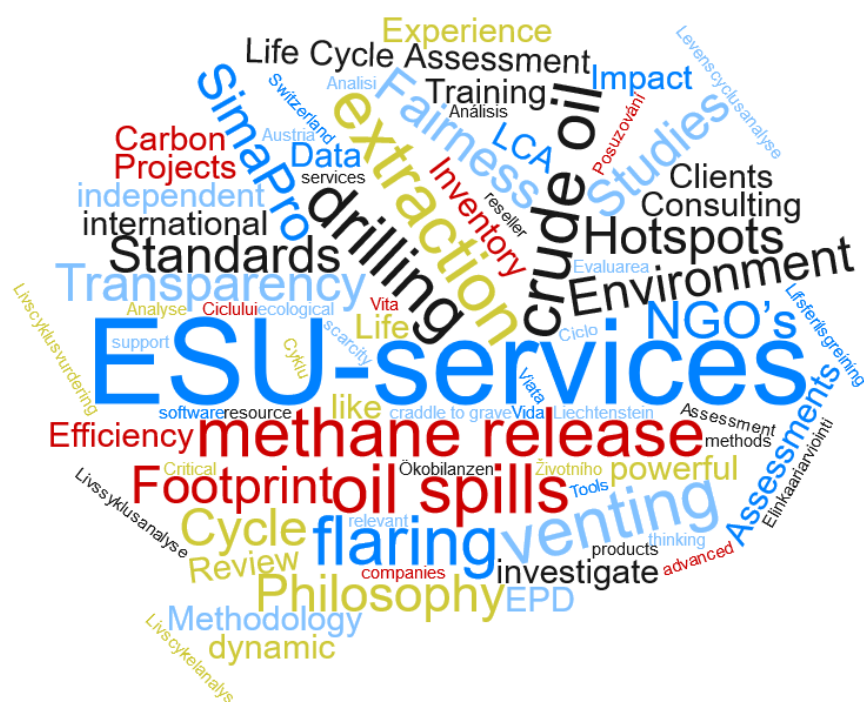


2025

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



Federal Office for the Environment (FOEN)

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

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Abbreviations

AE	United Arab Emirates
AL	Albania
AO	Angola
AR	Argentina
AT	Austria
AU	Australia
AZ	Azerbaijan
BD	Bangladesh
BE	Belgium
BG	Bulgaria
BH	Bahrain
BN	Brunei Darussalam
BO	Bolivia
BR	Brazil
BY	Belarus
CA	Canada
CH	Switzerland
CM	Cameroon
CN	China
CO	Colombia
CZ	Czech Republic
DE	Germany
DK	Denmark
DZ	Algeria
EC	Ecuador
EE	Estonia
EG	Egypt
EI	Energy Institute
EIA	Energy Information Administration
ENTSO-G	European Network of Transmission System Operators for Gas
ES	Spain
EU	European Union
FI	Finland
FR	France
GB	United Kingdom
GE	Georgia
GI	Gibraltar
GLO	Global
GQ	Equatorial Guinea
GR	Greece
HR	Croatia
HU	Hungary
ID	Indonesia
IE	Ireland
IEA	International Energy Agency
IL	Israel
IN	India
IQ	Iraq
IR	Iran

Abbreviations

IT	Italy
JP	Japan
KR	South Korea
KW	Kuwait
KZ	Kazakhstan
LCA	Life Cycle Assessment
LCI	Life Cycle Inventory
LNG	Liquefied Natural Gas
LT	Lithuania
LV	Latvia
LY	Libya
MM	Myanmar
MX	Mexico
MY	Malaysia
MZ	Mozambique
NG	Nigeria
NL	Netherlands
NO	Norway
NSP	Not Specified
OM	Oman
Others	Other countries or regions
PE	Peru
PG	Papua New Guinea
PK	Pakistan
PL	Poland
PT	Portugal
QA	Qatar
RER	Europe
RNA	Rest of North America
RO	Romania
ROAF	Rest of Africa
ROASP	Rest of Asia-Pacific
ROCIS	Rest of Commonwealth of Independent States
ROE	Rest of Europe
RoE	Rest of Europe (excluding specific countries)
ROME	Rest of Middle East
ROSCA	Rest of South and Central America
RoW	Rest of World
RS	Serbia
RU	Russia
SA	Saudi Arabia
SE	Sweden
SI	Slovenia
SK	Slovakia
SY	Syria
TH	Thailand
tkm	tonne-kilometer
TM	Turkmenistan
TN	Tunisia
TR	Turkey
TT	Trinidad and Tobago
TW	Taiwan
UA	Ukraine

Abbreviations

US	United States
UZ	Uzbekistan
VE	Venezuela
VN	Vietnam
YE	Yemen

1 Introduction

The goal of this study is to document the life cycle inventory data as submitted to Federal Office for the Environment (FOEN) for the implementation in their latest database release. Changes made by the commissioner to implement the data in their database are not described in this report. The content of this document therefore might not fully reflect the LCI data as provided with the database of the commissioner.

This document is based on the previous update of the life cycle inventory data for natural gas distribution (Bussa et al. 2021). extending the regional scope. 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 UVEK database for the reference year 2023. 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 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 55 countries (AU, AZ, BO, DZ, ID, IR, KZ, LY, MY, NG, NO, OM, PE, QA, RU, SA, TT, TM, VE, CA, MX, US, CN, JP, KR, AR, BR, EG, IN, KW, TW, TH, AE, IQ, UZ, BE, DE, IT, FR, NL, ES, CZ, DK, FI, GR, HU, IE, RO, SK, SE, BG, HR, RS and RoE) and four regions. Regional consumption mixes are calculated for RER, Europe without Switzerland, GLO and RoW. 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 1%_{vol} to the 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. 2025a are included as well. In total, 50 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 2023 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)
- Details 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:

- EI (2024): Published annually and available with 2023 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 (2024a, 2025a): 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 2023 are not available for all European countries at the time of this project.
- Eurostat (2024b, c): 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 2023 are available.
- Due to the dynamic changes in recent months on the European gas market, the Swiss gas industry does not compile an import portfolio for Switzerland at the moment.
- Department for Energy Security and Net Zero (2024): The Department for Energy Security and Net Zero provides data on the natural gas imports and exports of the United Kingdom for 2023. Imports via pipeline and LNG are presented separately.

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

2.1 Net producing countries

Defined as countries that do not import natural gas according to trade statistics, and where production (minus exports) exceeds domestic consumption, the following nations are categorized as self-sufficient in natural gas: AU, AZ, BO, DZ, ID, IR, KZ, LY, MY, NG, NO, OM, PE, QA, RU, SA, TT, TM, and VE. These countries are modeled as sourcing 100% of their natural gas from domestic production

2.2 Non-European countries

The consumption mixes for CA, MX, US, CN, JP, KR, AR, BR, EG, IN, KW, TW, TH, AE, IQ and UZ were calculated based on the production and trade statistics provided in EI 2024 and are summarized in Tab. 2.1. The consumption mix is calculated as imports plus own production (where applicable) minus exports in the case of CA and US.

