Life Cycle Inventory of Natural Gas Supply

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Carried out by

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On behalf of the
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Preface for the 2012 update

This report is a follow-up of the ecoinvent reports on natural gas (Faist Emmenegger et al. 2003;Faist Emmenegger et al. 2007).

In the revision of the natural gas inventory data in 2012 the supply mixes were updated and new datasets representing the production and the transport of liquefied natural gas from Nigeria and the Region Middle East were generated. The production and supply chain of natural gas from Russia was inventoried with specific data for the first time. The production in Norway was updated with recent data. Other production datasets were only slightly adjusted. In the datasets representing the regional distribution in the high pressure and low pressure gas network data about energy consumption and leakage rates were updated.

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Summary

The natural gas energy system is described from the perspective of the European consumer. The natural gas process chains of the most important countries of origin are considered. These are: Norway, Russia, the Netherlands, North African Countries, the Region Middle East, the United Kingdom, Nigeria and Germany. Liquefied natural gas imports from Nigeria, the Region Middle East and partially from North African Countries are considered in this report in a simplified form. Natural gas produced in North America and supplied to Japan are also considered in this report.

A share of the natural gas is produced in combination with crude oil. Combined production is modelled as multi-functional processes and production efforts and emissions are shared between oil and natural gas produced. Further destinctions are made for onshore and offshore production as well as for "sweet" and sulphurous natural gas, for which a more extensive processing is necessary. Compressor stations with gas turbines of a 10 MW performance class are used for the long-distance transport of natural gas. These turbines are operated with the natural gas from the pipeline.

Abbreviations

µg	Microgram: 10-9 kg
C/H	Hydrocarbons
CFC	Chlorofluorocarbon
CH	Switzerland
DE	Germany
DIN	Deutsches Institut für Normung e.V.
DVGW	Deutsche Vereinigung des Gas- und Wasserfaches
DZ	Algeria
GCV	Gross calorific value
HDPE	High density polyethylene
H-gas	High calorific natural gas
HP	High pressure
K	Degree Kelvin
kBq	Kilobecquerel
LCA	Life Cycle Assessment
LCI	Life Cycle Inventory Analysis
LCIA	Life Cycle Impact Assessment
LDPE	Low density polyethylene
L-gas	Low-calorific natural gas
LNG	Liquid Natural Gas
m3	Cubic metre
MWI	Municipal Waste Incinerator
NAC	North African Countries
NCS	Norwegian Continental Shelf
NCV	Net calorific value
NG	Nigeria
NGL	Natural gas liquids: mixture of ethane, propane, butane and pentane
NL	Netherlands
Nm3	Normal cubic meter
NMVOC	Non-methane volatile organic compounds
NO	Norway
o.e.	Oil equivalent: 1 Nm3 oil = 1 Nm3 o.e., 1'000 Nm3 mnatural gas = 1 Nm3 o.e. resp. 0.84 kg o.e., 1 kg o.e. = 42.3 MJ (NCV).
PAHs	Polycyclic aromatic hydrocarbons
PE	Polyethylene
PJ	Petajoule: 1015 Joule
RER	Europe
RME	Region Middle East
RU	Russian Federation
SDg2	Square of the geometric standard deviation
SVGW	Swiss Association of gas and water (Schweizerischer Verein des Gas- und Wasserfaches)
TJ	Terajoule: 1012 Joule
UCTE	Union for the Co-ordination of Transmission of Electricity
VOC	Volatile organic compound

Indices

e	Index: electric
in	Index: input
out	Index: output
th	Thermic

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1 Introduction

Natural gas is created alongside with crude oil and coal. In the first case the base material was plankton, which sank to the bottom of the sea where it fermented to sludge. With the deposition of debris from the main land the plankton was transformed to bitumen in catalytic processes. Under high pressure and temperatures liquid and gaseous hydrocarbons were formed. The natural gas created in this process stems from basins rich in hydrocarbons such as the North Sea or the Persian Gulf.

In the co-creation of natural gas with charcoal the base material was mainly higher plants that were deposited in quickly descending troughs from various time periods but mostly from the Carboniferous period. Through coalification the organic material was transformed first to peat, later to lignite, hard coal and anthracite. Gaseous reaction products of this process (especially methane) were split off. Natural gas from coalification can be found in vast amounts e.g. in the Netherlands and the southern North Sea.

More recent theories assume that a part of the natural gas is of non-biological origin. It is assumed that natural gas from biological origin is enriched with non-fossil natural gas from the earth’s interior. These theories further lead to the assumption that below the known reservoirs of fossil fuels even greater natural gas reservoirs could be found in greater depths.

2 Reserves and resources

The natural gas reserves which are recoverable with existing technology (proved reserves) are distinguished from the undiscovered gas and the resource growth. These estimations are subject to considerable uncertainties. They are updated on an annual basis. Table 2.1 gives an overview of the proved reserves, the annual production and the reserves-to-production ratio.

Tab. 2.1 Proved resources, annual production rates and reserves-to-production ratios from (BP 2011)

	Proved reserves 2010	**Production 2010**	**R/P ratio 2010**
	10^9 Nm^3	10^9 Nm^3	years
North America	9‘900	826	12.0
C. & South America	7‘400	161	45.9
Europe & Eurasia	63‘100	1043	60.5
Of which: Russian Federation	44‘800	589	76.0
Middle East	75‘800	461	>100.0
Africa	14‘700	209	70.5
Asia Pacific	16‘200	493	32.8
World	187‘100	3193	58.6

The largest natural gas reserves are located in Russia and the Middle East (see Tab. 2.1). With the current depletion rate the reserves-to-production ratio (R/P ratio) amounts to roughly 60 years. In the last twenty years the proved reserves have increased by 50 percent (BP 2011). This increase is due to the discovery of new and the revaluation of known reserves. At the same time consumption has increased by 62 %. The increased production has resulted in lower R/P ratios.

3 Properties of Natural Gas

3.1 Classification of fuel gases

Various fuel gases are available on the market, some of which are natural gas, coke-oven gas and blast furnace gas. The following chapters describe the natural gas system. The production of coke-oven gas is described in Röder et al. (2007). Blast furnace gas is recovered as a by-product of blast furnaces and is described in in Classen et al. (Classen et al. 2007).

