	0.6%	1.1%	1.4%
Netherlands	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Norway	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Not specified	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Oman	0.0%	0.0%	0.0%	0.6%	2.6%	9.8%
Peru	0.1%	0.0%	0.0%	0.1%	0.7%	1.8%
Papua New Guinea	0.0%	0.0%	0.0%	1.2%	4.7%	0.4%
Poland	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Qatar	0.0%	0.0%	0.0%	3.3%	12.2%	25.1%
Romania	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Other Africa	0.0%	0.0%	0.0%	0.4%	0.3%	0.6%
Other Asia Pacific	0.0%	0.0%	0.0%	0.2%	0.2%	0.1%
Rest of Europe	0.0%	0.0%	0.0%	0.1%	0.2%	0.4%
Other Middle East	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Other S. & Cent. America	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Russian Federation	0.0%	0.0%	0.0%	3.7%	8.6%	6.1%
Saudi Arabia	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Turkmenistan	0.0%	0.0%	0.0%	8.5%	0.0%	0.0%
Trinidad and Tobago	0.5%	0.1%	0.1%	0.2%	0.0%	0.1%
United States	20.8%	66.6%	90.8%	3.3%	9.5%	18.9%
Uzbekistan	0.0%	0.0%	0.0%	1.2%	0.0%	0.0%
Venezuela	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Yemen	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Total	**100.0%**	**100.0%**	**100.0%**	**100.0%**	**100.0%**	**100.0%**

Not all countries of origin are included in Meili et al. (2023b), hence these countries were excluded from the modelled mixes and the contribution of the other countries was scaled accordingly. Tab. 2.2 shows the country specific LCIs modelled in this study.

Tab. 2.2 Modelled natural gas consumption mix for CA, MX, US, CN, JP and KR. Marked in green: Countries modelled in this study

Origin of natural gas	**CA**	**MX**	**US**	**CN**	**JP**	**KR**
	%	%	%	%	%	%
United Arab Emirates	0.0%	0.0%	0.0%	0.3%	2.0%	0.6%
Angola	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Australia	0.0%	0.0%	0.0%	12.1%	40.3%	20.6%
Azerbaijan	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Belgium	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Brunei Darussalam	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Bolivia	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Brazil	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Canada	78.6%	0.0%	9.1%	0.0%	0.0%	0.0%
Cameroon	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
China	0.0%	0.0%	0.0%	58.2%	0.0%	0.0%
Colombia	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Germany	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Denmark	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Algeria	0.0%	0.0%	0.0%	0.1%	0.0%	0.0%
Ecuador	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Egypt	0.0%	0.0%	0.0%	0.5%	0.3%	0.4%
Spain	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
France	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
United Kingdom	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Equatorial Guinea	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Indonesia	0.0%	0.4%	0.0%	1.8%	2.9%	5.2%
Iraq	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Iran	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Italy	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Japan	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
South Korea	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Kuwait	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Kazakhstan	0.0%	0.0%	0.0%	1.6%	0.0%	0.0%
Libya	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Myanmar	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Mexico	0.0%	32.9%	0.0%	0.0%	0.0%	0.0%
Malaysia	0.0%	0.0%	0.0%	3.3%	15.4%	8.5%
Nigeria	0.0%	0.0%	0.0%	0.6%	1.3%	1.4%
Netherlands	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Norway	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Not specified	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Oman	0.0%	0.0%	0.0%	0.6%	2.9%	10.0%
Peru	0.1%	0.0%	0.0%	0.1%	0.8%	1.9%
Papua New Guinea	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Poland	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Qatar	0.0%	0.0%	0.0%	3.4%	13.7%	25.7%
Romania	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Other Africa	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Other Asia Pacific	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Rest of Europe	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Other Middle East	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Other S. & Cent. America	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Russian Federation	0.0%	0.0%	0.0%	3.8%	9.7%	6.3%
Saudi Arabia	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Turkmenistan	0.0%	0.0%	0.0%	8.8%	0.0%	0.0%
Trinidad and Tobago	0.5%	0.1%	0.1%	0.2%	0.0%	0.1%
United States	20.8%	66.6%	90.8%	3.5%	10.7%	19.4%
Uzbekistan	0.0%	0.0%	0.0%	1.2%	0.0%	0.0%
Venezuela	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Yemen	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Total	**100.0%**	**100.0%**	**100.0%**	**100.0%**	**100.0%**	**100.0%**

2.2 European countries

For European countries, no trade data are provided anymore on country-specific level by BP (2022). The consumption mixes for TR, BE, DE, IT, FR, NL, ES were calculated based on the annual Eurostat import statistics (EUROSTAT 2023a). In the case of Germany, where a considerable share of the natural gas imports was reported as not further classified, the gap could be partly filled with information of other countries reporting exports to Germany (EUROSTAT 2023b). Domestic production of natural gas is based on EUROSTAT (2023e).

As no source is available presenting sufficient detail to model the Swiss natural gas mix by country of origin, the mix was modelled based on the monthly exports reported to Switzerland by its neighbouring countries (EUROSTAT 2023d).

Since the United Kingdom imports a significant amount natural gas via LNG from Non-European countries, the approach used for Switzerland could not be applied here. Instead, the data provided by Department for Business 2022 were used.

In cases where imports from a net-importing country were reported, the consumption mix was used instead of the production dataset, e.g. German imports from Belgium are modelled with the Belgian consumption mix and not with natural gas extracted in Belgium.

Tab. 2.3 Natural gas consumption mix in TR, BE, FR, DE, NL, IT, ES, GB and CH. Marked in green: Countries modelled in this study

Origin of natural gas	**TR**	**BE**	**FR**	**DE**	**NL**	**IT**	**ES**	**GB**	**CH**
	%	%	%	%	%	%	%	%	%
United Arab Emirates	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Angola	0.0%	0.0%	0.0%	0.0%	0.4%	0.0%	1.0%	0.0%	0.0%
Australia	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Azerbaijan	15.0%	0.0%	0.0%	0.0%	0.0%	9.5%	0.0%	0.0%	0.0%
Belgium	0.0%	0.0%	0.9%	0.5%	3.1%	0.0%	0.0%	2.3%	0.0%
Brunei Darussalam	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Bolivia	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Brazil	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Canada	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Cameroon	0.0%	0.0%	0.0%	0.0%	0.2%	0.0%	0.0%	0.0%	0.0%
China	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Colombia	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Germany	0.0%	0.0%	0.4%	6.0%	0.8%	0.0%	0.0%	0.0%	54.5%
Denmark	0.0%	0.6%	0.0%	0.0%	0.8%	0.0%	0.0%	0.0%	0.0%
Algeria	10.2%	0.4%	8.4%	0.0%	0.2%	29.5%	43.4%	0.9%	0.0%
Ecuador	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Egypt	2.3%	0.4%	0.0%	0.0%	0.0%	0.3%	1.0%	0.0%	0.0%
Spain	0.2%	0.0%	1.7%	0.0%	0.0%	0.1%	0.1%	0.0%	0.0%
France	0.0%	0.8%	0.0%	0.0%	1.5%	0.0%	4.7%	0.0%	33.1%
United Kingdom	0.0%	1.6%	0.0%	0.0%	2.2%	0.0%	0.0%	36.8%	0.0%
Equatorial Guinea	0.0%	0.0%	0.0%	0.0%	0.2%	0.0%	2.2%	0.0%	0.0%
Indonesia	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Iraq	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Iran	16.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Italy	0.0%	0.0%	0.0%	0.0%	0.0%	4.2%	0.0%	0.0%	11.2%
Japan	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
South Korea	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Kuwait	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Kazakhstan	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Libya	0.0%	0.0%	0.0%	0.0%	0.0%	4.2%	0.0%	0.0%	0.0%
Myanmar	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Mexico	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Malaysia	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Nigeria	2.4%	0.0%	6.6%	0.0%	0.6%	0.3%	11.6%	0.1%	0.0%
Netherlands	0.0%	15.1%	7.9%	8.2%	41.1%	0.4%	0.0%	2.9%	0.1%
Norway	0.0%	56.8%	32.0%	17.9%	19.9%	2.6%	2.9%	40.0%	0.0%
Not specified	0.0%	0.0%	13.3%	5.9%	0.6%	0.0%	0.0%	0.2%	1.1%
Oman	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Peru	0.0%	0.0%	0.0%	0.0%	0.6%	0.0%	0.2%	1.0%	0.0%
Papua New Guinea	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Poland	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Qatar	0.5%	11.9%	1.1%	0.0%	0.3%	9.0%	6.4%	7.0%	0.0%
Romania	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Other Africa	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Other Asia Pacific	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Rest of Europe	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Other Middle East	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Other S. & Cent. America	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Russian Federation	44.9%	11.9%	21.9%	61.5%	20.4%	38.3%	8.8%	3.8%	0.0%
Saudi Arabia	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Turkmenistan	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Trinidad and Tobago	0.3%	0.0%	0.0%	0.0%	0.2%	0.0%	3.0%	0.2%	0.0%
United States	8.1%	0.7%	5.8%	0.0%	7.1%	1.5%	14.8%	4.8%	0.0%
Uzbekistan	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Venezuela	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Yemen	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Total	**100.0%**	**100.0%**	**100.0%**	**100.0%**	**100.0%**	**100.0%**	**100.0%**	**100.0%**	**100.0%**

Tab. 2.4 Modelled natural gas consumption mix for TR, BE, FR, DE, NL, IT, ES, GB and CH. Marked in green: Countries modelled in this study

Origin of natural gas	**TR**	**BE**	**FR**	**DE**	**NL**	**IT**	**ES**	**GB**	**CH**
	%	%	%	%	%	%	%	%	%
United Arab Emirates	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Angola	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Australia	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Azerbaijan	15.1%	0.0%	0.0%	0.0%	0.0%	9.5%	0.0%	0.0%	0.0%
Belgium	0.0%	0.0%	1.1%	0.6%	3.2%	0.0%	0.0%	2.3%	0.0%
Brunei Darussalam	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Bolivia	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Brazil	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Canada	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Cameroon	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
China	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Colombia	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Germany	0.0%	0.0%	0.5%	6.3%	0.8%	0.0%	0.0%	0.0%	55.1%
Denmark	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Algeria	10.2%	0.4%	9.8%	0.0%	0.2%	29.5%	44.9%	0.9%	0.0%
Ecuador	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Egypt	2.3%	0.4%	0.0%	0.0%	0.0%	0.3%	1.0%	0.0%	0.0%
Spain	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
France	0.0%	0.8%	0.1%	0.0%	1.5%	0.0%	4.8%	0.0%	33.5%
United Kingdom	0.0%	1.6%	0.0%	0.0%	2.3%	0.0%	0.0%	36.9%	0.0%
Equatorial Guinea	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Indonesia	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Iraq	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Iran	16.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Italy	0.0%	0.0%	0.0%	0.0%	0.0%	4.2%	0.0%	0.0%	11.3%
Japan	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
South Korea	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Kuwait	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Kazakhstan	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Libya	0.0%	0.0%	0.0%	0.0%	0.0%	4.2%	0.0%	0.0%	0.0%
Myanmar	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Mexico	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Malaysia	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Nigeria	2.4%	0.0%	7.7%	0.0%	0.6%	0.3%	12.0%	0.1%	0.0%
Netherlands	0.0%	15.1%	9.3%	8.7%	42.0%	0.4%	0.0%	2.9%	0.1%
Norway	0.0%	57.1%	37.7%	19.0%	20.4%	2.6%	3.0%	40.1%	0.0%
Not specified	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Oman	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Peru	0.0%	0.0%	0.0%	0.0%	0.7%	0.0%	0.2%	1.0%	0.0%
Papua New Guinea	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Poland	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Qatar	0.5%	12.0%	1.3%	0.0%	0.3%	9.0%	6.6%	7.0%	0.0%
Romania	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Other Africa	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Other Asia Pacific	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Rest of Europe	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Other Middle East	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Other S. & Cent. America	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Russian Federation	45.0%	12.0%	25.7%	65.4%	20.8%	38.4%	9.1%	3.8%	0.0%
Saudi Arabia	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Turkmenistan	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Trinidad and Tobago	0.3%	0.0%	0.0%	0.0%	0.2%	0.0%	3.1%	0.2%	0.0%
United States	8.1%	0.7%	6.9%	0.0%	7.3%	1.5%	15.3%	4.8%	0.0%
Uzbekistan	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Venezuela	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Yemen	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Total	**100.0%**	**100.0%**	**100.0%**	**100.0%**	**100.0%**	**100.0%**	**100.0%**	**100.0%**	**100.0%**

2.3 Regions

For the European Union and North American natural gas supply mixes the domestic production as well as their imports from non-domestic net exporting countries were considered (BP 2022). Tab. 2.5 shows the natural gas supply mix for the Europe Union and the modelled inventory and Tab. 2.6 shows the information for North America.