Tab. 2.1 Natural gas consumption mixes in non-European countries. Marked in green: Countries modelled in this study

	CA	MX	US	CN	JP	KR	AR	BR	EG	IN	KW	PK	TW	TH	AE	IQ	UZ
Source	Energy Institute	Energy Institute	Energy Institute	Energy Institute	Energy Institute	Energy Institute	Energy Institute	Energy Institute	Energy Institute	Energy Institute	Energy Institute	Energy Institute	Energy Institute	Energy Institute	Energy Institute	Energy Institute	Energy Institute
AE				0.25%	1.27%	1.05%				7.15%	0.40%		0.66%		74.50%		
AO										1.58%							
AR							89.42%										
AU				8.38%	41.51%	23.51%				0.76%	0.41%		40.00%	8.16%			
BN				0.25%	3.76%	1.19%							1.30%	0.96%			
BO							4.73%	17.97%									
BR								77.71%									
CA	90.52%		8.67%														
CN				59.54%													
DZ				0.12%	0.09%	0.29%	0.13%	0.33%		0.75%	0.45%			0.22%			
EG				0.10%	0.20%	0.63%	0.11%		99.99%	0.43%		0.25%	0.29%				
ID		0.34%		1.39%	4.58%	6.58%			0.01%			0.92%	2.35%	1.29%			
IN										50.45%							
IQ																53.10%	
IR																46.90%	
KW											60.25%						
KZ				1.18%													
MM				0.93%										11.36%			
MX		36.46%	0.00%														
MY				2.46%	15.80%	13.76%					0.85%		3.16%	5.45%			
NG				0.41%	0.38%	1.35%	0.18%			1.65%	5.35%	1.47%	1.54%	0.79%			
NSP				0.05%	0.10%	0.14%	0.00%	0.21%		0.90%							
OM				0.35%	3.29%	11.37%				1.76%	2.27%	0.26%	1.86%	1.78%			
PE	0.03%	0.21%		0.05%	0.38%	1.59%							0.69%				
PG				0.89%	5.76%	1.44%							7.22%				
PK												73.39%					
QA				5.82%	4.43%	19.51%	0.40%			23.93%	22.97%	23.30%	27.87%	8.31%	25.50%		
ROAF				0.31%	0.39%	1.39%	0.22%			1.98%	1.30%		0.35%	2.67%			
ROASP				0.01%	0.36%	0.75%				0.11%	0.35%			0.54%			
ROE																0.01%	0.00%
ROSCA			0.01%	0.00%													
RU				8.21%	9.25%	3.74%		0.28%		0.92%	0.44%		2.79%				3.33%
TH														54.48%			
TM				7.75%													1.78%
TT	0.04%		0.04%	0.13%	0.09%	0.03%	0.37%	0.08%		0.59%	0.77%	0.20%		0.61%			
US	9.40%	62.99%	91.28%	1.10%	8.33%	11.69%	4.43%	3.43%		7.03%	4.20%	0.22%	9.91%	3.38%			
UZ				0.31%													94.88%
Total	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%
Total modelled	100.00%	100.00%	99.99%	97.56%	89.62%	95.10%	99.78%	99.79%	100.00%	97.01%	98.35%	26.61%	91.13%	84.47%	100.00%	100.00%	100.00%

Not all countries of origin are included in Meili et al. 2025a, 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.

Market situation for supplies to individual countries and regions

Tab. 2.2 Modelled natural gas consumption mix for non-European countries.

	CA	MX	US	CN	JP	KR	AR	BR	EG	IN	KW	PK	TW	TH	AE	IQ	UZ
AE				0.26%	1.42%	1.10%				7.37%	0.41%			0.72%		74.50%	
AO										1.63%							
AR							89.62%										
AU				8.59%	46.32%	24.72%				0.79%	0.42%			43.90%	9.66%		
BO							4.74%	18.01%									
BR								77.87%									
CA	90.52%		8.67%														
CN				61.03%													
DZ				0.12%	0.10%	0.31%	0.13%	0.33%		0.78%	0.46%			0.26%			
EG				0.10%	0.23%	0.66%	0.11%		99.99%	0.45%		0.93%	0.32%				
ID		0.34%		1.42%	5.11%	6.92%				0.01%		3.46%	2.58%	1.53%			
IN										52.00%							
IQ																53.10%	
IR																46.90%	
KW											61.26%						
KZ				1.21%													
MX		36.46%	0.00%														
MY				2.52%	17.63%	14.47%					0.86%		3.47%	6.45%			
NG				0.42%	0.43%	1.42%	0.18%			1.71%	5.44%	5.52%	1.69%	0.94%			
OM				0.36%	3.67%	11.96%				1.81%	2.30%	0.96%	2.05%	2.10%			
PE	0.03%	0.21%		0.05%	0.43%	1.68%							0.75%				
QA				5.96%	4.94%	20.51%	0.41%			24.67%	23.35%	87.56%	30.59%	9.84%	25.50%		
RoE																0.01%	0.00%
RU				8.42%	10.32%	3.93%		0.28%		0.95%	0.45%		3.06%				3.33%
TH														64.50%			
TM				7.95%													1.78%
TT	0.04%		0.04%	0.13%	0.11%	0.04%	0.37%	0.08%		0.61%	0.78%	0.74%		0.72%			
US	9.40%	62.99%	91.29%	1.13%	9.30%	12.29%	4.44%	3.44%		7.25%	4.27%	0.84%	10.87%	4.00%			
UZ				0.32%													94.88%
Total	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%

2.3 European countries

For European countries, no trade data are provided anymore on country-specific level by EI (2024). In the case of BE, DE, IT, FR, NL, ES, CZ, DK, FI, GR, HU, IE, RO, SK, SE, BG, HR, RS and RoE, the consumption mixes are calculated based on the annual Eurostat import statistics (EUROSTAT 2025a). For TR, AT and PL no data was reported in the annual statistics; these countries' consumption mixes are modelled based on the monthly import statistics (EUROSTAT 2024b). Main methodological difference between both statistics is that the annual trade provide imports from countries of origin, while the monthly data refer to the physical flows crossing the borders and hence show mainly transit countries and not countries of origin. Since no European country except Norway can meet its natural gas demand from own production and it is thus assumed that European countries export their consumption mix and not their own production, the monthly data was suitable for the existing model with few assumptions based on a comparative analysis of monthly and annual data for 2022:

1. Imports from TR were modelled as natural gas produced in AZ to avoid natural gas from IR in European mixes
2. Imports from UA were modelled as natural gas produced in RU

All German LNG imports are classified as not specified. This gap was filled with data from BDEW 2024.

Some trade flow could not be represented which the current model. This was the case for Turkish LNG import from BE. This flow can be understood as LNG ships partly unloading in BE and then continuing their trip to TR, but not as natural gas extracted and liquefied in BE. Since the country of origin of the LNG was not known, these trade flows were considered as unspecified origin.

Domestic production of natural gas is based on EUROSTAT 2025b where possible, otherwise EUROSTAT (2025b) is used.

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 2024c).

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 Energy Security and Net Zero 2024 were used.