In the first half of the 20th century gas won through gasification of hard coal was commonly used. After the introduction of natural gas, coal gas - also known as city gas or illumination gas - lost its importance. The exploration of the Dutch natural gas field in the vicinity of Groningen led to a boom in the demand of natural gas in Europe from 1965 onwards. Today natural gas makes up 25 percent of the primary energy consumption in Europe (BP 2011).

The relevance of coke oven gas and blast furnace gas is decreasing. In Germany for example the share of coke oven gas of the total gas supply has dropped below 3 percent (Cerbe et al. 1999). Blast furnace gas provides about 4.6 percent of the fuel gases used in Germany.

Biogas is a fuel gas gaining importance. Processed biogas with sufficiently high methane content can be fed into the natural gas distribution network.

Natural gas, coke oven gas, furnace gas and biogas differ substantially with regard to their chemical composition. Tab. 3.1 shows typical values of the composition of the five fuel gases.

Tab. 3.1 Composition of fuel gases (reference values) (**Cerbe et al. 1999**; Bruijstens et al. 2008)

	H_2	CO	CH_4	C_2H_6	C_3H_8	C_4H_{10}	Other C_XH_Y	CO_2	N_2	O_2
	vol. %	vol. %	vol. %	vol. %	vol. %	vol. %	vol. %	vol. %	vol. %	vol. %
Blast furnace gas	4.1	21.4						22.0	52.5	
Coke oven gas	54.5	5.5	25.3				2.3	2.3	9.6	0.5
Natural gas L			81.8	2.8	0.4	0.2		0.8	14.0	
Natural gas H			93.0	3.0	1.3	0.6		1.0	1.1	
Biomethane [1)]			>97					< 2	< 0.8	0.2

1) The composition of biogas can vary depending on the feedstock. The data shown here is for upgraded biogas (biomethane) from a plant in Stockholm, Sweden.

Natural gas is rich in methane. The high content of nitrogen and carbon monoxide is typical for blast furnace gas. Coke-oven gas on the other hand shows high levels of hydrogen. Natural gas is classified as high-calorific (H-gas or High-gas) and low-calorific gas (L-gas or Low gas) based on the methane content. H-gas contains between 87 and 99 vol. % and L-gas between 80 and 87 vol. % methane.

In Germany the properties and composition of commercial fuel gases are regulated according to the DIN and DVGW directives, in Switzerland according to the SVGW directives. A number of secondary gas substances are limited by threshold values. “Common business practices” for non-odorized high-calorific gas in transboundary traffic in Europe are stated as follows: the total sulfur content must not exceed 30 mg/Nm^3, hydrogen sulfide content needs to be below 5 mg/Nm^3. Further threshold values exist for different hydrocarbons, water, dust, liquids, mercaptans, nitrogen oxides, ammoniac and hydrogen cyanide.

3.2 Fuel data of raw natural gas

This section shows the composition of natural gas after the extraction and before processing, the so-called raw gases. These compositions are used to calculate emissions at the extraction and processing of natural gas. The resource use is quantified as “Gas, natural, in ground”. This covers both natural gas from carbonification and natural gas formed in association with crude oil (also known as associated petrol gas, APG). The natural gas is processed to ensure the purity and quality needed for end-use. During the transport and distribution the composition of the natural gas changes only slightly.

The composition of raw gases from different origins varies considerably. The main component is methane; other important components are ethane, propane, nitrogen, carbon dioxide, helium, sulfurous substances and higher hydrocarbons (higher C/H). The sulphurous compounds are mainly hydrogen sulphide, as well as carbonyl sulphide (COS), carbon disulphide (CS_2) other organic sulphites, disulphides, mercaptaines and thiopenes. Among the higher hydrocarbons benzene, toluene and xylene are of importance because of their toxicity <Nerger et al. 1987>.

Tab. 3.2 shows the chemical composition of various rawgases prior to processing. A differentiation is made between so-called "sour" gases (with high sulphur content) and "sweet" gases.

Tab. 3.2 Chemical composition of raw gases prior to processing

Substances	Range of fluctuation	Raw gas from Groningen (NL)	Raw gas from Südoldenburg (DE), "sour"	Raw gas from Bentheim (DE)	Mean raw gas (NO)	Raw gas from Urengoy „C", West-Sibiria
	vol. %	vol. %	vol. %	vol. %	vol. %	vol. %
Methane	>80	81.5	79.1	93.2	88.8	99.0
Ethane C_2H_6	up to 8	2.8	0.3	0.6	4.8	0.1
Propane C_3H_8	up to 3	0.4			1.7	0.01
Butane C_4H_{10}		0.14	<0.01		0.7	0.015
Higher C/H	up to 4	0.14			0.7	0
H_2S	0-24		6.9			8.5 E-06
CO_2	up to 18	0.92	9.1		1.6	0.085
N_2	up to 15	14.1	4.6	6.2	1.4	0.79
	<Infras 1981>	<Infras 1981>	<Infras 1981>	<Landolt Börnstein 1972>	(Statoil 2001b)*	(Müller et al. 1997)

*) Weighted mean value for natural gases processed in the plants Kollsnes and Kårsto.

In addition to the substances mentioned above natural gas may contain further substances that are of importance from an environmental point of view. Raw gas can be enriched with other substances in trace concentrations up to 10^{-3} bis 10^{-6} g/Nm^3 <Nerger et al. 1987>. In the United States and Europe, natural gas is tested for mercury since the 1930'ies. Steinfatt & Hoffmann (1996) report mercury concentrations of natural gas from Algeria, the Netherlands and Germany. The mercury contents are shown in Tab. 3.3.

Tab. 3.3 Mercury contents of natural gas from Algeria, the Netherlands and Germany (Steinfatt & Hoffmann 1996)

Region	**Elemental mercury (µg/Nm^3)**
Algeria	58-193
The Netherlands (North Sea)	180
Germany	Up to 11'000*)
Russia (Dnjepr-Donetzk)	53

*) The mercury content of german deposits is in the range of the Dutch ones, however in rare cases it can reach up to 11'000 µg/Nm^3.