Tab. 2.5 Natural gas imported to the European Union in 2021, by origin (BP 2022). Marked in green: Countries modelled in this study

	Origin of natural gas transported to Europe	natural gas imported	Share for import mix in 2021	LCI modelled
		billion m^3	%	%
1	Russian Federation	128.6	33.8%	34.4%
2	Norway	69.7	18.3%	18.6%
3	Algeria	42.5	11.2%	11.4%
4	United Kingdom	28.1	7.4%	7.5%
5	United States	26.5	7.0%	7.1%
6	Qatar	19.4	5.1%	5.2%
7	Netherlands	15.6	4.1%	4.2%
8	Nigeria	11.1	2.9%	3.0%
9	Romania	7.3	1.9%	1.9%
10	Azerbaijan	7.0	1.8%	1.9%
11	Rest of Europe	4.6	1.2%	
12	Germany	3.9	1.0%	1.0%
13	Poland	3.3	0.9%	0.9%
14	Italy	2.7	0.7%	0.7%
15	Libya	2.6	0.7%	0.7%
16	Egypt	2.2	0.6%	0.6%
17	Trinidad and Tobago	2.0	0.5%	0.5%
18	Denmark	1.1	0.3%	
19	Peru	1.1	0.3%	0.3%
20	Other Africa	0.8	0.2%	
	Total	**380.3**	**100.0%**	**100.0%**

Tab. 2.6 Natural gas imported to Northern America in 2021, by origin (BP 2022). Marked in green: Countries modelled in this study

	Origin of natural gas transported to Northern America	natural gas consumed	Share for mix in 2019	LCI modelled
		billion m^3	%	%
1	United States	828.3	80.51%	80.51%
2	Canada	170.0	16.52%	16.52%
3	Mexico	28.8	2.80%	2.80%
4	Trinidad and Tobago	1.3	0.13%	0.13%
5	Indonesia	0.3	0.03%	0.03%
6	Peru	0.1	0.01%	0.01%
	Total	**1’028.9**	**100.0%**	**100.0%**

For the global natural gas supply mixes all producing countries were considered (BP 2022). Tab. 2.5 shows global the natural gas supply mix and the modelled inventory.

Tab. 2.7 Global natural gas mix in 2021, by origin (BP 2020, 2022). Marked in green: Countries modelled in this study

	Origin of natural gas global	natural gas consumed	Share for mix in 2019	LCI modelled
		billion m^3	%	%
1	United States	889.9	23.14%	24.33%
2	Russian Federation	668.4	17.38%	18.28%
3	Iran	244.5	6.36%	6.68%
4	China	199.3	5.18%	5.45%
5	Qatar	168.6	4.38%	4.61%
6	Canada	164.2	4.27%	4.49%
7	Australia	140.2	3.65%	3.83%
8	Saudi Arabia	111.7	2.91%	3.05%
9	Norway	108.9	2.83%	2.98%
10	Algeria	96.0	2.50%	2.62%
11	Turkmenistan	75.5	1.96%	2.07%
12	Malaysia	70.7	1.84%	1.93%
13	Egypt	64.6	1.68%	1.77%
14	Indonesia	56.5	1.47%	1.54%
15	United Arab Emirates	54.3	1.41%	1.48%
16	Uzbekistan	48.5	1.26%	1.33%
17	Nigeria	43.7	1.14%	1.20%
18	Oman	39.8	1.04%	1.09%
19	Argentina	36.8	0.96%	1.01%
20	United Kingdom	31.1	0.81%	0.85%
21	Pakistan	31.1	0.81%	
22	Kazakhstan	30.5	0.79%	0.83%
23	Azerbaijan	30.3	0.79%	0.83%
24	Thailand	30.0	0.78%	0.82%
25	Other Africa	29.2	0.76%	
26	Mexico	27.9	0.72%	0.76%
27	India	27.2	0.71%	0.74%
28	Other Asia Pacific	25.3	0.66%	
29	Trinidad and Tobago	23.6	0.61%	0.64%
30	Brazil	23.2	0.60%	0.63%
31	Bangladesh	23.0	0.60%	
32	Venezuela	22.8	0.59%	0.62%
33	Ukraine	17.7	0.46%	0.48%
34	Netherlands	17.2	0.45%	0.47%
35	Other Middle East	17.0	0.44%	
36	Kuwait	16.6	0.43%	0.45%
37	Bahrain	16.4	0.43%	
38	Myanmar	16.1	0.42%	
39	Bolivia	14.4	0.37%	0.39%
40	Colombia	12.0	0.31%	0.33%
41	Libya	11.8	0.31%	0.32%
42	Brunei Darussalam	11.0	0.29%	
43	Peru	10.9	0.28%	0.30%
44	Iraq	8.9	0.23%	0.24%
45	Romania	8.1	0.21%	0.22%
46	Vietnam	6.8	0.18%	
47	Rest of Europe	5.1	0.13%	
48	Germany	4.3	0.11%	0.12%
49	Poland	3.7	0.10%	0.10%
50	Italy	3.0	0.08%	0.08%
51	Syrian Arab Republic	2.7	0.07%	
52	Other S. & Cent. America	2.4	0.06%	
53	Denmark	1.2	0.03%	
54	Yemen	0.4	0.01%	
55	Other CIS	0.3	0.01%	
	Total	**3’845.6**	**100.0%**	**100.0%**

2.4 Share of pipeline and LNG transports

To model the natural gas supply (prior to its distribution within the studied regions and countries), the share of liquefied natural gas (LNG) in the supply mixes was assessed based on the BP statistics (2022) and Eurostat (2023a). Tab. 2.8 shows the share of pipeline and LNG-imports for regional mixes , while Tab. 2.9 shows the mode of transport for individual country mixes modelled.

Tab. 2.8 Mode of transport for natural gas supplies to Europe, North America and global (BP 2022)

Origin of natural gas transported to	**RER**		**RNA**		**GLO**	
	Transport via pipeline	**Transport via LNG-tanker**	**Transport via pipeline**	**Transport via LNG-tanker**	**Transport via pipeline**	**Transport via LNG-tanker**
United Arab Emirates					84.64%	15.36%
Argentina					100.00%	0.00%
Australia	0.00%	100.00%			26.59%	73.41%
Azerbaijan	100.00%	0.00%			100.00%	0.00%
Belgium					100.00%	0.00%
Bolivia					100.00%	0.00%
Brazil					100.00%	0.00%
Canada			100.00%	0.00%	100.00%	0.00%
China					100.00%	0.00%
Colombia					100.00%	0.00%
Germany	100.00%	0.00%			100.00%	0.00%
Algeria	68.96%	31.04%			84.06%	15.94%
Ecuador					100.00%	0.00%
Egypt	0.00%	100.00%			86.71%	13.29%
Spain					100.00%	0.00%
France					100.00%	0.00%
United Kingdom	100.00%	0.00%			100.00%	0.00%
Indonesia			0.00%	100.00%	75.30%	24.70%
India					100.00%	0.00%
Iraq					100.00%	0.00%
Iran					100.00%	0.00%
Italy	100.00%	0.00%			100.00%	0.00%
Japan					100.00%	0.00%
South Korea					100.00%	0.00%
Kuwait					100.00%	0.00%
Kazakhstan					100.00%	0.00%
Libya	100.00%	0.00%			100.00%	0.00%
Mexico			100.00%	0.00%	100.00%	0.00%
Malaysia					54.84%	45.16%
Nigeria	0.00%	100.00%			49.16%	50.84%
Netherlands	100.00%	0.00%			100.00%	0.00%
Norway	99.78%	0.22%			99.85%	0.15%
Oman					66.07%	33.93%
Peru	0.00%	100.00%	0.00%	100.00%	69.88%	30.12%
Poland	100.00%	0.00%			100.00%	0.00%
Qatar	0.00%	100.00%			39.68%	60.32%
Romania	100.00%	0.00%			100.00%	0.00%
Russian Federation	88.39%	11.61%			94.35%	5.65%
Saudi Arabia					100.00%	0.00%
Thailand					100.00%	0.00%
Turkmenistan					100.00%	0.00%
Turkey					100.00%	0.00%
Trinidad and Tobago	0.00%	100.00%	0.00%	100.00%	63.09%	36.91%
Taiwan					100.00%	0.00%
Ukraine	100.00%	0.00%			100.00%	0.00%
United States	0.00%	100.00%	99.95%	0.05%	89.83%	10.17%
Uzbekistan					100.00%	0.00%
Venezuela					100.00%	0.00%
Total imports	77.73%	22.27%	99.81%	0.19%	87.63%	12.37%

Tab. 2.9 Mode of transport for natural gas supplies to individual countries (BP 2022, BP 2020; EUROSTAT 2023a). Marked in green: Countries modelled in this study

Share of LNG Imports	**CA**	**MX**	**US**	**CN**	**JP**	**KR**	**TR**	**BE**	**FR**	**DE**	**NL**	**IT**	**ES**	**GB**	**CH**
	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%
United Arab Emirates				100%	100%	100%									
Angola				100%		100%					100%		100%		
Australia				100%	100%	100%									
Azerbaijan							0%					0%			
Belgium								0%	0%	0%	0%			0%	
Brunei Darussalam				100%	100%	100%									
Bolivia															
Brazil															
Canada	0%		0%												
Cameroon											100%				
China				0%											
Colombia															
Germany									0%	0%	0%				0%
Denmark								0%			0%	0%			
Algeria				100%			100%	100%	100%		100%	6%	13%	100%	
Ecuador															
Egypt				100%	100%	100%	100%	100%				100%	100%		
Spain							100%		0%			100%	0%		
France								0%	0%		0%		0%		0%
United Kingdom								0%			0%			0%	
Equatorial Guinea											100%		100%		
Indonesia		100%		100%	100%	100%									
Iraq															
Iran							0%								
Italy												0%			0%
Japan															
South Korea															
Kuwait															
Kazakhstan				0%											
Libya												0%			
Myanmar				0%											
Mexico		0%	0%												
Malaysia				100%	100%	100%									
Nigeria				100%	100%	100%	100%		100%		100%	100%	100%	100%	
Netherlands								0%	0%	0%	0%	0%		0%	0%
Norway								0%	0%	0%	0%	0%	0%	0%	
Not specified									0%	0%	0%			0%	0%
Oman				100%	100%	100%									
Peru	100%			100%	100%	100%					100%		100%	100%	
Papua New Guinea				100%	100%	100%							100%		
Poland															
Qatar				100%	100%	100%	100%	100%	100%		100%	100%	100%	100%	
Romania															
Other Africa				100%	100%	100%									
Other Asia Pacific				100%	100%	100%									
Rest of Europe				100%	100%	100%									
Other Middle East															
Other S. & Cent. America			100%	100%											
Russian Federation				45%	100%	100%	0%	53%	35%	0%	33%	0%	100%	100%	
Saudi Arabia															
Turkmenistan				0%											
Trinidad and Tobago	100%	100%	100%	100%		100%	100%				100%		100%	100%	
United States	0%	1%	0%	100%	100%	100%	100%	100%	100%		100%	100%	100%	100%	
Uzbekistan				0%											
Venezuela															
Yemen															
Total	**0.6%**	**1.0%**	**0.1%**	**29.4%**	**100.0%**	**100.0%**	**24.0%**	**19.6%**	**29.5%**	**0.0%**	**16.4%**	**13.0%**	**54.7%**	**17.8%**	**0.0%**

3 Properties of natural gas consumed

An overview with updated numbers of the composition of raw natural gas is provided in the accompanying report on crude oil and natural gas extraction (Meili et al. 2022a).