Market situation for supplies to individual countries and regions

Tab. 2.3 Natural gas consumption mix in modelled European countries. Marked in green: Countries modelled in this study

	TR	BE	DE	IT	FR	NL	ES	AT	CZ	DK	FI	GR	HU	IE	PL	RO	SK	SE	BG	HR	RS	GB	CH	RoE
Source	Eurostat	Eurostat	Eurostat, B	Eurostat	Eurostat	Eurostat	Eurostat	Eurostat	Eurostat	Eurostat	Eurostat	Eurostat	Eurostat	Eurostat	Eurostat	Eurostat	Eurostat	Eurostat	Eurostat	Eurostat	Eurostat	DESNZ	Eurostat	Eurostat
AE			0.08%																					
AO		1.21%	0.53%		0.41%	2.29%	0.78%															1.01%		
AU							0.02%																	
AZ	20.04%			15.56%								18.17%								81.33%				0.01%
BE		0.06%	19.69%		0.49%	5.24%									0.01%							0.00%		0.17%
BG																21.42%								
CH					0.16%																			
CM							1.08%																	
CZ																0.83%								
DE		0.10%	5.84%		0.74%	0.62%		38.39%		5.26%						6.21%							5.65%	0.03%
DK		0.28%				0.94%									32.46%			60.48%						0.06%
DZ	11.72%	0.40%		39.93%	8.80%	0.43%	29.30%				5.12%	6.35%				0.85%						0.61%		1.55%
EE															0.02%									1.08%
EG	2.58%	0.19%	0.08%	0.42%	0.83%	0.42%	1.13%					6.50%										0.33%		
GR																		9.83%						0.71%
ES					4.30%		0.08%																	
FR		6.68%	1.11%			1.54%	3.10%																85.12%	0.09%
GB		11.51%				4.64%								100.00%								43.61%		0.32%
GQ		0.39%				0.82%	0.48%								0.43%									0.11%
HR				0.05%									4.90%											0.05%
HU																0.23%					3.17%			
ID																					3.03%			
IR	10.58%																							
IT				4.20%				7.99%															6.39%	0.14%
LT															1.10%									3.96%
LY				3.92%																				
MZ	0.21%			0.24%																	6.35%			
NG	0.92%			0.44%	0.95%	0.89%	13.57%					1.70%									2.79%		0.58%	13.48%
NL		10.04%	23.29%	4.08%	5.58%	22.67%									0.03%							0.04%	0.19%	2.01%
NO	0.54%	22.55%	39.11%	6.26%	32.39%	17.77%	1.48%		87.00%	94.73%	21.28%	1.79%			0.44%			5.82%				32.84%		11.16%
NSP	1.57%		2.73%	1.43%	0.40%	0.70%	0.29%		4.91%	0.01%	9.23%	0.98%	5.50%		15.19%		36.08%	20.75%	7.11%			0.06%	2.65%	23.04%
OM	0.18%				0.20%	0.73%															10.95%			
PE					0.63%	0.20%	1.25%															2.23%		
PL															18.25%									0.30%
PT							2.54%																	
QA		18.71%		10.63%	4.99%	1.63%	3.57%								9.26%							3.40%		
RO													11.50%			77.50%				0.04%				0.44%
RU	41.77%	17.62%		4.56%	13.02%	2.60%	18.32%		8.09%		10.19%	43.83%	78.10%		2.49%		63.92%	12.95%			100.00%			5.38%
SI				0.06%																	7.25%			
SK								53.62%							0.61%									0.15%
TR	1.59%																							
TT	0.46%		0.30%		0.48%	2.24%	1.39%								0.45%						16.46%		0.66%	4.06%
US	7.85%	10.25%	7.25%	8.23%	25.63%	34.36%	20.89%				54.17%	20.68%			12.22%				1.69%	49.98%		14.64%		22.91%
Total	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%
Total modelled	98.23%	100.00%	97.27%	98.27%	99.60%	99.30%	96.09%	100.00%	95.09%	99.99%	90.77%	99.02%	94.50%	100.00%	83.70%	100.00%	63.92%	79.25%	92.89%	86.40%	100.00%	99.94%	97.35%	70.33%

Tab. 2.4 Modelled natural gas consumption mix for European countries.

	TR	BE	DE	IT	FR	NL	ES	AT	CZ	DK	FI	GR	HU	IE	PL	RO	SK	SE	BG	HR	RS	GB	CH	RoE
AE			0.08%																					
AO		1.21%	0.54%		0.42%	2.30%	0.82%															1.01%		
AU							0.02%																	
AZ	20.40%			15.84%								18.35%								87.56%				0.01%
BE		0.06%	20.24%		0.49%	5.28%									0.02%							0.00%		0.24%
BG																21.42%								
CH					0.17%																			
CZ															0.99%									
DE		0.10%	6.00%		0.75%	0.62%		38.39%		5.26%					7.42%								5.80%	0.05%
DK		0.28%				0.94%									38.78%			76.32%						0.09%
DZ	11.93%	0.40%		40.63%	8.84%	0.43%	30.49%				5.65%	6.42%					0.85%					0.61%		2.20%
EG	2.63%	0.19%	0.08%	0.43%	0.83%	0.42%	1.17%					6.56%										0.33%		
GR																			10.58%					1.02%
ES					4.31%		0.08%																	
FR		6.68%	1.14%			1.55%	3.23%																87.43%	0.12%
GB		11.51%				4.68%								100.00%								43.63%		0.46%
GQ		0.39%				0.83%	0.50%								0.51%									0.15%
HU																	0.23%				3.67%			
HR				0.05%									5.18%											0.07%
ID																				3.51%				
IR	10.77%																							
IT				4.28%				7.99%															6.57%	0.20%
LY				3.99%																				
NG	0.93%			0.45%	0.95%	0.89%	14.13%					1.72%									3.23%		0.58%	19.17%
NL		10.04%	23.94%	4.15%	5.60%	22.83%									0.04%							0.04%	0.20%	2.86%
NO	0.55%	22.55%	40.21%	6.37%	32.52%	17.89%	1.54%		91.49%	94.74%	23.45%	1.80%			0.53%			7.34%				32.86%		15.87%
OM	0.18%				0.20%		0.76%														12.68%			
PE					0.63%	0.20%	1.30%															2.23%		
PL															21.81%									0.42%
QA		18.71%		10.82%	5.01%	1.64%	3.72%								11.06%							3.40%		
RO																	77.50%		0.04%					0.62%
RU	42.52%	17.62%		4.64%	13.07%	2.62%	19.07%		8.51%		11.23%	44.27%	82.65%		2.97%		100.00%	16.34%			100.00%			7.65%
SK								53.62%							0.73%									0.21%
TR	1.61%																							
TT	0.47%		0.31%		0.48%	2.25%	1.45%								0.54%						19.06%	0.66%		5.77%
US	8.00%	10.25%	7.45%	8.37%	25.73%	34.61%	21.73%				59.68%	20.88%			14.60%				1.82%	57.85%		14.65%		32.57%
Total	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%

2.4 Regions

The global and Rest-of-World (defined as non European countries) mixes are modelled based on production and trade data from EI 2024, while the mixes for Europe and Europe without Switzerland are based on the consumption data from the same source.