The investigation of pipeline gases revealed a rapid decrease in the Hg-content in pipelines <Tunn 1973>. The study examined gas transported from the Netherlands to Germany. A large share of the mercury contained in the Groningen-gas was removed on the way to the Dutch-German border due to processing and condensate separation. From an initial concentration of 180 µg/Nm^3, the mercury concentration dropped down to 20 µg/Nm^3. In the german pipeline system the concentration is further reduced to 2 to 3 µg/Nm^3. Only when natural gas from german production is fed into the pipeline the concentration remains as high as 19 µg/Nm^3. However by the time the natural gas reaches the end consumer, the mercury concentration is reduced to very low levels, often below the detection limit (1 to 2 µg/Nm^3).

The raw gas of certain deposits shows traces of Radon-222, a radioactive gaseous decomposition product of uranium. <Gray 1990> summarised the results of various studies. Radon concentrations in natural gases at the production site range from 1 to 10 pCi/l[1] in Germany, from 1 to 45 pCi/l in the Netherlands and from 1 to 3 pCi/l in offshore-production in the North Sea. In this study the radon emissions are reported in kilobecquerel (kBq) units.

A more precise declaration of the various natural gases is not possible due to local and temporal variations, as well as a lack of data. For this study plausible standard gas compositions are defined, based on the data in Tab. 3.2 and the information mentioned above. The composition is given for important countries of origin for the Swiss and European natural gas supply: The standard composition is applied e.g. for the leakages in the exploration and processing of the natural gas. For the raw gas prior to processing plausible mean values from Tab. 3.2 are used: a mercury concentration of 200 µg/Nm^3 and a radon-222 concentration of 10 pCi/l or roughly 0.4 kBq/Nm^3. The calorific values and CO_2 emission factors were calculated assuming complete combustion.

Tab. 3.4 shows the chemical composition and the fuel data of the auxiliary modules “leakage raw gas sweet” and “leakage rawgas sour” which are used to calculate the composition of raw natural gases from different countries and regions (see Tab. 3.5). The latter composition data are used to model the leakage emissions of produced natural gas.

[1] 1 Ci = $3.7*10^{-7}$ KBq

Tab. 3.4 Fuel data for raw gases prior to processing. Sources: Tab. 3.2 and and notes in the text.

Gas type		Raw gas "sour" prior to processing	Raw gas "sweet" prior to processing	Raw gas "sour" prior to processing	Raw gas "sweet" prior to processing
Country of origin		Germany, Russian Federation	Norway, Netherlands, Germany, Russian Federation, Algeria	Germany, Russian Federation	Norway, Netherlands, Germany, Russian Federation, Algeria
Unit		vol. %	vol. %	*kg/Nm³*	*kg/Nm³*
Methane		70	85	0.50	0.61
Ethane		8	3	0.11	0.04
Propane		5		0.10	
Butane			1		
C5+		1	1	0.04	0.04
Carbon dioxide		5	10	0.10	0.02
Nitrogen		5		0.06	0.13
H_2S		6		0.09	
Mercury	µg/Nm³			*200*	*200*
Radon-222	kBq/Nm³			*0.4*	*0.4*
Gross calorific value GCV	MJ/Nm³			41	38
Net calorific value NCV	MJ/Nm³			37	34
Density	kg/Nm³			1.00	0.84
EF-CO_2 Hu *)	kg/GJ			89.2	88.7

*) Assumption: complete combustion

Tab. 3.5 Average composition of raw natural gas from DE, NAC, NL, NO and RU prior to processing based on their share of sour gas. Source: Tab. 3.4.

		Raw gas DE	Raw gas RU	Raw gas NO	Raw gas NL	Raw gas NAC	Raw gas NG
	Unit	Nm³	Nm³	Nm³	Nm³	Nm³	Nm³
Sour gas	%	50	20	5	0	0	0
CH_4 Methane	kg	0.555	0.588	0.6045	0.61	0.61	0.61
CO_2 Carbon dioxide	kg	0.06	0.036	0.024	0.02	0.02	0.02
Ethane	kg	0.075	0.054	0.0435	0.04	0.04	0.04
H_2S Hydrogen sulfide	kg	0.045	0.018	0.0045	0	0	0
Hg Mercury	kg	2.00E-07	2.00E-07	2.00E-07	2.00E-07	2.00E-07	2.00E-07
N_2 Nitrogen	kg	0.0365	0.0224	0.01535	0.013	0.013	0.013
NMVOC	kg	0.04	0.04	0.04	0.04	0.04	0.04
Propane	kg	0.05	0.02	0.005	0	0	0
Radioactive Rn 222	kBq	0.4	0.4	0.4	0.4	0.4	0.4

3.3 Fuel data – Natural Gas for final consumption

This Subchapter presents fuel data of natural gas at the point of final consumption in Europe and Switzerland. As has been noted earlier, the composition of natural gas fed into the European pipeline network already corresponds to the final consumption quality. Small amounts of condensates of higher hydrocarbonsand trace elements are formed during the transport. These are collected in separators at regular intervals. For safety reasons sulphur odorants are added before the natural gas is fed into the regional distribution system.

The standard composition after processing of natural gases from different countries of origin is listed in Tab. 3.6 , based on <DGMK 1992>. This composition is valid for natural gas used in compressor stations in the long-distance pipeline system as well as the final consumption in power plants and heating units.

For the sulphur and mercury content different values are used for long-distance transport and final consumption. For natural gas in pipelines a mercury concentration of 10 μg/Nm^3 is assumed, which is reduced to 1 μg/Nm^3 during transport (concentration in natural gas used for final consumption according to IGU (2000a)).

In Germany the threshold value for mercury in natural gas for final consumption is 28 μg Hg/m^3 (Vn). Measurements by Ruhrgas (IGU 2000a) have shown that the median mercury concentration in the German supply network is 1.0 μg Hg/Nm^3. In IGU (2000a) it is further statet that the heavy metal concentration of natural gas imported to Germany from different origins barely differs.