The quality of natural gas fed into the European gas network corresponds to the natural gas composition at the point of final consumption in Switzerland and the European Union. As for the raw gas, the composition of natural gas after processing depends on its origin (Schori et al. 2012). As available information on natural gas composition after processing is rather old (Schori et al. 2012) and not available for all countries of origin considered, a generic natural gas composition based on Swiss data is used for this study (see Tab. 3.1) (SWISSGAS 2019). The assumption for the mercury content is based on Schori et al. 2012.

Tab. 3.1 Generic gas composition used for this study (SWISSGAS 2019; Schori et al. 2012)

Substance	Unit	Value	Source
Methane, fossil	kg/m³	0.6629	Swissgas 2019
Ethane	kg/m³	0.0549	Swissgas 2019
Propane	kg/m³	0.0124	Swissgas 2019
Butane	kg/m³	0.0064	Swissgas 2019
NMVOC, non-methane volatile organic compounds	kg/m³	0.0005	Swissgas 2019
Carbon dioxide, fossil	kg/m³	0.0229	Swissgas 2019
Mercury (II)	kg/m³	1.00E-08	Schori 2012
Gross CV	MJ/m³	41.1	Swissgas 2019
Net CV	MJ/m³	36.0	BP Statistic
Density	kg/m³	0.735	BP Statistic

4 Life cycle inventory of long-distance transport

4.1 Overview

This chapter focuses on the long-distance transport from the countries of origin to destination countries and regions. Important parameters are the supply mixes, the transport modes, and the transport distances from the different origins to destinations.

Natural gas is mainly transported by long-distance pipelines with compressor stations driven by gas turbines as described in Subchapter 4.2. The transport by ship as LNG (liquefied natural gas) has become increasingly important in recent years and the process chain is described in Subchapter 4.3. The supply mixes at a specific destination are described in Subchapter 4.4. The well-established natural gas grid and the seasonal storage capacity in Europe allows to respond to demand peaks and to dispatch natural gas from different origins. It is included in the inventory of the long-distance transport to a specific destination and is described in Section 4.4.1.

Information about exported volumes and receiving countries is taken from (BP 2020). Where different pipelines route from the production to the receiving country exist, a weighted average transport distance was calculated. Where available, the different routes were weighted by actual flow rates, otherwise the pipeline capacities were used. For the reference transport distance to RER-region the transport distances individual receiving countries are weighted by the import volumes given in BP 2020. The average transport distance from Russia to Europe is based on Schuller et al. 2017 and Müller-Syring et al. 2016 as these studies present figures from direct communication with Gazprom. The Transmission Capacity Map of ENTSOG[1] is used together with online sources[2] to estimate the pipeline distances for other countries of origin supplying to Europe. For other regions, the country reports of the EIA[3] were used to identify the main pipeline routes. For EU producing countries it is assumed that domestic gas supplies are direct delivered to the distribution network and storages without long-distance transport. Due to the different scale of the Northern American market with larger distances and lower population densities, long-distance transport is included in the RNA-mix for trades between CA, MX and US. The global mix includes only long-distance transport for net-exporting countries. Some countries, e.g. Indonesia, only export via LNG and not via pipeline.

[1] www.entsog.eu/maps#
[2] www.wikipedia.org, www.maps.google.com
[3] https://www.eia.gov/international/analysis/world

Tab. 4.1 shows the distances for the pipeline import used in this study. Since Northa America does not import natural gas by pipeline from countries outside of the region, it is not included in the table.

Tab. 4.1 Transport distances from country of origin to destination regions

Origin of natural gas	**Destination**	**Distance offshore pipeline origin**	**Distance onshore pipeline origin**
		km	km
Azerbaijan	RER	110	3'310
Algeria		140	1'020
Libya		520	530
Norway		670	50
Russian Federation		340	3'540
Azerbaijan	GLO	-	690
Bolivia			2'100
Canada		-	1'400
Algeria		-	530
Indonesia		155	310
Iran		-	630
Kazakhstan		-	1'120
Libya		520	530
Mexico		-	150
Norway		670	50
Qatar		340	180
Russian Federation		340	3'540
Turkmenistan			1'830
United States		-	1'180
Uzbekistan			1'650

The shipping distances for LNG transport are estimated with an online tool[4]. The average transport distances from the gas field to the destination region are shown in Tab. 4.2. The ports of origin are mainly the same as for the transport of oil (Meili et al. 2022b) except for Russia and Norway. In both countries, the main liquefaction terminal is located far in the north and the distance changes considerably.

[4] www.sea-distances.org

Tab. 4.2 Transport distances from country of origin to destination regions for LNG imports

Origin of natural gas	Port of Origin for LNG imports	Destination	Distance gas field to liquefaction plant, offshore pipeline	Distance gas field to liquefaction plant, onshore pipeline	Distance LNG shipping
			km	km	km
Russian Federation	Sabetta	RER	-	30	4'900
Norway	Hammerfest		160	0	2'500
Algeria	Algiers		-	450	3'300
United States	Houston		-	1020	9'700
Qatar	Halul Island		90	0	11'700
Nigeria	Lagos		170	30	7'700
Egypt	Alexandria		-	0	5'850
Trinidad and Tobago	Port of Spain		-	0	7'502
Peru	Callao		-	0	11'445
Australia	Perth		-	0	17'733
Indonesia	Tanjung Priok	RNA	-	0	22'239
Trinidad and Tobago	Port of Spain		-	0	4'174
Peru	Callao		-	0	5'384
United Arab Emirates	Dubai or Abu Dhabi		-	0	17'861
Australia	Perth	GLO	-	0	20'400
Algeria	Algiers		-	450	9'688
Egypt	Alexandria		-	0	12'160
Indonesia	Tanjung Priok		-	0	22'239
Malaysia	Sungai UdangPort		-	0	21'526
Nigeria	Lagos		170	30	11'200
Norway	Hammerfest		160	0	9'300
Peru	Callao		-	0	5'384
Qatar	Halul Island		90	0	18'057
Russian Federation	Sabetta		-	30	11'100
Trinidad and Tobago	Port of Spain		-	0	4'174
United States	Houston		-	1020	1'300

Other than in the report on extraction (Meili et al. 2022a), the emission rates of the transport activities are not modelled with data from IEA 2020b. The data is only available on the level of natural gas producing countries and the available downstream data of IEA 2020b can neither be allocated to the different distribution stages (long-distance, regional, local) nor converted to tkm which is required for modelling the long-distance transport. Hence, different data sources (Faist-Emmenegger et al. 2015, Ushakov et al. 2019) were used.

4.2 Pipeline transport

4.2.1 Infrastructure

For the infrastructure of long-distance pipelines, the formerly consulted literature information on data for pipelines (Tab. 4.3-Tab. 4.5) is considered to be still valid (c.f. Schori et al. 2012). Pipeline diameters are used as indicator for pipeline capacity. No update was commissioned. Therefore, also uncertainty information is kept as in the former report.

Tab. 4.3 Unit process raw data of “Pipeline, natural gas, long distance, low capacity, onshore/GLO/I”

Explanations	Name	Location	InfrastructureProcess	Unit	*pipeline, natural gas, long distance, low capacity, onshore*	UncertaintyType	StandardDeviation95%	GeneralComment
	Location				*GLO*			
	InfrastructureProcess				*1*			
	Unit				*km*			
Resources, land	Transformation, from forest	-	0	m2	2.00E+3	1	2.11	(4,3,3,1,1,5); qualified estimates
	Transformation, to heterogeneous, agricultural	-	0	m2	2.00E+3	1	2.11	(4,3,3,1,1,5); qualified estimates
	Occupation, construction site	-	0	m2a	3.33E+3	1	1.64	(4,3,3,1,1,5); qualified estimates
Resources, in wa	Water, unspecified natural origin	-	0	m3	1.87E+2	1	1.10	(2,3,1,1,1,3); environmental report
Technosphere	diesel, burned in building machine	GLO	0	MJ	3.31E+6	1	1.10	(2,3,1,1,1,3); environmental report
	reinforcing steel, at plant	RER	0	kg	2.40E+5	1	1.22	(2,1,1,1,1,5); estimates based on published data
	polyethylene, LDPE, granulate, at plant	RER	0	kg	4.64E+3	1	1.31	(2,1,4,1,1,5); estimates based on published data
	sand, at mine	CH	0	kg	1.95E+6	1	1.31	(2,1,4,1,1,5); estimates based on published data
	bitumen, at refinery	RER	0	kg	2.32E+3	1	1.31	(2,1,4,1,1,5); estimates based on published data
	drawing of pipes, steel	RER	0	kg	2.40E+5	1	1.22	(2,1,1,1,1,5); estimates based on published data
	transport, helicopter	GLO	0	h	2.60E+1	1	2.10	(2,3,1,1,3,5); estimates based on published data
	transport, helicopter, LTO cycle	GLO	0	unit	1.04E+1	1	2.10	(2,3,1,1,3,5); estimates based on published data
	transport, lorry 32t	RER	0	tkm	1.78E+5	1	2.09	(4,5,na,na,na,na); standard distance
	transport, freight, rail	RER	0	tkm	5.03E+4	1	2.09	(4,5,na,na,na,na); standard distance
	disposal, natural gas pipeline, 0% water, to inert material landfill	CH	0	kg	1.10E+6	1	1.41	(3,5,3,1,3,5); estimates
	disposal, plastics, mixture, 15.3% water, to municipal incineration	CH	0	kg	2.32E+3	1	1.41	(3,5,3,1,3,5); estimates
	disposal, bitumen, 1.4% water, to sanitary landfill	CH	0	kg	1.16E+3	1	1.41	(3,5,3,1,3,5); estimates
	disposal, municipal solid waste, 22.9% water, to municipal incineration	CH	0	kg	4.84E+3	1	3.01	(2,3,1,1,1,3); environmental report
	disposal, hazardous waste, 25% water, to hazardous waste incineration	CH	0	kg	3.53E+3	1	3.01	(2,3,1,1,1,3); environmental report
Outputs	pipeline, natural gas, long distance, low capacity, onshore	GLO	1	km	1.00E+0			

Tab. 4.4 Unit process raw data of “Pipeline, natural gas, long distance, high capacity, onshore/ GLO/I”

Explanations	Name	Location	InfrastructureProcess	Unit	*pipeline, natural gas, long distance, high capacity, onshore*	UncertaintyType	StandardDeviation95%	GeneralComment
	Location				*GLO*			
	InfrastructureProcess				*1*			
	Unit				*km*			
Resources, land	Transformation, from forest	-	0	m2	2.00E+3	1	2.11	(4,3,3,1,1,5); qualified estimates
	Transformation, to heterogeneous, agricultural	-	0	m2	2.00E+3	1	2.11	(4,3,3,1,1,5); qualified estimates
	Occupation, construction site	-	0	m2a	3.33E+3	1	1.64	(4,3,3,1,1,5); qualified estimates
Resources, in wa	Water, unspecified natural origin	-	0	m3	1.87E+2	1	1.10	(2,3,1,1,1,3); environmental report
Technosphere	diesel, burned in building machine	GLO	0	MJ	3.31E+6	1	1.10	(2,3,1,1,1,3); environmental report
	reinforcing steel, at plant	RER	0	kg	3.76E+5	1	1.22	(2,1,1,1,1,5); estimates based on published data
	polyethylene, LDPE, granulate, at plant	RER	0	kg	4.64E+3	1	1.31	(2,1,4,1,1,5); estimates based on published data
	sand, at mine	CH	0	kg	2.28E+6	1	1.31	(2,1,4,1,1,5); estimates based on published data
	bitumen, at refinery	RER	0	kg	2.32E+3	1	1.31	(2,1,4,1,1,5); estimates based on published data
	drawing of pipes, steel	RER	0	kg	3.76E+5	1	1.22	(2,1,1,1,1,5); estimates based on published data
	transport, helicopter	GLO	0	h	2.60E+1	1	2.10	(2,3,1,1,3,5); estimates based on published data
	transport, helicopter, LTO cycle	GLO	0	unit	1.04E+1	1	2.10	(2,3,1,1,3,5); estimates based on published data
	transport, lorry 32t	RER	0	tkm	2.19E+5	1	2.09	(4,5,na,na,na,na); standard distance
	transport, freight, rail	RER	0	tkm	7.75E+4	1	2.09	(4,5,na,na,na,na); standard distance
	disposal, natural gas pipeline, 0% water, to inert material landfill	CH	0	kg	1.33E+6	1	1.41	(3,5,3,1,3,5); estimates
	disposal, plastics, mixture, 15.3% water, to municipal incineration	CH	0	kg	2.32E+3	1	1.41	(3,5,3,1,3,5); estimates
	disposal, bitumen, 1.4% water, to sanitary landfill	CH	0	kg	1.16E+3	1	1.41	(3,5,3,1,3,5); estimates
	disposal, municipal solid waste, 22.9% water, to municipal incineration	CH	0	kg	4.84E+3	1	1.10	(2,3,1,1,1,3); environmental report
	disposal, hazardous waste, 25% water, to hazardous waste incineration	CH	0	kg	3.53E+3	1	1.10	(2,3,1,1,1,3); environmental report
Outputs	pipeline, natural gas, long distance, high capacity, onshore	GLO	1	km	1.00E+0			