Tab. 2.5 Regional natural gas mixes (EI 2024). Marked in green: Countries modelled in this study

	Europe without Switzerland	RER	GLO	RoW
Source	Energy Institute	Energy Institute	Energy Institute	Energy Institute
AE			1.43%	1.52%
AO			0.14%	0.06%
AR			1.07%	1.14%
AT	1.59%	1.58%		
AU			3.91%	4.15%
AZ			0.92%	0.65%
BD				0.58%
BE	3.16%	3.14%		
BG	0.58%	0.58%		
BH				0.46%
BN				0.27%
BO			0.31%	0.33%
BR			0.60%	0.64%
CA			4.90%	5.21%
CH		0.63%		
CN			6.04%	6.41%
CO			0.31%	0.33%
CZ	1.54%	1.53%		
DE	17.43%	17.32%	0.10%	
DK	0.38%	0.37%		
DZ			2.62%	2.31%
EE	0.09%	0.08%		
EG			1.47%	1.48%
GR	1.24%	1.23%		
ES	6.75%	6.71%		
FI	0.28%	0.27%		
FR	7.80%	7.75%		
GB	14.63%	14.54%	0.89%	
GQ			0.20%	0.19%
HR	0.58%	0.57%		
HU	1.89%	1.87%		
ID			1.66%	1.76%
IL				0.64%
IN			0.81%	0.86%
IQ			0.26%	0.27%
IR			6.49%	6.75%
IT	13.50%	13.42%	0.07%	
KW			0.35%	0.37%
KZ			0.79%	0.84%
LT	0.36%	0.36%		
LV	0.18%	0.18%		
LY			0.42%	0.45%
MM				0.41%
MX			0.92%	0.97%
MY			2.09%	2.22%
NG			1.13%	0.94%
NL	5.94%	5.90%	0.25%	
NO	0.87%	0.87%	3.01%	
OM			1.11%	1.16%
PE			0.40%	0.34%
PK				0.76%
PL	4.51%	4.48%	0.09%	
PT	1.03%	1.03%		
QA			4.66%	4.38%
RO	2.09%	2.08%	0.23%	
ROAF				0.53%
ROASP				0.60%
ROCIS				0.01%
ROE	7.97%	7.92%		
ROME				0.02%
ROSCA				0.08%
RU			15.11%	14.86%
SA			2.94%	3.12%
SE	0.17%	0.16%		
SI	0.18%	0.18%		
SK	0.97%	0.96%		
SY				0.08%
TH			0.66%	0.70%
TM			1.97%	2.09%
TT			0.64%	0.57%
UA	4.32%	4.29%	0.46%	
US			26.68%	26.26%
UZ			1.14%	1.21%
VE			0.76%	0.81%
VN				0.20%
Total	100.00%	100.00%	100.00%	100.00%
Total modelled	98.17%	98.18%	100.00%	95.36%

Tab. 2.6 Modelled regional natural gas mixes

	Europe without Switzerland	RER	GLO	RoW
AE			1.43%	1.59%
AO			0.14%	0.06%
AR			1.07%	1.19%
AT	1.61%	1.60%		
AU			3.91%	4.36%
AZ			0.92%	0.68%
BE	3.22%	3.20%		
BG	0.59%	0.59%		
BO			0.31%	0.34%
BR			0.60%	0.67%
CA			4.90%	5.46%
CH		0.64%		
CN			6.04%	6.73%
CO			0.31%	0.35%
CZ	1.57%	1.56%		
DE	17.76%	17.64%	0.10%	
DK	0.38%	0.38%		
DZ			2.62%	2.42%
EG			1.47%	1.55%
GR	1.26%	1.26%		
ES	6.88%	6.83%		
FI	0.28%	0.28%		
FR	7.95%	7.90%		
GB	14.90%	14.81%	0.89%	
GQ			0.20%	0.20%
HU	1.92%	1.91%		
HR	0.59%	0.58%		
ID			1.66%	1.84%
IN			0.81%	0.91%
IQ			0.26%	0.29%
IR			6.49%	7.08%
IT	13.75%	13.66%	0.07%	
KW			0.35%	0.39%
KZ			0.79%	0.88%
LY			0.42%	0.47%
MX			0.92%	1.02%
MY			2.09%	2.33%
NG			1.13%	0.99%
NL	6.05%	6.01%	0.25%	
NO	0.89%	0.88%	3.01%	
OM			1.11%	1.22%
PE			0.40%	0.35%
PL	4.60%	4.57%	0.09%	
QA			4.66%	4.60%
RO	2.13%	2.12%	0.23%	
RoE	8.12%	8.06%		
RU			15.11%	15.59%
SA			2.94%	3.28%
SE	0.17%	0.17%		
SK	0.99%	0.98%		
TH			0.66%	0.74%
TM			1.97%	2.19%
TT			0.64%	0.60%
UA	4.40%	4.37%	0.46%	
US			26.68%	27.54%
UZ			1.14%	1.27%
VE			0.76%	0.85%
Total	100.00%	100.00%	100.00%	100.00%

2.5 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 EI (2024) and Eurostat (2024b, 2025a). Tab. 2.7 shows the share of pipeline and LNG-imports for regional mixes, while Tab. 2.8 and Tab. 2.9 show the mode of transport for individual country mixes modelled. Since the European and Europe without Switzerland mix are building up on the country-level consumption mixes, the share of LNG imports is already included in the country-specific datasets,

Tab. 2.7 Mode of transport for natural gas supplies to Europe and global (EI 2024)

	GLO	RoW
Source	Energy Institute	Energy Institute
AE	13.84%	13.71%
AO	94.04%	61.42%
AU	70.78%	70.78%
DZ	18.75%	2.15%
EG	8.55%	3.20%
GQ	70.80%	67.45%
ID	25.07%	24.96%
MY	44.75%	44.75%
NG	40.15%	23.91%
OM	35.48%	34.33%
PE	34.54%	17.77%
QA	59.88%	54.66%
RU	7.28%	4.28%
TT	41.97%	30.22%
US	11.05%	3.98%
Total	13.44%	10.18%

Market situation for supplies to individual countries and regions

Tab. 2.8 Mode of transport for natural gas supplies to individual countries (EI 2024). Marked in green: Countries modelled in this study

	CA	MX	US	CN	JP	KR	AR	BR	EG	IN	KW	PK	TW	TH	AE	IQ	UZ
Source	Energy Institute	Energy Institute	Energy Institute	Energy Institute	Energy Institute	Energy Institute	Energy Institute	Energy Institute	Energy Institute	Energy Institute	Energy Institute	Energy Institute	Energy Institute	Energy Institute	Energy Institute	Energy Institute	Energy Institute
AE				100.00%	100.00%	100.00%				100.00%	100.00%		100.00%		0.00%		
AO										100.00%							
AU				100.00%	100.00%	100.00%				100.00%	100.00%		100.00%	100.00%			
BN				100.00%	100.00%	100.00%							100.00%			100.00%	
DZ				100.00%	100.00%	100.00%	100.00%	100.00%		100.00%	100.00%			100.00%			
EG				100.00%	100.00%	100.00%	100.00%			100.00%		100.00%	100.00%				
ID		100.00%		100.00%	100.00%	100.00%			100.00%				100.00%	100.00%			
MY				100.00%	100.00%	100.00%					100.00%		100.00%	100.00%			
NG				100.00%	100.00%	100.00%	100.00%			100.00%	100.00%	100.00%	100.00%	100.00%			
OM				100.00%	100.00%	100.00%				100.00%	100.00%	100.00%	100.00%	100.00%			
PE	100.00%	100.00%		100.00%	100.00%	100.00%							100.00%				
PG				100.00%	100.00%	100.00%							100.00%				
QA				100.00%	100.00%	100.00%	100.00%			100.00%	100.00%	100.00%		100.00%	5.53%		
ROAF				100.00%	100.00%	100.00%	100.00%			100.00%	100.00%		100.00%	100.00%			
ROASP				100.00%	100.00%	100.00%				100.00%	100.00%			100.00%			
ROSCA			100.00%	100.00%													
RU				34.11%	100.00%	100.00%		100.00%		100.00%	100.00%		100.00%				
TT	100.00%		100.00%	100.00%	100.00%	100.00%	100.00%	100.00%		100.00%	100.00%	100.00%		100.00%			
US	0.01%	0.62%	0.00%	100.00%	100.00%	100.00%	100.00%	100.00%		100.00%	100.00%	100.00%	100.00%	100.00%			