Mercury is deposited in the gas drying plant. About 98 % of the produced mercury is removed as pasty mussy deposition at the cleaning of tanks and containers. Only about 2 % of the mercury is emitted via clean gas, produced water, condensate, as exhaust gas after combustion or in activated carbon (Hammerschmid 1996).

According to analytical parameters published in <Landolt Börnstein 1972> the natural gas produced in Northern Africa (NAC) can be classifies as "sweet gas".

The average composition of natural gas at final consumption in Switzerland is also shown in Tab. 3.6. The composition is evaluated at regular intervals by the Gasverbund Ostschweiz (SWISSGAS 1999). No data is available about specific concentrations of neither mercury nor radon-222 in the Swiss natural gas mix.

Tab. 3.6 Fuel data of natural gases after processing (CV: calorific value)

		Prod. NAC	**Prod. GB**	**Prod. NO**	**Prod. NL**	**Prod. DE**	**Prod. RU**	**Prod. RME**	**Prod. NG**	**Prod. RER**	**High pressure CH**
Source		SEDIGAS 1991 <Aróstegui 1997>	<ExternE 1999>	<DGMK 1992>	<DGMK 1992>	<DGMK 1992>	<DGMK 1992>	(DOE 2005)	(DOE 2005)		<Swissgas 1999>
		Nm^3	Nm^3	Nm^3	Nm^3	Nm^3	Nm^3	Nm^3	Nm^3	Nm^3	Nm^3
Methane	kg	0.65	0.667	0.719	0.671	0.69	0.716	0.67	0.69	0.7	0.68
Ethane	kg	0.10	0.041	0.074	0.023	0.008	0.006	0.05	0.04	0.026	0.03
Propane	kg	0.02		0.019	0.003	0.001	0.002	0.02	0.02	0.006	0.013
Butane	kg	0.00		0.006	0.001		0.001	0.01	0.01	0.002	0.006
C5+	kg		0.035	0.002			0.001			0.001	0.003
Carbondioxide	kg		0.006	0.013	0.008	0.002	0.001			0.006	0.011
Nitrogen	kg	0.01	0.036	0.007	0.118	0.062	0.007	0.003	0.001	0.061	0.020
Sulphur											
- non-odor. [1]	kg	2E-6	2E-6	2E-6	2E-6	2E-6	2E-6	2E-6	2E-6	2E-6	1.63E-6
- odorised [1]	kg										8.40E-6
Mercury [2]	kg	1E-08	2E-09	1E-08	1E-08	1E-08	1E-08			1E-09	0E+00
Gross CV	MJ	42.3	40.7	44.9	38.4	38.5	40.0	41.3	41.4	40.4	40.2
Net CV	MJ	38.5	37.0	40.8	34.9	35.0	36.4	37.5	37.6	36.8	36.5
Density	kg	0.78	0.78	0.84	0.82	0.76	0.73	0.76	0.76	0.80	0.76
EF-CO_2 [3]	kg/TJ	56000	56000	57400	56000	55200	55200	55600	55500	56000	56000
EF-SO_2 [4]											0.55

[1] Own estimation

[2] Reduced to 1 μg/Nm3 during the transport

[3] Rounded values. Calculation based on the C-content of the gas and the net calorific value

[4] Odorised. Calculation based on the net calorific value

4 Natural gas use

In this study both the average Swiss and the average European consumption mix are of interest[2]. In the framework of the LCA methodology the original source of the natural gas is of interest. Other than e.g. for electricity the physical natural gas flows correspond well to the contractual relations. Therefore the activities of trading countries are traced back to the original production origins by trade statistics.

The origin of natural gas consumed in Switzerland and Europe is deduced from data on trade movements provided in the BP Statistical Review of World Energy (2011, see Tab. 4.1 and Tab. 4.3).

The most important production countries for Europe are (in the order of their importance): Norway (25 %), the Russian Federation (24 %), the Netherlands (15 %), Nothern African Countries (mostly Algeria, 12 %), the Middle East (mostly Qatar, 8 %) and the United Kingdom (8 %). The remaining natural gas is supplied by Nigeria (4 %), Denmark (2 %) and Germany (1 %) and some small shares from Romania, Poland and Italy.

One third (31 %) of the natural gas supplied to Swiss consumers is produced in the Russian Federation. The Netherlands and Norway supply both about a quarter (27 % resp. 25 %) and Germany 8 % of the natural gas. The remaining shares of natural gas are produced in Northern Africa and the United Kingdom (2 % each) with some minor contributions from Nigeria, the Middle East and other countries.

To estimate the expenditures of natural gas supply (prior to its delivery within Europe and Switzerland), the share of liquefied natural gas (LNG) in the supply mixes was assessed based on the BP statistics (2011). The share of LNG of the gas supplied to Europe was 16 % in 2010. While a few years ago Algeria used to be the main supplier of LNG, the Middle East (especially Qatar) and Nigeria are now leading with respect to volumes of LNG exported to Europe. The Swiss supply mix contains only a share of 3 % of LNG, imported from Nigeria, the Middle East and Northern Africa.

[2] Countries considered for the European mix are: all EU members (state of 2011), Norway, Switzerland and the Baltic states.

Tab. 4.1 Direct natural gas imports for selected European countries in 2010. Numbers for production are written in italic. The amounts of imported gas (countries of origin) are specified in the columns, export in the rows (BP 2011).