Tab. 4.5 Unit process raw data of “Pipeline, natural gas, long distance, high capacity, offshore/ GLO/I”

Explanations	Name	Location	InfrastructureProcess	Unit	*pipeline, natural gas, long distance, high capacity, offshore*	UncertaintyType	StandardDeviation95%	GeneralComment
	Location				*GLO*			
	InfrastructureProcess				*1*			
	Unit				*km*			
Resources, land	Transformation, from sea and ocean	-	0	m2	1.10E+2	1	2.11	(4,3,3,1,1,5); estimates
	Transformation, to industrial area, benthos	-	0	m2	1.10E+2	1	2.11	(4,3,3,1,1,5); estimates
	Transformation, from industrial area, benthos	-	0	m2	5.50E+1	1	2.11	(4,3,3,1,1,5); estimates
	Transformation, to sea and ocean	-	0	m2	5.50E+1	1	2.11	(4,3,3,1,1,5); estimates
	Occupation, industrial area, benthos	-	0	m2a	5.50E+3	1	2.11	(4,3,3,1,1,5); estimates
Resources, in wa	Water, unspecified natural origin	-	0	m3	8.05E+2	1	1.10	(2,3,1,1,1,3); environmental report
Technosphere	diesel, burned in building machine	GLO	0	MJ	2.53E+6	1	2.01	(2,3,1,1,5,3); environmental report
	reinforcing steel, at plant	RER	0	kg	6.05E+5	1	1.22	(2,1,1,1,1,5); estimates based on published data
	concrete, sole plate and foundation, at plant	CH	0	m3	3.61E+2	1	1.31	(2,1,4,1,1,5); estimates based on published data
	aluminium, production mix, cast alloy, at plant	RER	0	kg	3.32E+3	1	10.43	(5,5,1,1,1,na); Estimation for aluminium anode, basic uncertainity estimated = 10
	cast iron, at plant	RER	0	kg	4.20E+0	1	10.43	(5,5,1,1,1,na); Estimation for aluminium anode, basic uncertainity estimated = 10
	MG-silicon, at plant	NO	0	kg	5.25E+0	1	10.43	(5,5,1,1,1,na); Estimation for aluminium anode, basic uncertainity estimated = 10
	copper, at regional storage	RER	0	kg	2.10E-1	1	10.43	(5,5,1,1,1,na); Estimation for aluminium anode, basic uncertainity estimated = 10
	zinc for coating, at regional storage	RER	0	kg	1.75E+2	1	10.43	(5,5,1,1,1,na); Estimation for aluminium anode, basic uncertainity estimated = 10
	drawing of pipes, steel	RER	0	kg	6.05E+5	1	1.22	(2,1,1,1,1,5); estimates based on published data
	transport, lorry 32t	RER	0	tkm	7.61E+4	1	2.09	(4,5,na,na,na,na); standard distance
	transport, freight, rail	RER	0	tkm	1.22E+5	1	2.09	(4,5,na,na,na,na); standard distance
	transport, transoceanic freight ship	OCE	0	tkm	1.82E+5	1	2.33	(5,3,1,1,3,5); estimated distances
	disposal, natural gas pipeline, 0% water, to inert material landfill	CH	0	kg	3.03E+5	1	1.41	(3,5,3,1,3,5); estimates
	disposal, municipal solid waste, 22.9% water, to municipal incineration	CH	0	kg	1.26E+3	1	1.10	(2,3,1,1,1,3); environmental report
	disposal, hazardous waste, 25% water, to hazardous waste incineration	CH	0	kg	1.13E+3	1	1.10	(2,3,1,1,1,3); environmental report
emission water, ocean	Aluminum	-	-	kg	2.82E+3	1	10.43	(5,5,1,1,1,na); Estimation 85% utilisation of anode
	Iron, ion	-	-	kg	3.57E+0	1	10.43	(5,5,1,1,1,na); Estimation 85% utilisation of anode
	Silicon	-	-	kg	4.46E+0	1	10.43	(5,5,1,1,1,na); Estimation 85% utilisation of anode
	Copper, ion	-	-	kg	1.79E-1	1	10.43	(5,5,1,1,1,na); Estimation 85% utilisation of anode
	Zinc, ion	-	-	kg	1.49E+2	1	10.43	(5,5,1,1,1,na); Estimation 85% utilisation of anode
	Titanium, ion	-	-	kg	7.44E-1	1	10.43	(5,5,1,1,1,na); Estimation 85% utilisation of anode
Outputs	pipeline, natural gas, long distance, high capacity, offshore	GLO	1	km	1.00E+0			

4.2.2 Operation of the network

4.2.2.1 Surveillance with helicopters

The amount of helicopter hours per km pipeline was assumed to remain constant (c.f. Tab. 4.3 and Tab. 4.4). The environmental impacts of the flights were modelled with the dataset "transport, helicopter, single engine, LTO cycle" of the UVEK database.

4.2.2.2 Operational energy use

To compensate the pressure loss in the long-distance pipeline network, compressor stations are located every 100-200 km along the network (Schori et al. 2012). The natural gas consumption of the compressor stations is expressed in % per 1'000 km pipeline. Schori et al. 2012 and Faist-Emmenegger et al. 2015 used a value of 1.9 %/1'000 km for Russian pipelines and of 1.8 %/1'000 km for all other countries. These values are based on older expert judgements. Müller-Syring et al. 2016 and Schuller et al. 2017 present more current values for several countries as shown in Tab. 4.6. Based on these numbers, average values were calculated for Russia, Europe, and other regions. As there is no traceable source given for the energy use in Dutch and African pipelines in Schuller et al. 2017 and these values are considerable higher than the other values, they are not considered in the calculation of the average. For countries of the former Soviet Union, the Middle East and Africa the energy use of Russian pipelines is applied, while for Northern America the European values are used.

Tab. 4.6 Energy use of long-distance pipelines in different regions. The values highlighted in grey are not used for calculating the averages used in this study.

Parameter	Unit	Schori 2012	Faist-Emmenegger 2015	Schuller 2017	Müller-Syring 2016	This study
Energy use (FSU)	%/1000 km	1.9%	1.9%	2.1%	2.3%	2.2%
Energy use (NL)	%/1000 km			3.0%	0.6%	
Energy use (NO)	%/1000 km			0.8%	1.5%	
Energy use (UK)	%/1000 km			0.8%		
Energy use (RER, RNA)	%/1000 km	1.8%	1.8%			0.9%
Energy use (RME, RAF, RAS, RLA)	%/1000 km	1.8%	1.8%	3.0%		2.2%

Emissions and infrastructure need of the compressor stations are modelled with the datasets "natural gas, burned in gas turbine". This dataset is used for all natural gas inputs for energy purposes. In former studies (Schori et al. 2012; Faist Emmenegger et al. 2007), three different datasets for modelling natural gas as energy input were used. It was differentiated between "natural gas, burned in gas turbines" and natural gas, burned in gas turbines, for compressor station". For the latter, it was assumed that relatively old turbines are in place, which results in high NO_x emissions.

For this study, it was assumed that turbines installed more than three decades ago were subsequently replaced by newer turbines and hence no differentiation between compressor stations and other turbines used is necessary. The third dataset "natural gas, burned in gas motor, for storage" was used in former studies to model the energy use of storage and liquefaction processes. As the dataset showed only slightly lower results than the dataset "natural gas, burned in gas turbine", it was replaced by the latter one in this study. The former datasets were only available for a few countries, with a country specific natural gas input. This is corrected in this study and the dataset “natural gas, burned in gas turbines” is modelled for all countries under study. The emissions are based on generic estimates of the former dataset since an update was not commissioned. Tab. 4.7 shows the data for the combustion in a gas turbine exemplarily for natural gas extracted in Norway.

Tab. 4.7 Unit process raw data of “natural gas, burned in gas turbine” (Example for Norway)

NO	Name	Location	Unit	natural gas, burned in gas turbine			
	Location			NO			
	Unit			MJ			
	natural gas, burned in gas turbine	NO	MJ	1.00E+0			
	gas turbine, 10MWe, at production plant	RER	unit	1.15E-10	1	3.28	(4,3,5,3,1,BU:3); infrastructure estimation
	Natural gas, at production	NO	Nm3	2.78E-02	1	1.57	(4,3,5,3,1,BU:1.05); natural gas input
	natural gas, at long-distance pipeline	NO	Nm3		1	1.57	(4,3,5,3,1,BU:1.05); natural gas input
air, high population	Methane, fossil	-	kg	4.50E-06	1	2.07	(5,5,5,3,1,BU:1.5); rough estimate
	Carbon monoxide, fossil	-	kg	4.00E-05	1	5.58	(5,5,5,3,1,BU:5); rough estimate
	Dinitrogen monoxide	-	kg	1.00E-06	1	2.07	(5,5,5,3,1,BU:1.5); rough estimate
	Nitrogen oxides	-	kg	1.30E-04	1	2.07	(5,5,5,3,1,BU:1.5); rough estimate
	NMVOC, non-methane volatile organic	-	kg	1.00E-06	1	2.07	(5,5,5,3,1,BU:1.5); rough estimate
	Sulfur dioxide	-	kg	5.50E-07	1	1.83	(5,5,5,3,1,BU:1.05); rough estimate
	Carbon dioxide, fossil	-	kg	5.60E-02	1	1.83	(5,5,5,3,1,BU:1.05); rough estimate
	Mercury	-	kg	3.00E-11	1	5.58	(5,5,5,3,1,BU:5); rough estimate
	Dioxin, 2,3,7,8 Tetrachlorodibenzo-p-	-	kg	2.90E-17	1	3.50	(5,5,5,3,1,BU:3); rough estimate
	Heat, waste	-	MJ	1.10E+00	1	1.83	(5,5,5,3,1,BU:1.05); rough estimate

4.2.2.3 *Natural gas losses and other process related emissions*

Natural gas losses in the long-distance network mainly occur at junctions between sections and pneumatic devices. Schori et al. 2012 differentiated for the loss rate between Russia and other regions, whereas Faist-Emmenegger et al. 2015 differentiated between Europe and other regions (see Tab. 4.8). The latter values are used for this study. As a conservative approach, it is assumed that the entire emissions are emitted to the atmosphere and no pollutants are held back by the soil.

Tab. 4.8 Leakage rates of long-distance pipelines in different regions

Parameter	**Unit**	**Schori 2012**	**Faist-Emmenegger 2015**	**This study**
Loss rate, FSU	%/1000 km	0.218%	0.204%	0.204%
Loss rate, RER and RNA	%/1000 km	0.026%	0.019%	0.019%
Loss rate, RM, RAS, RAF and RLA	%/1000 km	0.026%	0.204%	0.204%

The composition of the natural gas changes slightly during the long-distance transport as higher hydrocarbons and water condensate and are collected in condensate separators. It is further assumed that part of the mercury content is secreted with the condensate as well. As in Schori et al. 2012, 1.16 E-06 kg condensate are estimated per tkm pipeline transport. The treatment of the condensate is modelled with the dataset "Disposal, used mineral oil, 10% water, to hazardous waste incineration". A transport distance of 100 km is assumed to the treatment facility.

The figures derived in Schori et al. 2012 for the use of refrigerants are 6.93 E-08 kg/tkm freon and 2.2 E-08 kg/tkm halon. Due to the Montreal Protocol the use of chlorofluorocarbons and hydrochlorofluorocarbons is phasing out. It is assumed, that the substances are replaced by HFC-23 and the use of halon in 2019 is reduced by 90 % (UNEP 2018).