Tab. 2.9 Mode of transport for natural gas supplies to individual countries (EUROSTAT 2024b, 2025a). Marked in green: Countries modelled in this study

	TR	BE	DE	IT	FR	NL	ES	AT	CZ	DK	FI	GR	HU	IE	PL	RO	SK	SE	BG	HR	RS	GB	CH	RoE
Source	Eurostat	Eurostat	Eurostat, BDEW	Eurostat	Eurostat	Eurostat	Eurostat	Eurostat	Eurostat	Eurostat	Eurostat	Eurostat	Eurostat	Eurostat	Eurostat	Eurostat	Eurostat	Eurostat	Eurostat	Eurostat	Eurostat	DESNZ	Eurostat	Eurostat
AE			100.00%																					
AO		100.00%	100.00%		100.00%	100.00%	100.00%															100.00%		
AU							100.00%																	
BE																100.00%								0.00%
CM							100.00%									100.00%								
DZ	100.00%	100.00%		9.50%	100.00%	100.00%	18.41%				100.00%	100.00%										100.00%		0.00%
EE																100.00%						100.00%		0.00%
EG	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%					100.00%										100.00%		
GQ		100.00%				100.00%	100.00%									100.00%								100.00%
ID																					100.00%			
LT																6.47%								0.00%
MZ	100.00%			100.00%																				
NG	100.00%			100.00%	100.00%	100.00%	100.00%					100.00%									100.00%	100.00%		100.00%
NL																100.00%								0.00%
NO	100.00%	1.81%	0.77%	2.21%	7.96%	15.04%	63.34%				100.00%	100.00%			100.00%			100.00%				1.60%		90.52%
NSP			0.00%	100.00%	100.00%	41.96%	100.00%			100.00%	100.00%	100.00%						100.00%	100.00%					1.81%
OM	100.00%					100.00%	100.00%														100.00%			
PE						100.00%	100.00%															100.00%		
QA		100.00%		100.00%		100.00%	100.00%									100.00%						100.00%		
RU	3.70%	100.00%		3.04%	100.00%	100.00%	100.00%				100.00%	36.81%				100.00%		100.00%						45.99%
TT	100.00%		100.00%		100.00%	100.00%	100.00%									100.00%					100.00%	100.00%		100.00%
US	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%				100.00%	100.00%			100.00%				100.00%	100.00%		100.00%	100.00%	100.00%

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. 2025a)

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; EI 2024)

Substance	Unit	Value	Source
Methane, fossil	kg/m ³	0.6629	Swissgas 2019
Ethane	kg/m ³	0.0549	Swissgas 2019
Propane	kg/m ³	0.0124	Swissgas 2019
Butane	kg/m ³	0.0064	Swissgas 2019
NM VOC, non-methane volatile organic compounds	kg/m ³	0.0005	Swissgas 2019
Carbon dioxide, fossil	kg/m ³	0.0229	Swissgas 2019
Mercury (II)	kg/m ³	1.00E-08	Schori 2012
Gross CV	MJ/m ³	41.1	Swissgas 2019
Net CV	MJ/m ³	36.0	Energy Institute (EI) 2024
Density	kg/m ³	0.735	Energy Institute (EI) 2024

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.

The Transmission Capacity Map of ENTSOG¹ is used together with online sources² to estimate the pipeline distances for countries of origin supplying to Europe. For other regions, the country reports of the EIA³ were used to identify the main pipeline routes. For EU producing countries

¹ <https://entsog.eu/maps#>

² <https://wikipedia.org>, <https://maps.google.com>

³ <https://eia.gov/international/analysis/world>

it is assumed that domestic gas supplies are direct delivered to the distribution network and storages without long-distance transport. 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.

Other than in the report on extraction (Meili et al. 2025a), the emission rates of the transport activities are not modelled with data from IEA 2020. The data is only available on the level of natural gas producing countries and the available downstream data of IEA 2020 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. 4.1-Tab. 4.3) 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. 4.1 Unit process raw data of "Pipeline, natural gas, long distance, low capacity, onshore/GLO/I"

Explanations	Name	Location	Infrastructure	Process	Unit	pipeline, natural gas, long distance, low capacity, onshore	Uncertainty	Type	Standard Deviation	95%	General Comment
	Location Infrastructure Process Unit					GLO 1 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 Technosphere	Water, unspecified natural origin	-	0	m3		1.87E+2	1	1.10	(2,3,1,1,1,3);	environmental report	
	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. 4.2 Unit process raw data of "Pipeline, natural gas, long distance, high capacity, onshore/ GLO/I"

Explanations	Name	Location	Infrastructure	Process	Unit	pipeline, natural gas, long distance, high capacity, onshore	Uncertainty	Type	Standard Deviation	95%	General Comment
	Location Infrastructure Process Unit					GLO 1 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. 4.3 Unit process raw data of "Pipeline, natural gas, long distance, high capacity, offshore/ GLO/I"

Explanations	Name	Location	Infrastructure	Process	Unit	pipeline, natural gas, long distance, high capacity, offshore	Uncertainty type	Standard Deviation 95%	General Comment
	Location Infrastructure Unit					GLO 1 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 water Technosphere	Water, unspecified natural origin	-	0	m3		8.05E+2	1	1.10	(2,3,1,1,1,3); environmental report
	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 uncertainty 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 uncertainty 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 uncertainty 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 uncertainty 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 uncertainty 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. 4.1 and Tab. 4.2). 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. 4.4. 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. 4.4 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	Comment
Energy use (FSU)	%/1000 km	1.9%	1.9%	2.1%	2.3%	2.2%	average of Schuller 2017 and Müller-Syring 2016
Energy use (NL)	%/1000 km			3.0%	0.6%		part of RER
Energy use (NO)	%/1000 km			0.8%	1.5%		part of RER
Energy use (UK)	%/1000 km			0.8%			part of RER
Energy use (RER, RNA)	%/1000 km	1.8%	1.8%			0.9%	average of individual European countries in Schuller 2017 and Müller-Syring 2016
Energy use (RME, RAF, RAS, RLA)	%/1000 km	1.8%	1.8%	3.0%		2.2%	same value as for FSU

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. 4.5 shows the data for the combustion in a gas turbine exemplarily for natural gas extracted in Norway.