Production and import/export 2010	**Imports Switzerland**	**Imports Netherlands**	**Imports Germany**	**Imports ports-France**	**Imports other Europe**	**Total imports Europe**	
	10^9 Nm^3	10^9 Nm^3	10^9 Nm^3	10^9 Nm^3	10^9 Nm^3	10^9 Nm^3	%
Denmark (DK)	-	0.8	1.1		6.6	8.5	2
Germany (DE)	2.2	2.6	***10.6***	4.0	4.2	25.4	5
Netherlands (NL)	0.6	***43.6***	24.2	6.9	21.7	96.9	18
Norway (NO)	0.1	8.1	30.2	14.2	46.7	99.3	18
United Kingdom (GB)	-	1.5	2.9	0.6	67.8	72.8	13
Other Europe [1)]	0.6	-	-	1.8	7.6	1.3	0
Russian Federation (RUS)	0.3	4.0	34.4	8.1	46.4	114.4	21
Northern Africa (NAC) [2)]	-	-	-	7.0	55.3	64.1	12
Middle East (RME) [3)]	-	-	-	2.5	32.0	34.6	6
Nigeria [4)]	-	-	-	3.9	15.7	22.5	4
Total	3.6	60.6	103.4	48.9	306.3	544.3	100

[1)] Including domestic production of Romania, Poland and Italy

[2)] Algeria incl. small share from Lybia

[3)] Qatar incl. small share from Yemen and Oman

[4)] Incl. small shares from Trinidad & Tobago, Peru and USA

The calculation of the supply mixes is based on the statistical imformation provided in BP (BP 2011), taking into account the indirect imports. Tab. 4.1 shows the direct natural gas imports in 2010 with the domestic production (in italic letters). The calculation of the Swiss supply mix is shown in Tab. 4.2 as is the supply mix used in this study. For this study only the most important producing countries were considered. The production from Denmark was attributed to Norway, since the Danish production is important in the Danish and Swedish supply mix (97 % for both) and the production technology is similar to the one used in Norway. Other minor production was not taken into account. This leads to a representativity of 91 % for Italy since the Italian natural gas production is neglected; for all other supply mixes 99 – 100 % of the production is covered. The supply mixes were extrapolated to cover 100 % of the production volume. An overview of all assessed supply mixes is given in Tab. 4.3.

Tab. 4.2 Origin of natural gas supplied in Switzerland (supply mix) (BP 2011; INSEE 2011)

	Germany	France	Nether-lands	Norway	Russian Federation	Supply mix	
						Detailed	This study
	%	%	%	%	%	%	%
Import mix Switzerland	59.2	16.5	15.2	1.4	7.7		
Belgium	0.0	0.4	0.0	0.0	0.0	0.4	**-**
Germany	6.1	1.3	0.7	0.0	0.0	8.1	**8.1**
Denmark	0.7	0.0	0.2	0.0	0.0	0.8	**-**
United Kingdom	1.6	0.2	0.4	0.0	0.0	2.2	**2.2**
Netherlands	13.9	2.3	10.9	0.0	0.0	27.1	**27.3**
Norway	17.3	4.8	2.0	1.4	0.0	25.5	**26.5** [1)]
Europe Rest [2)]	0.0	0.2	0.0	0.0	0.0	0.2	**-**
Russia	19.7	2.7	1.0	0.0	7.7	31.2	**31.4**
Northern Africa [3)]	0.0	2.4	0.0	0.0	0.0	2.4	**2.4**
Middle East [4)]	0.0	0.8	0.0	0.0	0.0	0.8	**0.9**
Nigeria [5)]	0.0	1.3	0.0	0.0	0.0	1.3	**1.3**
Total	59.2	16.5	15.2	1.4	7.7	100	**100**

[1)] Including production from Denmark

[2)] Including domestic production of Rumania, Poland and Italy

[3)] Algeria incl. small share from Lybia

[4)] Qatar incl. small share from Yemen and Oman

[5)] Incl. small shares from Trinidad & Tobago, Peru and USA

Tab. 4.3 European natural gas supply mixes with LNG shares (calculations based on BP 2011). The supply mix for a specific country is displayed in the columns; exporting countries/regions are shown in the rows (calculated based on origin and composition, see Tab. 3.6). (LNG: Liquefied Natural Gas)

Supply mix (part1)	**AT**	**BE**	**CH**	**CZ**	**DE**	**DK**	**ES**	**FI**	**FR**
	%	%	%	%	%	%	%	%	%
Germany	0.7	1.3	8.1	-	11.3	0.3	0.1	-	1.6
United Kingdom	0.2	11.1	2.2	-	2.0	0.1	0.1	-	1.7
Netherlands	1.5	18.5	27.3	-	17.0	0.7	0.1	-	12.7
Norway	17.9	37.4	26.5	26.9	34.4	97.9	9.3	-	34.7
Russia	79.7	2.6	31.4	73.1	34.9	1.0	0.1	100.0	20.8
North Africa	-	0.9	2.4	-	0.0	-	41.3	-	14.5
Middle East	-	26.3	0.9	-	0.4	-	16.3	-	5.9
Nigeria	-	1.9	1.3	-	0.1	-	32.7	-	8.2
LNG share	0.0	28.4	2.9	0.0	0.4	0.0	60.9	-	18.4

Supply mix (part 2)	**GB**	**GR**	**HU**	**IE**	**IT**	**NL**	**SE**	**SK**	**RER**
	%	%	%	%	%	%	%	%	%
Germany	0.4	-	1.2	-	0.8	0.5	2.9	-	1.3
United Kingdom	52.0	-	0.2	52.2	0.7	1.4	-	-	7.6
Netherlands	5.5	-	2.3	7.4	8.6	73.2	-	-	15.1
Norway	25.4	-	3.9	24.3	10.4	16.5	97.1	-	27.3
Russia	0.5	52.8	89.8	-	20.7	8.1	-	100.0	24.0
North Africa	1.2	27.3	1.3	1.3	50.0	0.0	-	-	12.0
Middle East	13.0	-	0.5	12.9	8.3	0.3	-	-	8.2
Nigeria	2.0	19.8	0.8	2.0	0.6	0.0	-	-	4.4
LNG share	15.4	27.8	1.6	15.3	24.4	0.4	0.0	-	16.3

5 System description

5.1 Division into process steps

The natural gas energy system is distinguished into 5 process steps for final energy supply and two final consumption processes (see Fig. 5.1). These seven processes are mostly spatially separated and are therefore treated separately.

Every main process step is treated in a separate chapter in this report. Exploration and production are however dealt with together, since they are not easily separable. For instance a part of the natural gas processing takes place on offshore production platforms.