4.2.3 Inventory of natural gas transport in pipelines

4.2.3.1 Description

The data of Algerian natural gas transport is shown exemplarily in Tab. 4.9. The inventories describe the energy consumption and emissions linked to the transport of one ton natural gas over a distance of one km in the unit ton-km (tkm). Onshore pipelines were modelled for all countries, offshore pipelines only for countries where necessary (c.f. Tab. 4.1).

The leakage rate of Russian pipelines is higher than in other regions (Faist-Emmenegger et al. 2015). The refrigerant emissions as well as the amount of secreted condensate is assumed to be equal in all countries. Furthermore, it is assumed that the emissions and energy use of offshore pipeline are equal to the ones of onshore pipelines.

4.2.3.2 Data quality

The energy use data is based on qualified estimates from industrial experts for the years 2014 and 2015 (Müller-Syring et al. 2016; Schuller et al. 2017). The infrastructure needs are based on values given in Schori et al. 2012 (qualified estimates). Dutch company reports (Gasunie 1998; 2001) are used for the amount of condensate (verified data partly based on assumptions) and refrigerant emissions. The refrigerants used are updated to current legislation (non-expert estimate). Other emissions are calculated based on the loss rates (qualified estimates) and a generic natural gas composition. For the auxiliary datasets "Natural gas, burned in gas turbine", the natural gas input is specified by country of origin. For the emissions, generic factors were used.

Tab. 4.9 Unit process raw data of the pipeline transport from Algeria

Name	Location	Unit	*transport, natural gas, onshore pipeline, long distance*	*transport, natural gas, offshore pipeline, long distance*	UncertaintyType	Standard-Deviation95%	GeneralComment
Location			*DZ*	*DZ*			
InfrastructureProcess			*0*	*0*			
Unit			*tkm*	*tkm*			
transport, natural gas, onshore pipeline, long distance	DZ	tkm	1.00E+0				
transport, natural gas, offshore pipeline, long distance	DZ	tkm		1.00E+0			
natural gas, at production	DZ	Nm3	2.78E-03	2.78E-03	1	1.21	(4,2,1,1,1,BU:1.05); Imports via pipeline + losses
natural gas, burned in gas turbine	DZ	MJ	7.95E-01	7.95E-01	1	1.3	(4,2,2,3,3,BU:1.05); Qualified estimates from different gas companies
pipeline, natural gas, long distance, high capacity, offshore	GLO	km		1.78E-09	1	3.32	(4,3,5,3,3,BU:3); based on estimated standard capacity
pipeline, natural gas, long distance, high capacity, onshore	GLO	km	2.59E-09		1	3.32	(4,3,5,3,3,BU:3); based on estimated standard capacity
transport, freight, lorry 16-32 metric ton, fleet average	RER	tkm	1.16E-07	1.16E-07	1	1.15	(3,4,1,1,1,BU:1.05); Average weighted distance is estimated based on trade statistics and pipeline network.
Methane, fossil	-	kg	1.84E-03	1.84E-03	1	1.57	(2,3,4,1,1,BU:1.5); Calculated based on leakage and average gas composition
Ethane	-	kg	1.52E-04	1.52E-04	1	1.57	(2,3,4,1,1,BU:1.5); Calculated based on leakage and average gas composition
Propane	-	kg	3.43E-05	3.43E-05	1	1.57	(2,3,4,1,1,BU:1.5); Calculated based on leakage and average gas composition
Butane	-	kg	1.76E-05	1.76E-05	1	1.57	(2,3,4,1,1,BU:1.5); Calculated based on leakage and average gas composition
NMVOC, non-methane volatile organic compounds	-	kg	1.27E-06	1.27E-06	1	1.57	(2,3,4,1,1,BU:1.5); Calculated based on leakage and average gas composition
Carbon dioxide, fossil	-	kg	6.36E-05	6.36E-05	1	1.22	(2,3,4,1,1,BU:1.05); Calculated based on leakage and average gas composition
Mercury (II)	-	kg	2.78E-11	2.78E-11	1	5.06	(2,3,4,1,1,BU:5); Calculated based on leakage and average gas composition
Methane, bromochlorodifluoro-, Halon 1211	-	kg	2.24E-09	2.24E-09	1	2.11	(5,5,5,3,3,BU:1.5); assuming 10% halon compared to Schori 2012
Methane, trifluoro-, HFC-23	-	kg	8.95E-08	8.95E-08	1	2.11	(5,5,5,3,3,BU:1.5); assuming 90% HFC-23 compared to Schori 2012

4.3 Transport of Liquefied Natural Gas

4.3.1 Natural Gas Liquefaction

After extraction, the natural gas is transported via pipeline to the liquefaction plant at the coast. In the liquefaction plant, the natural gas is cooled to -161 °C to reach its liquid state and the CO_2 is separated. The volume of natural gas in liquid state decreases to 1/600 of the volume in gaseous state. The liquefaction process is modelled in the dataset "Natural gas, liquefied, at liquefaction plant". Schori et al. 2012 stated that 15 % of the natural gas is consumed to run the liquefaction process, in Faist-Emmenegger et al. 2015 this value decreased to 10.3 %. More recent figures published in Pospíšil et al. 2019 indicate that on average 8.6 % of the natural gas is consumed in the liquefaction process. The latter value was used in this study.

In most liquefaction plants, the separated CO_2 is emitted into air and not pumped back into the gas reservoir[5]. The resulting CO_2-emissions are based on the natural gas composition. The leakage rate of 0.05 %, based on Schori et al. 2012, is used to calculate the emissions of other natural gas components. The infrastructure requirements of liquefaction and evaporation plants are based on Schori et al. 2012.

4.3.2 Storage and ship transportation of LNG

Prior to the transoceanic transport by LNG carriers, the LNG is stored in storage tanks. Typically, the storage and transport time of LNG is very short. The duration of storage is between 1 and 1.5 days (Cerbe et al. 1999). Assuming a service lifetime of the tank of 50 years, this leads to 9'000 turnover cycles per tank. Therefore, the material usage per transported Nm^3 of natural gas is very small. In this study the material use for the tanks is therefore not included.

According to IMO 2016, early LNG carriers burned LNG for steam propulsion as modelled in Schori et al. 2012, but most modern LNG carriers use dual fuel diesel engines as in the study of Faist-Emmenegger et al. 2015 (see Tab. 4.10). The values of the latter studies are used in this study. The share of LNG, which evaporates during the transport (boil-off gas), is used as fuel and burned in the engine (IMO 2015).

Tab. 4.10 Fuel consumption of LNG carriers

Parameter	Unit	Schori 2012	Faist Emmenegger 2015	This study
LNG consumption	Nm^3/tkm	0.00935	0.00429	0.00429
heavy fuel oil consumption	MJ/tkm		0.06789	0.06789

IMO 2015 stated emission factors for various marine fuels including heavy fuel oil (HFO), marine diesel oil (MDO) and LNG combusted in Otto-cycle engines. Ushakov et al. 2019 present emission factors for LNG combusted in Otto-cycle engines based on ocean and manufacturer measurements. The latter ones were used for this study, values for substances not reported in Ushakov et al. 2019 are supplemented with data from IMO 2015. The emission factors for

5 https://www2.gov.bc.ca/assets/gov/environment/climate-change/ind/lng/lng_production_in_british_columbia_-_ghg_emissions_assessment_and_benchmarking_-_may_2013.pdf, online 11.09.2020

different marine fuels are given in Tab. 4.11. To calculate the airborne emissions of the LNG-transport, the fuel consumption as reported in Tab. 4.10 is multiplied with the emission factors for HFO and LNG as given in Tab. 4.11.

Tab. 4.11 Emission factor for marine fuels based on IMO 2015 and Stenersen and Thonstad 2017. HFO: heavy fuel oil, MDO: marine diesel oil, LNG: liquefied natural gas

Source		**IMO 2015**	**IMO 2015**	**IMO 2015**	**Ushakov 2019**	**This study**
Substance	**Unit**	**HFO**	**MDO**	**LNG (Otto-cycle)**	**LNG (Otto-cycle)**	**LNG (Otto-cycle)**
Methane	g/g fuel	6.00E-05	6.00E-05	5.12E-02	4.09E-02	4.09E-02
Carbon dioxide	g/g fuel	3.11E+00	3.21E+00	2.75E+00	2.63E+00	2.63E+00
Carbon monoxide	g/g fuel	2.77E-03	2.77E-03	7.83E-03	1.10E-02	1.10E-02
NMVOC	g/g fuel	3.08E-03	3.08E-03	3.01E-03	2.30E-03	2.30E-03
Nitrogen oxides	g/g fuel	6.05E-02	5.68E-02	7.83E-03	1.04E-02	1.04E-02
Dinitrogen monoxide	g/g fuel	1.60E-04	1.50E-04	1.10E-04		1.10E-04

As in Schori et al. 2012, it is assumed that the wastewater is contaminated with 10% bilge oil[6] and that 2.18 E-03 kg wastewater are discarded per tkm.

Fuel consumption, emissions and infrastructure requirements are modelled in the dataset "Transport, liquefied natural gas (country code), freight ship", while the transport distance is considered in the dataset "Natural gas, liquefied, at freight ship".

4.3.3 Evaporation plant

Various regasification technologies to vaporize LNG are available; common heat sources are ambient air, sea water and natural gas. The selected technology depends on the geographical and meteorological conditions of the location. Open rack vaporizers (ORV) use seawater to vaporize the LNG. Sodium hypochlorite is added to the seawater inlet stream to avoid algae growth within the heat exchanger tubes. The colder seawater is then, together with the sodium hypochlorite, discharged to the sea. Seawater only is only an effective heat source for vaporizing LNG if its temperature is higher 5 °C. In submerged combustion vaporizers (SCV), LNG flows in tubes through a water bath, which is heated by burning natural gas. SCVs are mainly used for peak shaving purposes. The technology mix in Europe is calculated based on the shares of technologies used: 60 % open rack vaporizers (ORV) and 40 % submerged combustion vaporizers (Agarwal et al. 2017) and used for other regions as well. Tab. 4.12 shows the energy and material consumption recorded of different vaporizing technologies and the values derived for this study. The vaporized LNG is fed into the natural gas distribution network. Methane emissions from the evaporation are estimated as 3.5E-04 kg Methane/m^3 (Schori et al. 2012).

6 Bilges are the lowest compartments of ships. Water collects there, which can be contaminated with harmful substances.

Tab. 4.12 Energy and material consumption of vaporizing technologies in different sources.

Parameter	Unit	Schori 2012	Faist Emmenegger 2015	Pospisil 2019	Agarwal 2017	Asprofos engineering 2014	This study	This study	This study
Technology		SCV	average	SCV	SCV	ORV	ORV	SCV	RER-mix
Electricity	MJ/Nm³		0.042						
Natural gas	%	1.6%	0.43%	1.0-2.5%	1.5-2.0%			1.7%	0.69%
Sea water	m³/m³ gas					1.1E+01	1.1E+01		6.4E+00
Sodium hypochlorite	kg/m³ gas					5.6E-02	5.6E-02		3.4E-02

4.3.4 Inventory of LNG transport

4.3.4.1 Description

The inventory data of the LNG datasets are shown exemplarily for LNG in Tab. 4.13 and Tab. 4.14. The inventories describe the energy consumption and emissions linked to the liquefaction, transport, and evaporation of one cubic metre natural gas in gaseous form.

The inventory data of the modelled countries differs with respect to the emissions and natural gas consumption as the country specific natural gas composition and heating values were used for the calculation.

4.3.4.2 Data quality

The energy use of the liquefaction and evaporation process is based on the average values of different scientific publications summarized in Pospíšil et al. 2019 (qualified estimates). The material consumption of the evaporation process calculated based on figures given in an environmental study for a Greek LNG terminal (Asprofos Engineering 2014) (qualified estimates). Emission factors based on measurements and expert estimations (qualified estimates) and qualified estimates of fuel consumption are used to model transport the emissions. Emissions during liquefaction are calculated based on the leakage rates (qualified estimates) and the country specific natural gas composition. The infrastructure requirements are based on rough estimates.