Tab. 4.5 Unit process raw data of “natural gas, burned in gas turbine” (Example for Norway)

Name	Location	Unit	Natural gas, burned in gas turbine {NO} U	Uncertainty Type	Standard-Deviation95%	GeneralComment
Location			NO			
Unit			MJ			
Natural gas, burned in gas turbine {NO} U	NO	MJ	1.00E+0			
Natural gas, high pressure, at consumer {NO} U	NO	MJ	1.00E+00	1	1.56882825	(4,3,5,3,1,BU:1.05); natural gas input
Gas turbine, 10MWe, at production plant {RER} U	RER	unit	1.15E-10	1	4.00802103	(4,5,5,5,5,BU:3); Infrastructure estimation
Methane, fossil	-	kg	4.50E-06	1	1.568145	(2,3,4,1,1,BU:1.5); Calculated based on leakage and average gas composition
NM VOC, non-methane volatile organic compounds, unspecified	-	kg	1.00E-06	1	1.568145	(2,3,4,1,1,BU:1.5); Calculated based on leakage and average gas composition
Carbon dioxide, fossil	-	kg	5.60E-02	1	1.22256878	(2,3,4,1,1,BU:1.05); Calculated based on leakage and average gas composition
Mercury	-	kg	3.00E-11	1	5.05916245	(2,3,4,1,1,BU:5); Calculated based on leakage and average gas composition
Carbon monoxide, fossil	-	kg	4.00E-05	1	5.62935903	(5,5,5,3,3,BU:5); rough estimate
Dinitrogen monoxide	-	kg	1.00E-06	1	2.1135841	(5,5,5,3,3,BU:1.5); rough estimate
Nitrogen oxides	-	kg	1.30E-04	1	2.1135841	(5,5,5,3,3,BU:1.5); rough estimate
Sulfur dioxide	-	kg	5.50E-07	1	1.87933697	(5,5,5,3,3,BU:1.05); rough estimate
Dioxin, 2,3,7,8 Tetrachlorodibenzo-p-	-	kg	2.90E-17	1	3.54645735	(5,5,5,3,3,BU:3); rough estimate
Heat, waste	-	MJ	1.10E+00	1	1.87933697	(5,5,5,3,3,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. 4.6). 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. 4.6 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. 4.7. 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.

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. 4.7 Unit process raw data of the pipeline transport from Algeria

Name	Location	Unit	Transport, natural gas, onshore pipeline, long distance {DZ} U	Transport, natural gas, offshore pipeline, long distance {DZ} U	Uncertainty Type	Standard-Deviation95%	GeneralComment
Location			DZ	DZ			
InfrastructureProcess			0	0			
Unit			tkm	tkm			
Transport, natural gas, onshore pipeline, long distance {DZ} U	DZ	tkm	1.00E+0				
Transport, natural gas, offshore pipeline, long distance {DZ} U	DZ	tkm		1.00E+0			
Natural gas, at production {DZ} U	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} U	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} U	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} U	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} U	RER	tkm	1.16E-07	1.16E-07			
Disposal, used mineral oil, 10% water, to hazardous waste incineration {CH} U	CH	kg	1.16E-06	1.16E-06	1	1.6	(3,4,5,3,3,BU:1.05); based on dutch data
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
NM VOC, non-methane volatile organic compounds, unspecified orig	-	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	-	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 $-161\text{ }^{\circ}\text{C}$ 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 reservoir⁴. 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. 4.8). 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. 4.8 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

⁴ 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. 4.9. To calculate the airborne emissions of the LNG-transport, the fuel consumption as reported in Tab. 4.8 is multiplied with the emission factors for HFO and LNG as given in Tab. 4.9.

Tab. 4.9 Emission factor for marine fuels based on IMO 2015 and Ushakov et al. 2019. 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
NM VOC	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 oil⁵ 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. 4.10 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/m³ (Schori et al. 2012).

⁵ Bilges are the lowest compartments of ships. Water collects there, which can be contaminated with harmful substances.

Tab. 4.10 Energy and material consumption of vaporizing technologies in different sources. The values highlighted in grey are not used for calculating the averages used in this study.

Parameter	Unit	Schori 2012	Faist Emmenegger 2015	Pospisil 2019	Agarwal 2017	Asprofos engineering 2014	This study	This study	This study	Comment
Technology		SCV	average	SCV	SCV	ORV	ORV	SCV	RER-mix	
Electricity	MJ/Nm ³		0.042							
Natural gas	%	1.6%	0.43%	1.0-2.5%	1.5-2.0%			1.7%	0.69%	SCV: Average of Schori 2012, Pospisil 2019 and Agarwal 2017 RER-mix: 60% SCV
Sea water	m ³ /m ³ gas					1.1E+01	1.1E+01		6.4E+00	ORV: value of Asprofos engineering 2014 RER-mix: 40% ORV
Sodium hypochlorite	kg/m ³ gas					5.6E-02	5.6E-02		3.4E-02	ORV: value of Asprofos engineering 2014 RER-mix: 40% ORV

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. 4.11 and Tab. 4.12. 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. 4.11 Unit raw datasets for LNG (Example for US delivered to GLO)

Name	Location	Unit	Natural gas, liquefied, at liquefaction plant {US} U	Natural gas, liquefied, production US, at freight ship {GLO} U	Natural gas, production US, at evaporation plant {GLO} U	Uncertainty Type	Standard-Deviation	GeneralComment
Location			US	GLO	GLO			
InfrastructureProcess			0	0	0			
Unit			Nm3	Nm3	Nm3			
Natural gas, liquefied, at liquefaction plant {US} U	US	Nm3	1.00E+0					
Natural gas, liquefied, production US, at freight ship {GLO} U	GLO	Nm3		1.00E+0				
Natural gas, production US, at evaporation plant {GLO} U	GLO	Nm3			1.00E+0			
Natural gas, at production {US} U	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} U	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
NM VOC, non-methane volatile organic compounds, unspecified orig	-	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	-	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} U	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} U	US	Nm3		1.00E+00		1	1.24	(4,3,3,1,1,BU:1.05); Based on data from Faist-Emmenegger (2015)
Natural gas, liquefied, production US, at freight ship {GLO} U	GLO	Nm3			1.00E+00	1	1.05	(1,1,1,1,1,BU:1.05);
Sodium hypochlorite, 15% in H2O, at plant {RER} U	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. 4.12 Unit raw datasets for LNG transport (Example for US)

Name	Location	Unit	Transport, liquefied natural gas US, freight ship {OCE} U	Uncertainty Type	Standard-Deviation 95%	GeneralComment
Location Unit			OCE tkm			
Transport, liquefied natural gas US, freight ship {OCE} U	OCE	tkm	1.00E+0			
Transport, freight, lorry 16-32 metric ton, fleet average {RER} U	RER	tkm	1.09E-05	1	2.3	(3,4,5,3,3,BU:2); estimates for waste transport
Methane, fossil	-	kg	1.29E-04	1	1.57	(2,3,4,1,1,BU:1.5); Based on data from IMO(2015) and Sternersen (2017)
Carbon dioxide, fossil	-	kg	1.34E-02	1	1.22	(2,3,4,1,1,BU:1.05); Based on data from IMO(2015) and Sternersen (2017)
Carbon monoxide, fossil	-	kg	3.92E-05	1	5.63	(5,5,5,3,3,BU:5); Based on data from IMO(2015) and Sternersen (2017)
Dinitrogen monoxide	-	kg	6.10E-07	1	2.11	(5,5,5,3,3,BU:1.5); Based on data from IMO(2015) and Sternersen (2017)
Nitrogen oxides	-	kg	1.32E-04	1	2.11	(5,5,5,3,3,BU:1.5); Based on data from IMO(2015) and Sternersen (2017)
Natural gas, liquefied, at liquefaction plant {US} U	US	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} U	RER	kg	1.65E-03	1	1.24	(4,3,3,1,1,BU:1.05); Based on data from Faist-Emmenegger (2015)
Transoceanic freight ship {OCE} U	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} U	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} U	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} U	CH	kg	2.18E-04	1	1.53	(2,4,5,1,1,BU:1.05); Assumptions on the basis of older data

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.⁶ Converting a depleted natural gas field to a storage facility allows the further use of existing wells, gathering systems, and pipeline connections.⁷ 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. 4.13. 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 m³. 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.