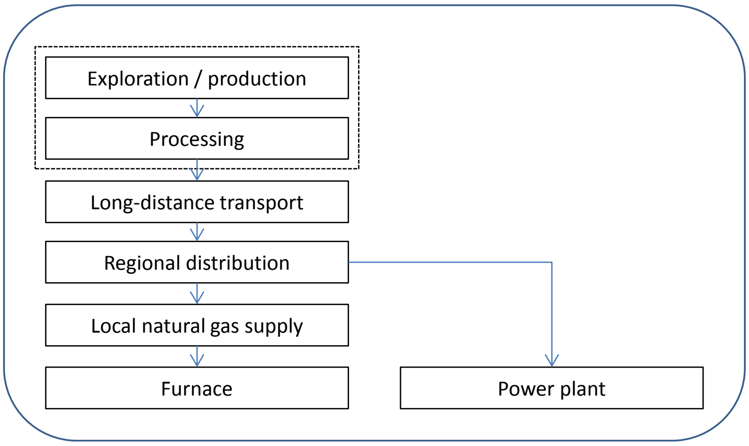

Fig. 5.1 Main process steps in the natural gas supply chain in this report

5.2 Division into modules

5.2.1 Detailed subdivision of the natural gas chain

The modules exploration/production up until the long-distance transport are distinguished for the most important countries of origin (NO, NL, DE, RUS, NAC, RME, NG, GB). The modules regional distribution link to the relevant supply mixes in 2010 (see statistics in Tab. 4.1 and Tab. 4.3). Fig. 5.2 shows the resulting structure of the natural gas chains in this report.

The seasonal storage in cavern or aquifer storage is allocated to the module long-distance transport, short-term storage is however considered in the module local natural gas supply. All inventoried material and energy flows are relating to the gas output of the respective module.

The gas output streams of the modules production, processing and long-distance transport are specified as Nm^3 standard volume (in the following m^3 always stands for Nm^3). The natural gas outputs of regional distribution, of the local supply as well as of the final consumption are given in energetic units (MJ). Energetic specifications in the report refer to the net calorific value (lower heating value) of the respective natural gas. The share biomethane fed into the gas grid is not considered for the process “Natural gas, at consumer”. In Switzerland the share of biogas in the gas grid is well below one per cent[3] (BFE 2010) and additionally there is a marked for biogas credits[4]. They can be purchased in an analogue manner as certified electricity, e.g. for domestic heating or as fuel for natural gas cars, thus further reducing the share of biogas in the grid.

[3] In 2009 40 GWh of biogas were fed into the natural gas network in Switzerland. This corresponds to 0.13 percent of the final consumption.

[4] E.g. naturmade certified biogas, see www.nature-made.ch

Most of the modules shown in Fig. 5.1 are linked to infrastructure modules and further modules containing construction and working materials, transport processes, further energy carriers, other energy systems and disposal processes.

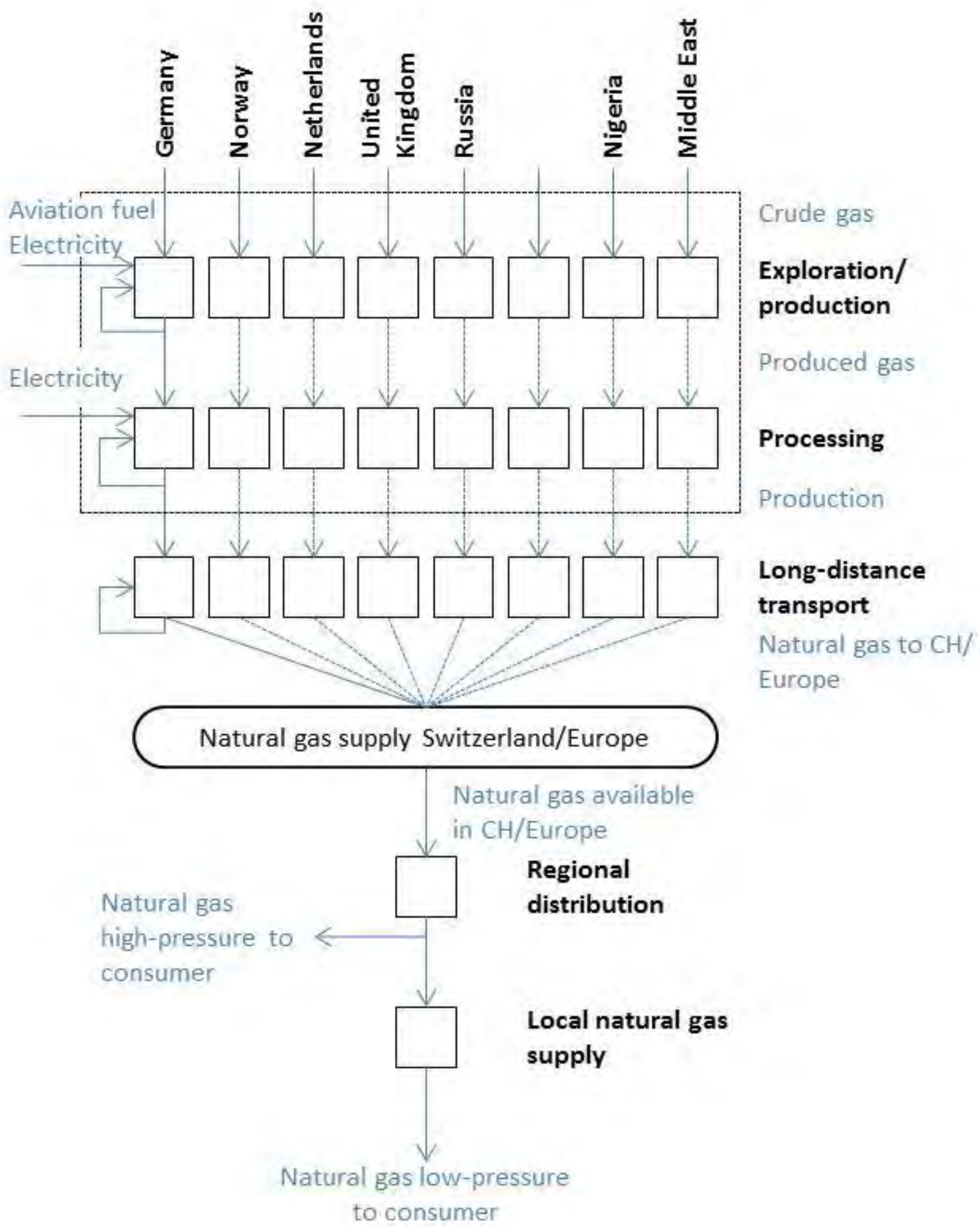

Fig. 5.2 Structure of the process chain for the provision of natural gas from different origins as used in this study