Tab. 4.13 Unit raw datasets for LNG (Example for US delivered to GLO)

Name	Location	Unit	natural gas, liquefied, at liquefaction plant	natural gas, liquefied, production US, at harbour	natural gas, production US, at evaporation plant	UncertaintyType	StandardDeviation95%	GeneralComment
Location			US	GLO	GLO			
InfrastructureProcess			0	0	0			
Unit			Nm3	Nm3	Nm3			
natural gas, liquefied, at liquefaction plant	US	Nm3	1.00E+0					
natural gas, liquefied, production US, at harbour	GLO	Nm3		1.00E+0				
natural gas, production US, at evaporation plant	GLO	Nm3			1.00E+0			
natural gas, at production	US	Nm3	1.00E+00			1	1.21	(4,2,1,1,1,BU:1.05); Imports via pipeline + losses
natural gas, burned in gas turbine	US	MJ	3.11E+00		2.48E-01	1	1.3	(4,2,2,3,3,BU:1.05); Based on technology average
Methane, fossil	-	kg	3.31E-04		3.50E-04	1	1.57	(2,3,4,1,1,BU:1.5); based on leakage rate
Ethane	-	kg	2.75E-05			1	1.57	(2,3,4,1,1,BU:1.5); Calculated based on leakage and average gas composition
Propane	-	kg	6.18E-06			1	1.57	(2,3,4,1,1,BU:1.5); Calculated based on leakage and average gas composition
Butane	-	kg	3.18E-06			1	1.57	(2,3,4,1,1,BU:1.5); Calculated based on leakage and average gas composition
NMVOC, non-methane volatile organic compounds	-	kg	2.29E-07			1	1.57	(2,3,4,1,1,BU:1.5); Calculated based on leakage and average gas composition
Carbon dioxide, fossil	-	kg	2.29E-02			1	1.22	(2,3,4,1,1,BU:1.05); Calculated based on leakage and average gas composition
Mercury (II)	-	kg	5.00E-12			1	5.06	(2,3,4,1,1,BU:5); Calculated based on leakage and average gas composition
production plant, natural gas	GLO	unit	7.89E-13		7.89E-13	1	3.29	(5,3,3,3,3,BU:3); Estimate for Europe
natural gas, liquefied, at liquefaction plant	US	Nm3		1.00E+00		1	1.24	(4,3,3,1,1,BU:1.05); Based on data from Faist-Emmenegger (2015)
transport, liquefied natural gas US, freight ship	OCE	tkm		7.42E+00		1	2.08	(3,3,3,1,3,BU:2); Average weighted distance based on BP statistics for 2021
natural gas, liquefied, production US, at harbour	GLO	Nm3			1.00E+00	1	1.05	(1,1,1,1,1,BU:1.05);
sodium hypochlorite, 15% in H2O, at plant	RER	kg			3.36E-02	1	1.4	(4,5,3,3,3,BU:1.05); Environmental report of Greek site
Water, salt, ocean	-	m3			6.42E+00	1	1.4	(4,5,3,3,3,BU:1.05); Environmental report of Greek site
Water	-	kg			6.42E+03	1	1.69	(4,5,3,3,3,BU:1.5); Environmental report of Greek site
Sodium	-	kg			1.04E-02	1	5.17	(4,5,3,3,3,BU:5); Environmental report of Greek site
Hypochlorite	-	kg			2.32E-02	1	3.15	(4,5,3,3,3,BU:3); Environmental report of Greek site

Tab. 4.14 Unit raw datasets for LNG transport (Example for Nigeria)

NG	Name	Location	Unit	transport, liquefied natural gas NG, freight ship	UncertaintyType	StandardDeviation95%	GeneralComment
	Location			OCE			
	Unit			tkm			
	transport, liquefied natural gas NG, freight ship	OCE	tkm	1.00E+0			
	natural gas, liquefied, at liquefaction plant	NG	Nm3	4.29E-03	1	1.24	(4,3,3,1,1,BU:1.05); Based on data from Faist-Emmenegger (2015)
	heavy fuel oil, at regional storage	RER	kg	1.65E-03	1	1.24	(4,3,3,1,1,BU:1.05); Based on data from Faist-Emmenegger (2015)
	transport, freight, lorry 16-32 metric ton, fleet average	RER	tkm	1.09E-05	1	2.06	(4,3,3,1,1,BU:2); Environmental report of Italian company
	transoceanic freight ship	OCE	unit	2.43E-11	1	3.47	(5,4,5,1,1,BU:3); Assumptions on the basis of older data
	operation, maintenance, port	RER	unit	2.43E-11	1	3.47	(5,4,5,1,1,BU:3); Assumptions on the basis of older data
	maintenance, transoceanic freight ship	RER	unit	2.43E-11	1	3.47	(5,4,5,1,1,BU:3); Assumptions on the basis of older data
	disposal, bilge oil, 90% water, to hazardous waste incineration	CH	kg	2.18E-04	1	1.53	(2,4,5,1,1,BU:1.05); Assumptions on the basis of older data
emission air, low population density	Methane, fossil	-	kg	1.33E-04	1	1.58	(4,3,3,1,1,BU:1.5); Based on data from IMO (2015) and Sternersen (2017)
	Carbon dioxide, fossil	-	kg	1.37E-02	1	1.24	(4,3,3,1,1,BU:1.05); Based on data from IMO (2015) and Sternersen (2017)
	Carbon monoxide, fossil	-	kg	4.04E-05	1	5.07	(4,3,3,1,1,BU:5); Based on data from IMO (2015) and Sternersen (2017)
	Nitrogen oxides	-	kg	1.34E-04	1	1.58	(4,3,3,1,1,BU:1.5); Based on data from IMO (2015) and Sternersen (2017)
	Dinitrogen monoxide	-	kg	6.22E-07	1	1.58	(4,3,3,1,1,BU:1.5); Based on data from IMO (2015) and Sternersen (2017)

4.4 Arrival at destination

4.4.1 Seasonal natural gas storage

The temporal storage of natural gas is important to compensate for seasonal demand fluctuations as well as for strategic purposes. In Schori et al. 2012, it is assumed that a share of 10 % of the natural gas supply was temporarily stored. The natural gas is stored underground in caverns or permeable rock foundations with a compressor station on the surface. The energy expenditures of the compressor stations depend on the storage depth and the operation pressure. Schori et al. 2012 assumed a natural gas consumption of the compressor station of 1.5 % of the stored natural gas. The natural gas losses during seasonal storage depend on the storage type. Schori et al. 2012 used an average leakage rate of 0.1 % of the stored gas. Faist-Emmenegger et al. 2015 used the same figures. The European Commission 2015 stated that in the recent years the storage capacities increased faster than the natural gas consumption, hence, in this study it is assumed that 15 % of the natural gas supply is temporarily stored, the other figures remain unchanged. These values are used for all regions under study.

The seasonal natural gas storage is modelled in the inventory "Natural gas, production (country code), at long-distance pipeline", the emissions caused by leakages are modelled as direct emissions of the process. The dataset "Natural gas, burned in gas turbine" is used to account for the emissions and infrastructure of the operational energy requirements of the storage capacities. In 2021, approximately 68% of the European gas storage facilities were depleted fields, 25% caverns and 7% aquifer.[7] Converting a depleted natural as field to a storage facility allows the further use of existing wells, gathering systems, and pipeline connections.[8] The infrastructure of the storage is hence neglected in this study as it is assumed to be insignificant.

4.4.2 Inventory of arrival at destination

4.4.2.1 Description

The inventory of imports from a specific country of origin is exemplarily shown for Norwegian natural gas imported to Germany in Tab. 4.15. The inventory describes the imports per pipeline and LNG as well as the seasonal storage in the destination country. In previous studies, this dataset was modelled in m^3. In this study the unit was changed to MJ.

4.4.2.2 Data quality

The energy use for temporal storage is based on qualified estimates from industry experts. The emissions during liquefaction are calculated based on the leakage rates (qualified estimates) and the natural gas composition.

[7] https://www.gie.eu/transparency/databases/storage-database/
[8] https://www.eia.gov/naturalgas/storage/basics/

Tab. 4.15 Unit process raw data for the imports of Norwegian natural gas to DE

Name	Location	Unit	*natural gas, production NO, at long-distance pipeline*	UncertaintyType	StandardDeviation95%	GeneralComment
Location			*DE*			
InfrastructureProcess			*0*			
Unit			*MJ*			
natural gas, production NO, at long-distance pipeline	DE	MJ	1.00E+0			
natural gas, at production	NO	Nm3	2.78E-02	1	1.20897507	(4,2,1,1,1,BU:1.05); Imports via pipeline + losses
natural gas, burned in gas turbine	NO	MJ	2.25E-03	1	1.30415785	(4,2,2,3,3,BU:1.05); Energy expenditure of seasonal storage
transport, natural gas, offshore pipeline, long distance	NO	tkm	1.04E-02	1	3.32095505	(4,3,5,3,3,BU:3); based on estimated standard capacity
Methane, fossil	-	kg	1.84E-06	1	1.568145	(2,3,4,1,1,BU:1.5);Emissions from storage. Calculated based on average losses and gas composition
Ethane	-	kg	1.53E-07	1	1.568145	(2,3,4,1,1,BU:1.5);Emissions from storage. Calculated based on average losses and gas composition
Propane	-	kg	3.43E-08	1	1.568145	(2,3,4,1,1,BU:1.5);Emissions from storage. Calculated based on average losses and gas composition
Butane	-	kg	1.76E-08	1	1.568145	(2,3,4,1,1,BU:1.5);Emissions from storage. Calculated based on average losses and gas composition
NMVOC, non-methane volatile organic compounds	-	kg	1.27E-09	1	1.568145	(2,3,4,1,1,BU:1.5);Emissions from storage. Calculated based on average losses and gas composition
Carbon dioxide, fossil	-	kg	6.37E-08	1	1.22256878	(2,3,4,1,1,BU:1.05);Emissions from storage. Calculated based on average losses and gas composition
Mercury (II)	-	kg	2.78E-14	1	5.05916245	(2,3,4,1,1,BU:5);Emissions from storage. Calculated based on average losses and gas composition

5 Life cycle inventory of regional distribution

5.1 Overview

In the long-distance pipeline network, natural gas is transported with a pressure of 70 bar. For the regional distribution, the pressure is reduced to 1-5 bar overpressure (high-pressure network). The pressure is further reduced to less than 0.1 bar overpressure for the local distribution (low-pressure network) which is described in Chapter 6.

Large consumers, e.g. power plants and industries, obtain natural gas from the high-pressure network. Schori et al. 2012 reported, that 18% of the Swiss natural gas consumption is supplied at the high-pressure level, while Faist-Emmenegger et al. 2015 assumed a share of 23 %. For the EU-15[9], a share of 56 % was assumed, due to the larger importance of industry (Schori et al. 2012). In this study, the value of Faist-Emmenegger et al. 2015 is used for all regions.

The high-pressure network accounted for 21 % of the total length of the distribution network in Switzerland in 2018. For the EU-27[10], a similar figure of 19 % is reported[11].

5.2 Infrastructure

The inventories are not updated and kept the same as in a former study (Schori et al. 2012). The share of modern polyethylene pipelines used in Switzerland increased in the recent years. This is not reflected in this study as an update of the infrastructure was not commissioned. This can be justified by the relatively low importance of the infrastructure in the overall LCIA. Tab. 5.1 and Tab. 5.2 show the life cycle inventories for the construction of pipelines for the regional distribution in Switzerland and Europe, based on former studies (Schori et al. 2012).