⁶ <https://gie.eu/transparency/databases/storage-database/>

⁷ <https://eia.gov/naturalgas/storage/basics/>

Tab. 4.13 Unit process raw data for the imports of Norwegian natural gas to DE

Name	Location	Unit	Natural gas, production NO, at long-distance pipeline {DE} U	Uncertainty Type	Standard-Deviation95%	GeneralComment
Location Unit			DE MJ			
Natural gas, production NO, at long-distance pipeline {DE} U	DE	MJ	1.00E+0			
Natural gas, at production {NO} U	NO	Nm3	2.76E-02	1	1.20897507	(4,2,1,1,1,BU:1.05); Imports via pipeline + losses
Natural gas, production NO, at evaporation plant {DE} U	DE	Nm3	2.14E-04	1	1.20897507	(4,2,1,1,1,BU:1.05); Imports via LNG
Natural gas, burned in gas turbine {NO} U	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} U	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
NM VOC, non-methane volatile organic compounds, unspecified orig	-	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	-	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-15⁸, 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-27⁹, a similar figure of 19 % is reported¹⁰.

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).

⁸ Belgium, Germany, France, Italy, Luxembourg, Netherlands, Denmark, Ireland, Greece, Portugal, Spain, Finland, Austria, Sweden, United Kingdom

⁹ EU-28 without Croatia

¹⁰ Marcogaz 2012: Gas infrastructure – position paper on BAT. Retrieved from: <https://marco-gaz.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	Infrastructure	Process	Unit	pipeline, natural gas, high pressure distribution network	Uncertainty Type	Standard Deviation 95%	General Comment
	Location Infrastructure Unit					CH 1 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
Outputs	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
	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	StandardDeviation95%	GeneralComment
	Location InfrastructureProcess Unit				RER 1 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
Technosphere	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	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
Outputs	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
	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.¹¹ 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%

¹¹ 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 2018.¹² 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 network¹³

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.

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

¹³ 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 {CH} U	Uncertainty Type	Standard Deviation 95%	General Comment
Location			CH			
Unit			MJ			
Natural gas, high pressure, at consumer {CH} U	CH	MJ	1.00E+0	1	1.57	(4,3,5,3,1,BU:1.05); including leakage
Natural gas, high pressure, at consumer {CH} U	CH	MJ	1.05E-03	1	1.57	(4,2,2,3,3,BU:1.05); Qualified estimates from different gas companies
Natural gas, burned in gas turbine {CH} U	CH	MJ	4.90E-03	1	1.3	(4,3,5,3,3,BU:3); based on estimated standard capacity
Pipeline, natural gas, high pressure distribution network {CH} U	CH	km	1.07E-09	1	3.32	(4,3,5,3,1,BU:1.05); natural gas input
Natural gas, high pressure, at consumer {DE} U	DE	MJ	5.80E-02	1	1.57	(4,3,5,3,1,BU:1.05); natural gas input
Natural gas, high pressure, at consumer {FR} U	FR	MJ	8.74E-01	1	1.57	(4,3,5,3,1,BU:1.05); natural gas input
Natural gas, high pressure, at consumer {IT} U	IT	MJ	6.57E-02	1	1.57	(4,3,5,3,1,BU:1.05); natural gas input
Natural gas, high pressure, at consumer {NL} U	NL	MJ	1.99E-03	1	1.57	(4,3,5,3,1,BU:1.05); natural gas input
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
NM VOC, non-methane volatile organic compounds, unspecified orig	-	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	Uncertainty Type	Standard Deviation 95%	General Comment
	Location InfrastructureProcess Unit				CH 1 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
Outputs	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
	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 2018.¹⁴ 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 Nm³ natural gas (see Tab. 3.1) and divided by the net calorific value.

Tab. 6.3 Emission rates of the low-pressure network¹⁵

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

¹⁴ Data provided by Carbotech

¹⁵ 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

Name	Location	Unit	<i>Natural gas, low pressure, at consumer {CH} U</i> Uncertainty Type Standard-Deviation 95%			GeneralComment
Location Unit			CH MJ			
Natural gas, low pressure, at consumer {CH} U	CH	MJ	1.00E+0			
Natural gas, high pressure, at consumer {CH} U	CH	MJ	1.00E+00	1	1.57	(4,3,5,3,1,BU:1.05); natural gas input
Natural gas, burned in gas turbine {CH} U	CH	MJ	1.23E-03	1	1.3	(4,2,2,3,3,BU:1.05); Qualified estimates from different gas companies
Pipeline, natural gas, low pressure distribution network {CH} U	CH	km	3.97E-09	1	3.32	(4,3,5,3,3,BU:3); calculation based on network length and capacity utilization
Methane, fossil	-	kg	4.67E-05	1	1.57	(2,3,4,1,1,BU:1.5); Calculated based on leakage and average gas composition
Ethane	-	kg	3.87E-06	1	1.57	(2,3,4,1,1,BU:1.5); Calculated based on leakage and average gas composition
Propane	-	kg	8.70E-07	1	1.57	(2,3,4,1,1,BU:1.5); Calculated based on leakage and average gas composition
Butane	-	kg	4.47E-07	1	1.57	(2,3,4,1,1,BU:1.5); Calculated based on leakage and average gas composition
NM VOC, non-methane volatile organic compounds, unspecified orig	-	kg	3.22E-08	1	1.57	(2,3,4,1,1,BU:1.5); Calculated based on leakage and average gas composition
Carbon dioxide, fossil	-	kg	1.62E-06	1	1.22	(2,3,4,1,1,BU:1.05); Calculated based on leakage and average gas composition

7 Outlook

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

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/ m³ 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.