Fig. 5.3 gives a detailed overview of the data structure for the Netherlands. Natural gas from countries with a share of sour gas require sweetening and thus call for the module "Sweetening, natural gas" (Germany, Russia). The module "Drying, natural gas" is used by all countries, unless this process is already included in the production data.

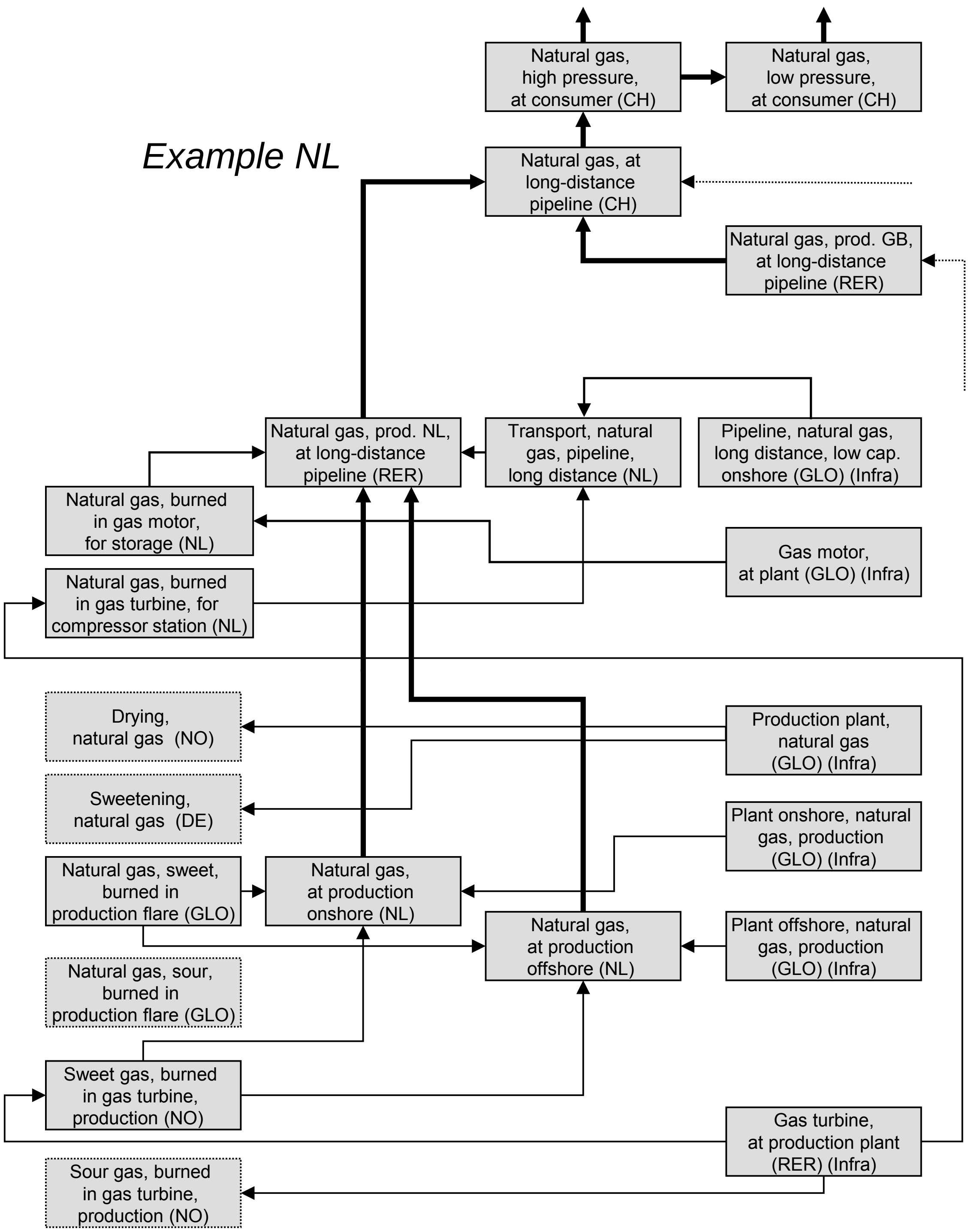

Fig. 5.3: Example for the data structure of natural gas from the Netherlands (NL) supplied to Switzerland (CH). Modules with a dotted border line are only used for the supply chain of selected countries/regions. E.g. the module “Sweetening” is used by the modules “Natural gas, at production” in Russia and Germany. For the production of sour gas the corresponding module representing the gas turbine is used.

From Nigeria, the Middle East and partly from North Africa natural gas is imported in the form of LNG. The structure of this supply chain is shown in Fig. 5.4.