[9] Belgium, Germany, France, Italy, Luxembourg, Netherlands, Denmark, Ireland, Greece, Portugal, Spain, Finland, Austria, Sweden, United Kingdom

[10] EU-28 without Croatia

[11] Marcogaz 2012: Gas infrastructure – position paper on BAT. Retrieved from: https://www.marcogaz.org/app/download/7928289563/WG-AE-12-29.pdf?t=1541675447, online 04.12.2020

Tab. 5.1 Unit process raw data of “pipeline, natural gas, high-pressure distribution network” (CH)

Explanations	Name	Location	InfrastructureProcess	Unit	*pipeline, natural gas, high pressure distribution network*	UncertaintyType	StandardDeviation 95%	GeneralComment
	Location				*CH*			
	InfrastructureProcess				*1*			
	Unit				*km*			
Resources, land	Transformation, from forest	-	0	m2	2.00E+3	1	2.45	(4,3,3,1,1,5); qualified estimate
	Transformation, to arable	-	0	m2	2.00E+3	1	2.45	(4,3,3,1,1,5); qualified estimate
	Transformation, from unknown	-	0	m2	2.49E+0	1	2.11	(4,3,3,1,1,5); qualified estimate
	Transformation, to industrial area, built up	-	0	m2	2.49E+0	1	2.11	(4,3,3,1,1,5); qualified estimate
	Occupation, industrial area, built up	-	0	m2a	4.97E+1	1	1.64	(4,3,3,1,1,5); qualified estimate
	Occupation, construction site	-	0	m2a	3.33E+3	1	2.01	(4,3,3,1,1,5); qualified estimate
Technosphere	reinforcing steel, at plant	RER	0	kg	2.34E+4	1	1.76	(4,3,3,1,1,5); qualified estimate
	cast iron, at plant	RER	0	kg	9.49E+2	1	1.76	(4,3,3,1,1,5); qualified estimate
	polyethylene, HDPE, granulate, at plant	RER	0	kg	9.38E+2	1	1.76	(4,3,3,1,1,5); qualified estimate
	polyethylene, LDPE, granulate, at plant	RER	0	kg	1.09E+3	1	1.76	(4,3,3,1,1,5); qualified estimate
	concrete, normal, at plant	CH	0	m3	2.73E+0	1	1.76	(4,3,3,1,1,5); qualified estimate
	cement, unspecified, at plant	CH	0	kg	3.90E+3	1	1.76	(4,3,3,1,1,5); qualified estimate
	sand, at mine	CH	0	kg	7.86E+5	1	1.76	(4,3,3,1,1,5); qualified estimate
	bitumen, at refinery	RER	0	kg	7.69E+2	1	1.76	(4,3,3,1,1,5); qualified estimate
	drawing of pipes, steel	RER	0	kg	2.44E+4	1	1.76	(4,3,3,1,1,5); qualified estimate
	transport, passenger car	CH	0	pkm	9.60E+2	1	2.45	(4,3,3,1,1,5); qualified estimate
	transport, helicopter	GLO	0	h	4.80E+0	1	2.45	(4,3,3,1,1,5); qualified estimate
	transport, helicopter, LTO cycle	GLO	0	unit	1.92E+0	1	2.45	(4,3,3,1,1,5); qualified estimate
	transport, lorry 28t	CH	0	tkm	1.72E+4	1	2.09	(4,5,na,na,na,na); standard distance
	transport, lorry 32t	RER	0	tkm	6.80E+2	1	2.32	(5,1,1,3,3,5); estimates for waste transport
	transport, freight, rail	CH	0	tkm	1.59E+4	1	2.09	(4,5,na,na,na,na); standard distance
	excavation, skid-steer loader	RER	0	m3	1.90E+4	1	2.45	(4,3,3,1,1,5); qualified estimate
	excavation, hydraulic digger	RER	0	m3	1.20E+3	1	2.45	(4,3,3,1,1,5); qualified estimate
	building, hall, steel construction	CH	1	m2	2.00E-1	1	3.11	(4,3,3,1,1,5); qualified estimate
	building, multi-storey	RER	1	m3	1.60E+1	1	3.11	(4,3,3,1,1,5); qualified estimate
	disposal, natural gas pipeline, 0% water, to inert material landfill	CH	0	kg	1.22E+4	1	1.76	(4,3,3,1,1,5); qualified estimate
	disposal, plastics, mixture, 15.3% water, to municipal incineration	CH	0	kg	1.01E+3	1	1.76	(4,3,3,1,1,5); qualified estimate
	disposal, bitumen, 1.4% water, to sanitary landfill	CH	0	kg	3.84E+2	1	1.76	(4,3,3,1,1,5); qualified estimate
Outputs	pipeline, natural gas, high pressure distribution network	CH	1	km	1.00E+0			

Tab. 5.2: Unit process raw data of "pipeline, natural gas, high-pressure distribution network" (RER)

Explanations	Name	Location	InfrastructureProcess	Unit	*pipeline, natural gas, high pressure distribution network*	UncertaintyType	StandardDeviation 95%	GeneralComment
	Location				*RER*			
	InfrastructureProcess				*1*			
	Unit				*km*			
Resources, land	Transformation, from forest	-	0	m2	2.00E+3	1	2.45	(4,3,3,3,1,5); qualified estimate for CH
	Transformation, to arable	-	0	m2	2.00E+3	1	2.45	(4,3,3,3,1,5); qualified estimate for CH
	Transformation, from unknown	-	0	m2	2.49E+0	1	2.11	(4,3,3,3,1,5); qualified estimate for CH
	Transformation, to industrial area, built up	-	0	m2	2.49E+0	1	2.11	(4,3,3,3,1,5); qualified estimate for CH
	Occupation, industrial area, built up	-	0	m2a	4.97E+1	1	1.64	(4,3,3,3,1,5); qualified estimate for CH
	Occupation, construction site	-	0	m2a	3.33E+3	1	2.01	(4,3,3,3,1,5); qualified estimate for CH
Technosphere	reinforcing steel, at plant	RER	0	kg	1.36E+4	1	1.77	(4,3,3,3,1,5); qualified estimate for CH
	cast iron, at plant	RER	0	kg	3.38E+2	1	1.77	(4,3,3,3,1,5); qualified estimate for CH
	polyethylene, HDPE, granulate, at plant	RER	0	kg	2.39E+3	1	1.77	(4,3,3,3,1,5); qualified estimate for CH
	polyethylene, LDPE, granulate, at plant	RER	0	kg	7.58E+2	1	1.77	(4,3,3,3,1,5); qualified estimate for CH
	concrete, normal, at plant	CH	0	m3	2.73E+0	1	1.77	(4,3,3,3,1,5); qualified estimate for CH
	cement, unspecified, at plant	CH	0	kg	3.90E+3	1	1.77	(4,3,3,3,1,5); qualified estimate for CH
	sand, at mine	CH	0	kg	6.10E+5	1	1.77	(4,3,3,3,1,5); qualified estimate for CH
	bitumen, at refinery	RER	0	kg	1.26E+3	1	1.77	(4,3,3,3,1,5); qualified estimate for CH
	drawing of pipes, steel	RER	0	kg	1.39E+4	1	1.77	(4,3,3,3,1,5); qualified estimate for CH
	transport, helicopter	GLO	0	h	1.04E+1	1	2.45	(4,3,3,3,1,5); qualified estimate for CH
	transport, helicopter, LTO cycle	GLO	0	unit	4.16E+0	1	2.45	(4,3,3,3,1,5); qualified estimate for CH
	transport, lorry 32t	RER	0	tkm	3.32E+4	1	2.09	(4,5,na,na,na,na); standard distance
	transport, freight, rail	RER	0	tkm	4.56E+3	1	2.09	(4,5,na,na,na,na); standard distance
	excavation, skid-steer loader	RER	0	m3	1.90E+4	1	2.45	(4,3,3,3,1,5); qualified estimate for CH
	excavation, hydraulic digger	RER	0	m3	1.20E+3	1	2.45	(4,3,3,3,1,5); qualified estimate for CH
	building, hall, steel construction	CH	1	m2	2.00E-1	1	3.11	(4,3,3,3,1,5); qualified estimate for CH
	building, multi-storey	RER	1	m3	1.60E+1	1	3.11	(4,3,3,3,1,5); qualified estimate for CH
	disposal, natural gas pipeline, 0% water, to inert material landfill	CH	0	kg	6.96E+3	1	1.77	(4,3,3,3,1,5); qualified estimate for CH
	disposal, plastics, mixture, 15.3% water, to municipal incineration	CH	0	kg	1.57E+3	1	1.77	(4,3,3,3,1,5); qualified estimate for CH
	disposal, bitumen, 1.4% water, to sanitary landfill	CH	0	kg	6.32E+2	1	1.77	(4,3,3,3,1,5); qualified estimate for CH
Outputs	pipeline, natural gas, high pressure distribution network	RER	1	km	1.00E+0			

5.3 Operation of the network

5.3.1 Energy use

Heat is required to reduce the pressure of the natural gas before entering the regional distribution network. This service is not included in the long-distance inventories but is accounted for in the dataset "natural gas, high-pressure, at consumer". For 2019, the Swiss compressor station in Ruswil reported a natural gas consumption of 600 TJ.[12] Tab. 5.3 shows the natural gas consumption per MJ supplied, as reported in former studies, and the value used for this study, as calculated based on official data from the central compressor station in Ruswil. The infrastructure and emissions associated with the combustion of natural gas are modelled with the dataset "natural gas, burned in gas turbine".

Tab. 5.3 Natural gas consumption in the high-pressure network

Source	Natural gas consumption
Schori 2012	0.56%
Faist Emmenegger 2015	0.59%
This study	**0.49%**

12 Communication by Email with Mischa Zschokke (Carbotech), 01.12.2020

5.3.2 Emissions

The emission rate is calculated based on reported methane emissions of the Swiss distribution network for 2018.[13] The available figures for the distribution network differentiate between pipeline leakages, emissions due to pipeline fractures and maintenance, emissions at connection point of households and small businesses as well as emissions at the connection point of industry and power plants. For the emission-rate of the high-pressure network, the emissions at connection points of industry and power plants as well as a share of the emissions due to leakages, fractures, and maintenance, considering the ratio of the length of the high-pressure and low-pressure network, are taken into account. These values are summed up and divided by the annual natural gas consumption in Switzerland. The derived emission rate is considerably higher than the values used in former studies (see Tab. 5.4). In the former studies, only the pipeline leakages were included and thus, the total emission rate was underestimated. To calculate the airborne emissions of the regional distribution of 1 MJ natural gas, the emission rate is multiplied with the substance content of 1 Nm³ natural gas (see Tab. 3.1) and divided by the net calorific value.

Tab. 5.4 Emission rates of the high-pressure network[14]

Source	**Emission rate**
Schori 2012	0.04%
Faist Emmenegger 2015	0.01%
This study	**0.10%**

5.4 Inventory of the regional distribution

5.4.1 Description

The dataset «natural gas, high-pressure, at consumer» is shown exemplarily for Switzerland in

Tab. 5.5. It describes the supply mix according to chapter 2, energy use, emissions, and infrastructure requirements for the regional distribution of 1 MJ natural gas. The same values for emissions, energy use and infrastructure needs are used for Switzerland and other countries/regions. This is justified by the good quality of the Swiss data. The inventories only differ regarding the natural gas supply mix used.

5.4.2 Data quality

Recent data is available for the energy use and emissions in the Swiss distribution network (non-verified data partly based on qualified estimates). For the emission rate not only pipeline leakages as in former studies, but also emissions due to fractures and maintenance as well as emissions at the connection point of the consumers are considered. Infrastructure requirements are based on qualified estimates. The infrastructure processes were not updated, but the impact on the emission rate was considered.

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13 Communication by Email with Mischa Zschokke (Carbotech), 01.12.2020

14 The exact value was not reported in Faist-Emmenegger et al. 2015. The emission rate was estimated based on the emissions and gas composition.