8 References

- Agarwal et al. 2017 Agarwal R., Rainey T., Rahman S., Steinberg T., Perrons R. and Brown R. (2017) LNG Regasification Terminals: The Role of Geography and Meteorology on Technology Choices. In: *Energies*, **10**(12), pp., 10.3390/en10122152.
- Asprofos Engineering 2014 Asprofos Engineering (2014) Cumulative Impacts Assessment for the 2nd Upgrade of the LNG Terminal in Revithoussa Island, Greece.
- BDEW 2024 BDEW (2024) Die Energieversorgung 2023 – Jahresbericht – Aktualisierte Fassung. BDEW Bundesverband der Energie- und Wasserwirtschaft e.V., Berlin, retrieved from: https://www.bdew.de/media/documents/Jahresbericht_2023_UPDATE_Mai_2024_final_V2.pdf.
- Bussa et al. 2021 Bussa M., Jungbluth N. and Meili C. (2021) Life cycle inventories of long-distance transport and distribution of natural gas. ESU-services Ltd. commissioned by FOEN and VSG, Schaffhausen, CH, retrieved from: <https://esu-services.ch/data/public-lci-reports/>.
- Cerbe et al. 1999 Cerbe G., Carlowitz O., Kätelhön J. E., Köhler H., Lehmann J., Lendt B., Lethen H., Mauruschat H. and Pietsch H. (1999) Grundlagen der Gastechnik: Gasbeschaffung, Gasverteilung, Gasverwendung. 5., vollständig neubearbeitete Auflage Edition. Carl Hanser Verlag, ISBN 3-446-21109-8, München Wien.
- Department for Energy Security and Net Zero 2024 Department for Energy Security and Net Zero (2024) Digest of UK Energy Statistics (DUKES): natural gas, retrieved from: <https://www.gov.uk/government/statistics/natural-gas-chapter-4-digest-of-united-kingdom-energy-statistics-dukes>.
- EI 2024 EI (2024) Energy Institute Statistical Review of World Energy. Energy Institute, London, retrieved from: <https://www.energyinst.org/statistical-review/home>.
- European Commission 2015 European Commission (2015) The role of gas storage in internal market and in ensuring security of supply.
- EUROSTAT 2024a EUROSTAT (2024a) Supply and transformation of oil and petroleum products - monthly data, retrieved from: https://ec.europa.eu/eurostat/databrowser/view/nrg_cb_oilm/default/table?lang=en&category=nrg.nrg_quant.nrg_quantm.nrg_cb_m.
- EUROSTAT 2024b EUROSTAT (2024b) Imports of natural gas by partner country - monthly data, retrieved from: https://ec.europa.eu/eurostat/databrowser/view/nrg_ti_gasm/default/table?lang=en.
- EUROSTAT 2024c EUROSTAT (2024c) Exports of natural gas by partner country - monthly data, retrieved from: https://ec.europa.eu/eurostat/databrowser/view/nrg_te_gasm/default/table?lang=en.
- EUROSTAT 2025a EUROSTAT (2025a) Imports of natural gas by partner country, retrieved from: https://ec.europa.eu/eurostat/databrowser/view/nrg_ti_gas/default/table?lang=en.
- EUROSTAT 2025b EUROSTAT (2025b) Supply, transformation and consumption of gas, retrieved from: https://ec.europa.eu/eurostat/databrowser/view/nrg_cb_gas/default/table?lang=en.
- Faist-Emmenegger et al. 2015 Faist-Emmenegger M., Del Duce A. and Zah R. (2015) Update and extension of the inventory data for energy gases. Quantis, Zürich, Switzerland.
- Faist Emmenegger et al. 2007 Faist Emmenegger M., Heck T., Jungbluth N. and Tuchschnid M. (2007) Erdgas. In: *Sachbilanzen von Energiesystemen: Grundlagen für*

- den ökologischen Vergleich von Energiesystemen und den Einbezug von Energiesystemen in Ökobilanzen für die Schweiz*, Vol. ecoinvent report No. 6-V, v2.0 (Ed. Dones R.). Paul Scherrer Institut Villigen, Swiss Centre for Life Cycle Inventories, Dübendorf, CH retrieved from: <https://ecoinvent.org>.
- Gasunie 1998 Gasunie (1998) Environmental annual report 1997. N.V. Nederlandse Gasunie, Groningen, retrieved from: https://www.gasunie.nl/eng/f_gml.htm.
- Gasunie 2001 Gasunie (2001) Safety, Health & Environment - annual report 2000. N.V. Nederlandse Gasunie, Groningen, retrieved from: <https://www.gasunie.nl>.
- IEA 2020 IEA (2020) Methane Tracker 2020. IEA, Paris, retrieved from: <https://www.iea.org/reports/methane-tracker-2020>.
- IMO 2015 IMO (2015) Third IMO GHG Study 2014.
- IMO 2016 IMO (2016) Studies on the feasibility and use of LNG as a fuel for shipping.
- Meili & Jungbluth 2019a Meili C. and Jungbluth N. (2019a) Life cycle inventories of long-distance transport of crude oil. ESU-services Ltd. commissioned by Plastics Europe, Schaffhausen, Switzerland, retrieved from: confidential.
- Meili & Jungbluth 2019b Meili C. and Jungbluth N. (2019b) Life cycle inventories of crude oil and natural gas extraction. ESU-services Ltd. commissioned by Plastics Europe, Schaffhausen, Switzerland, retrieved from: confidential.
- Meili et al. 2025a Meili C., Jungbluth N., Bussa M., Stefanel A. and Rajabihamedani S. (2025a) Life cycle inventories of crude oil and natural gas extraction. ESU-services Ltd. commissioned by FOEN, Schaffhausen, Switzerland, retrieved from: <https://esu-services.ch/data/public-lci-reports/>.
- Meili et al. 2025b Meili C., Jungbluth N., Bussa M. and Stefanel A. (2025b) Life cycle inventories of long-distance transport of crude oil. ESU-services Ltd. commissioned by FOEN, Schaffhausen, Switzerland, retrieved from: <https://esu-services.ch/data/public-lci-reports/>.
- Müller-Syring et al. 2016 Müller-Syring G., Große C., Glandien J. and Eyßer M. (2016) Critical Evaluation of Default Values for the GHG Emissions of the Natural Gas Supply Chain.
- Pospíšil et al. 2019 Pospíšil J., Charvát P., Arsenyeva O., Klimeš L., Špiláček M. and Klemeš J. J. (2019) Energy demand of liquefaction and regasification of natural gas and the potential of LNG for operative thermal energy storage. In: *Renewable and Sustainable Energy Reviews*, **99**, pp. 1-15, 10.1016/j.rser.2018.09.027.
- Schori et al. 2012 Schori S., Bauer C. and Frischknecht R. (2012) Life Cycle Inventory of Natural Gas Supply. Paul Scherrer Institut Villigen, Swiss Centre for Life Cycle Inventories, Dübendorf, CH.
- Schuller et al. 2017 Schuller O., Reuter B., Hengstler J., Whitehouse S. and Zeitzén L. (2017) Greenhousegas Intensity of Natural Gas Transport.
- SWISSGAS 2019 SWISSGAS (2019) Erdgas - Zusammensetzung der Swissgas - Importe im Jahre 2019. Schweizerische Aktiengesellschaft für Erdgas.
- UNEP 2018 UNEP (2018) Montreal Protocol Substances that Deplete the Ozone Layer - Report of the Halons Technical Options Committee - Assessment Report. United Nations Environment Programme, retrieved from: https://ozone.unep.org/sites/default/files/2019-04/HTOC_assessment_2018.pdf.
- Ushakov et al. 2019 Ushakov S., Stenersen D. and Einang P. M. (2019) Methane slip from gas fuelled ships: a comprehensive summary based on measurement data. In: *Journal of Marine Science and Technology*, pp., <https://doi.org/10.1007/s00773-018-00622-z>.