Tab. 5.5 Unit raw dataset for the regional distribution in Switzerland

Name	Location	Unit	*natural gas, high pressure, at consumer*	UncertaintyType	Standard-Deviation95%	GeneralComment
Location			*CH*			
InfrastructureProcess			*0*			
Unit			*MJ*			
natural gas, high pressure, at consumer	CH	MJ	1.00E+0			
natural gas, high pressure, at consumer	CH	MJ	1.05E-03	1	1.57	(4,3,5,3,1,BU:1.05); including leakage
natural gas, burned in gas turbine	CH	MJ	4.90E-03	1	1.3	(4,2,2,3,3,BU:1.05); Qualified estimates from different gas companies
pipeline, natural gas, high pressure distribution network	CH	km	1.07E-09	1	3.32	(4,3,5,3,3,BU:3); based on estimated standard capacity
natural gas, high pressure, at consumer	DE	MJ	5.51E-01	1	1.21	(1,1,1,1,3,BU:1.05); Eurostat 2023 for European countries, BP 2022 for other countries and regions
natural gas, high pressure, at consumer	FR	MJ	3.35E-01	1	1.21	(1,1,1,1,3,BU:1.05); Eurostat 2023 for European countries, BP 2022 for other countries and regions
natural gas, high pressure, at consumer	IT	MJ	1.13E-01	1	1.21	(1,1,1,1,3,BU:1.05); Eurostat 2023 for European countries, BP 2022 for other countries and regions
natural gas, high pressure, at consumer	NL	MJ	7.20E-04	1	1.21	(1,1,1,1,3,BU:1.05); Eurostat 2023 for European countries, BP 2022 for other countries and regions
Methane, fossil	-	kg	1.93E-05	1	1.57	(2,3,4,1,1,BU:1.5); Calculated based on leakage and average gas composition
Ethane	-	kg	1.59E-06	1	1.57	(2,3,4,1,1,BU:1.5); Calculated based on leakage and average gas composition
Propane	-	kg	3.59E-07	1	1.57	(2,3,4,1,1,BU:1.5); Calculated based on leakage and average gas composition
Butane	-	kg	1.85E-07	1	1.57	(2,3,4,1,1,BU:1.5); Calculated based on leakage and average gas composition
NMVOC, non-methane volatile organic compounds	-	kg	1.33E-08	1	1.57	(2,3,4,1,1,BU:1.5); Calculated based on leakage and average gas composition
Carbon dioxide, fossil	-	kg	6.66E-07	1	1.22	(2,3,4,1,1,BU:1.05); Calculated based on leakage and average gas composition

6 Life cycle inventory of the local supply

6.1 Overview

This chapter describes the local distribution of natural gas to households and small business using the low-pressure network with an overpressure below 0.1 bar. The process step has the dataset "natural gas, high-pressure, at consumer" as input. That means, all gas consumed annually passes the high-pressure network, while only 77 % of the annual consumption flow through the low-pressure network since 23 % are supplied to consumers at high-pressure level (Schori et al. 2012).

6.2 Infrastructure

The inventories are not updated and kept the same as in a former study (Schori et al. 2012). The share of modern polyethylene pipelines in Switzerland increased in the recent years. This is not reflected in this study as an update of the infrastructure is not commissioned. This can be justified by the relatively low importance of the infrastructure in LCIA. Tab. 6.1 shows the life cycle inventory for the construction of pipelines for the regional distribution in Switzerland, based on former studies (Schori et al. 2012). The same dataset is used for the local supply in other countries and regions.

Tab. 6.1: Unit process raw data of „Pipeline, natural gas, low-pressure distribution network“

Explanations	Name	Location	InfrastructureProcess	Unit	*pipeline, natural gas, low pressure distribution network*	UncertaintyType	StandardDeviation 95%	GeneralComment
	Location				*CH*			
	InfrastructureProcess				*1*			
	Unit				*km*			
Technosphere	Transformation, from unknown	-	0	m2	7.14E+0	1	2.11	(4,3,3,1,1,5); qualified estimate
	Transformation, to industrial area, built up	-	0	m2	7.14E+0	1	2.11	(4,3,3,1,1,5); qualified estimate
	Occupation, industrial area, built up	-	0	m2a	1.43E+2	1	1.64	(4,3,3,1,1,5); qualified estimate
	Occupation, construction site	-	0	m2a	3.33E+3	1	2.01	(4,3,3,3,1,5); qualified estimate for CH
	reinforcing steel, at plant	RER	0	kg	5.24E+3	1	1.64	(4,3,3,1,1,5); qualified estimate
	cast iron, at plant	RER	0	kg	6.30E+3	1	1.64	(4,3,3,1,1,5); qualified estimate
	polyethylene, HDPE, granulate, at plant	RER	0	kg	4.63E+3	1	1.64	(4,3,3,1,1,5); qualified estimate
	polyethylene, LDPE, granulate, at plant	RER	0	kg	4.90E+2	1	1.64	(4,3,3,1,1,5); qualified estimate
	concrete, normal, at plant	CH	0	m3	2.73E+0	1	1.64	(4,3,3,1,1,5); qualified estimate
	gravel, round, at mine	CH	0	kg	2.80E+4	1	1.64	(4,3,3,1,1,5); qualified estimate
	cement, unspecified, at plant	CH	0	kg	2.84E+3	1	1.64	(4,3,3,1,1,5); qualified estimate
	sand, at mine	CH	0	kg	3.76E+5	1	1.64	(4,3,3,1,1,5); qualified estimate
	bitumen, at refinery	RER	0	kg	1.22E+3	1	1.64	(4,3,3,1,1,5); qualified estimate
	drawing of pipes, steel	RER	0	kg	1.15E+4	1	1.64	(4,3,3,1,1,5); qualified estimate
	transport, passenger car	CH	0	pkm	3.77E+4	1	2.34	(4,3,3,1,1,5); qualified estimate
	transport, lorry 28t	CH	0	tkm	9.05E+3	1	2.09	(4,5,na,na,na,na); standard distance
	transport, lorry 32t	RER	0	tkm	3.17E+2	1	2.32	(5,1,1,3,3,5); estimates for waste transport
	transport, freight, rail	CH	0	tkm	8.97E+3	1	2.09	(4,5,na,na,na,na); standard distance
	excavation, skid-steer loader	RER	0	m3	6.76E+2	1	2.34	(4,3,3,1,1,5); qualified estimate
	building, multi-storey	RER	1	m3	5.00E+1	1	3.11	(4,3,3,1,1,5); qualified estimate
	disposal, plastics, mixture, 15.3% water, to municipal incineration	CH	0	kg	5.12E+3	1	1.64	(4,3,3,1,1,5); qualified estimate
	disposal, bitumen, 1.4% water, to sanitary landfill	CH	0	kg	1.22E+3	1	1.64	(4,3,3,1,1,5); qualified estimate
Outputs	pipeline, natural gas, low pressure distribution network	CH	1	km	1.00E+0			

6.3 Operation of the network

6.3.1 Energy use

In Schori et al. 2012 it is assumed that, for Switzerland, 80 % of the energy use in the distribution network is used in the compressor station in Ruswil and 20 % in the local distribution network. The natural gas use of the compressor station Ruswil was 600 TJ in 2019 (cf. Chapter 4.4). Applying the same assumption results in a natural gas consumption of 150 TJ in the low-pressure network. Tab. 6.2 shows the natural gas consumption per MJ supplied as reported in former studies and the value used for this study. The infrastructure and emissions associated with the combustion of natural gas are modelled with the dataset “natural gas, burned in gas turbine”.

Tab. 6.2 Natural gas consumption in the low-pressure network

Source	Natural gas consumption
Schori 2012	0.14%
Faist Emmenegger 2015	0.15%
This study	**0.12%**

6.3.2 Emissions

The emission rate is calculated based on reported methane emissions of the Swiss distribution network for 2018.[15] For the emission rate of the low-pressure network, the emissions at the connection points of households and small businesses as well as a share of the emissions due to leakages, fractures, and maintenance, considering the ratio of the length of the high-pressure and low-pressure network, are considered. These values are summed up and divided by the 77% of the annual natural gas consumption in Switzerland as 23% of the annual demand are consumed by end-users of the high-pressure network. Tab. 6.3 shows the emission rates of former studies and the value calculated for this study. In Faist-Emmenegger et al. 2015 and this study, the consideration of the increased share of PE-pipelines in the low-pressure network resulted in a lower emission rate. To calculate the airborne emissions of the local distribution of 1 MJ natural gas, the emission rate is multiplied with the substance content of 1 Nm^3 natural gas (see Tab. 3.1) and divided by the net calorific value.

Tab. 6.3 Emission rates of the low-pressure network[16]

Source	Emission rate
Schori 2012	0.43%
Faist Emmenegger 2015	0.25%
This study	**0.25%**

15 Date provided by Carbotech

16 The exact value was not reported in Faist-Emmenegger et al. 2015. The emission rate was estimated based on the emissions and gas composition

6.4 Inventory data for the local natural gas supply

6.4.1 Description

The dataset «natural gas, low-pressure, at consumer» is shown exemplarily for Switzerland in Tab. 6.4. It describes the energy use, emissions and infrastructure requirements for the local distribution of 1 MJ natural gas. The same values for emissions, energy use and infrastructure needs are used for all regions. This is justified by the good quality of the Swiss data.

6.4.2 Data quality

Recent data is available for the energy use and emissions in the Swiss distribution network (non-verified data partly based on qualified estimates). Infrastructure requirements are based on qualified estimates. The infrastructure processes were not updated, but the impact on the emission rate was considered.

Tab. 6.4 Unit raw dataset for the local distribution in Switzerland

CH	Name	Location	Unit	*natural gas, low pressure, at consumer*	UncertaintyType	Standard-Deviation95%	GeneralComment
	Location			*CH*			
	Unit			*MJ*			
	natural gas, high pressure, at consumer	CH	MJ				
	natural gas, low pressure, at consumer	CH	MJ	1.00E+0			
	natural gas, burned in gas turbine	CH	MJ	1.23E-03	1	1.07	(1,3,1,3,1,BU:1.05); based on data of Swiss compressor station
	natural gas, at long-distance pipeline	CH	Nm3		1	1.12	(3,1,1,3,1,BU:1.05); including leakage
	natural gas, high pressure, at consumer	CH	MJ	1.00E+00	1	1.12	(3,1,1,3,1,BU:1.05); including leakage
	pipeline, natural gas, high pressure distribution network	CH	km		1	3.27	(4,1,5,3,1,BU:3); calculation based on network length and capacity utilization.
	pipeline, natural gas, low pressure distribution network	CH	km	3.97E-09	1	3.27	(4,1,5,3,1,BU:3); calculation based on network length and capacity utilization.
air, low population	Methane, fossil	-	kg	4.67E-05	1	1.52	(3,1,1,1,1,BU:1.5); calculated based on gas mix and leakage
	Ethane	-	kg	3.87E-06	1	1.52	(3,1,1,1,1,BU:1.5); calculated based on gas mix and leakage
	Propane	-	kg	8.70E-07	1	1.52	(3,1,1,1,1,BU:1.5); calculated based on gas mix and leakage
	Butane	-	kg	4.47E-07	1	1.52	(3,1,1,1,1,BU:1.5); calculated based on gas mix and leakage
	NMVOC, non-methane volatile organic	-	kg	3.22E-08	1	1.52	(3,1,1,1,1,BU:1.5); calculated based on gas mix and leakage
	Carbon dioxide, fossil	-	kg	1.62E-06	1	1.11	(3,1,1,1,1,BU:1.05); calculated based on gas mix and leakage

7 Outlook

The following updates where not within the scope of this project. They would be recommended for follow-up projects.

The UVEK database includes data for the supply of natural gas to Japan. An update was not commissioned. It is recommended to update these data and harmonize the assumptions for the three datasets:

- Liquefied, at freight ship/JP (including the mix)
- Evaporation plant
- High pressure supply

The present update for natural gas is also relevant for LCI related to plastic products and other products made directly from natural gas. The data for plastics in the ecoinvent and UVEK database are not yet linked to these inventories. It would be recommended to establish new LCI data linked to the inventories presented in this report. More recent data for the natural gas transmission and distribution infrastructure are available (e.g. Schuller et al. 2017). It would be recommended to update the material needs for different infrastructure facilities (pipelines, liquefaction facility, etc) and the infrastructure requirements of the transport processes (e.g. km pipeline/ m^3 natural gas transported). The infrastructure for seasonal storage of natural gas is not yet considered in the inventories. Its relevance should at least be estimated roughly. The emissions of the gas turbines used for modelling the energy demand of the transport and distribution activities are based on rough estimates and should be updated as well.

As the import of LNG is increasingly important for the European natural gas supply, it is recommended to investigate the process in more detail in a future update.

The LCI is built up for different life cycle stages. It would be recommended to do an assessment and interpretation of the global warming potential for the full chain, in order to better understand possible deviations from data sources like the analysis in the world energy outlook 2018 (IEA 2018, page 486ff).

Before starting the next updated it would be recommended to check if it is possible to reduce the number of datasets, e.g. by directly integrating the supply mix in the dataset for natural gas, at high pressure network.

The corona crisis might have had some influence on the supply situation after the year 2019. The Russian war in the Ukraine which started in 2022 leads to an important shift in the supply situation for this year and the years to follow. It is recommended to investigate the supply situation in 2023 as soon as statistical data are available.

Due to the reduction of supplies from Russia to Europe by Russia, important amounts of natural gas have been flared in 2022. This should also be considered in an updated inventory for supplies from Russia.

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