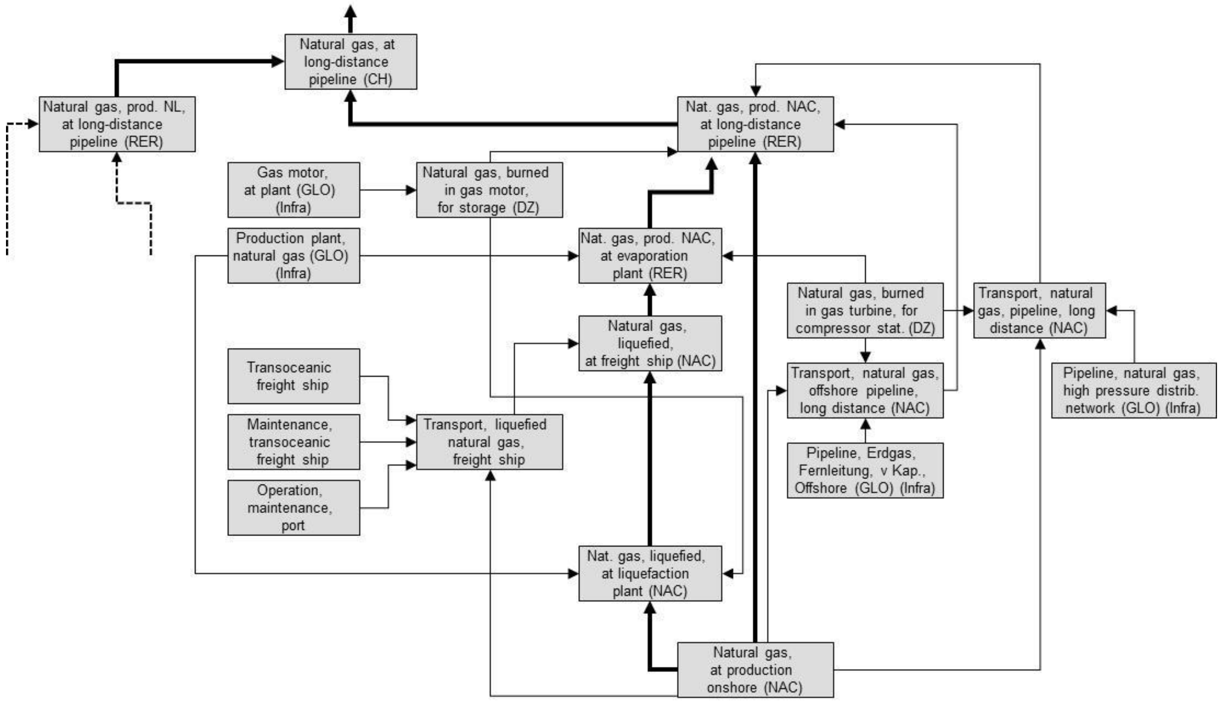

Fig. 5.4 Structure of the natural gas supply from North Africa (pipeline and LNG transport)

5.3 System characteristics

The most important natural gas specific system characteristics are explained in the sections below.

5.3.1 Temporal characteristics

Most of the statistical data describing the natural gas chain refers to 2010. Sources for technological data may date back a few decades.

From a methodical perspective the mixing of newer and older data can be justified if in all areas newer data was considered where considerable changes in technology has taken place. For slowly changing parameters the age of the data is of smaller significance.

An important assumption for all energy systems is, that the material and service inputs from a time far away is modelled with respect to the current technology (2010). This means that steel which was used to manufacture Swiss natural gas pipelines in 1972 is modelled with the current production (or the most recent date for which data is available).

The allocation of materials used over a longer time period per m^3 natural gas is especially difficult for the gas network. In this report a simple statistical allocation is used. The natural gas network existing today is inventoried with respect to its material composition. Further it is assumed that the current capacity utilisation represents a typical average value for past and future operation.

5.3.2 Geographical characteristics

The life cycle inventories of natural gas supply cover European countries including Switzerland, as well as North America and Japan.

In line with other energy systems the electricity needs abroad is inventoried with electricity from the respective electricity grid.

6 Life cycle inventory of exploration, production and processing

6.1 Overview

This chapter describes the exploration and production activities for natural gas from dedicated and combined production. It covers the producing countries Norway (NO), the Netherlands (NL), Germany (DE), the Russian Federation (RU), the United Kingdom (UK), North Africa (NAC), Nigeria (NG) and the Region Middle East (RME). The combined production of crude oil and natural gas in the Netherlands, Nigeria, the United Kingdom and Norway are presented in the section on oil („Erdöl") in the previous edition of the report of Jungbluth (2003).

The production of natural gas is preceded by the exploration of reservoirs. Electromagnetic and seismic studies are followed by exploratory drillings. If the size of the reservoir and the quality of the gas is satisfactory, production drillings are carried out for the extraction of the natural gas. Exploration drillings are included in the production of natural gas (stated as meter drilled per m^3 produced gas, see Subchapter 6.2).

Onshore and offshore drilling takes place in unique drilling environments, which require special techniques and equipment. The most frequently used technology for onshore exploratory and production drillings is rotary drilling with a drilling tower. For offshore production drilling platforms need to be constructed with concrete and steel. According to the statistics (seeTab. 4.2), roughly 54 % of the natural gas consumed in Europe and 50 % of the natural gas consumed in Switzerland originates from offshore production (Tab. 6.1).

Tab. 6.1 Countries of origin of the natural gas for Switzerland and Europe (2010) and shares from offshore production (OED 2011; TNO 2011)

	Origin of natural gas		Share offshore production
	Supply mix Swizerland	Supply mix Europe	
Source →	Tab. 4.2	Tab. 4.2	(dti 2001; OED 2011; TNO 2011)
North Africa [1)]	2 %	12 %	0 %
Germany	8 %	1 %	0%
Russian Federation	31 %	24 %	0%
Norway [2)]	26 %	27 %	100 %
Netherlands	27 %	15 %	74 %
United Kingdom	2 %	8 %	97 %
Nigeria	1 %	4 %	0 % [3)]
Middle East	1 %	8 %	100 %

[1)] Including LNG

[2)] Including natural gas produced in Denmark (1 % of Swiss supply mix, 2 % of European supply mix)

[3)] For simplification 100 % onshore production is assumed (Jungbluth 2003)

A share of the natural gas is produced in combination with crude oil, the so called associated petrol gas (APG). Tab. 6.2 presents the share of combined production of natural gas relative to the total natural gas production for producing countries which are important for Europe.

Tab. 6.2 Share of combined production of total produced natural gas

	Combined production	Source
Northern Africa	4 %	Own estimation, see 6.3.1, p. 47
Germany	<1 %	(WEG 2011)
Russian Federation	4 %	Tab. 6.32, p.41
Norway	60 %-70 %	(OED 2000)
Netherlands	5 %	<MEZ 1992>

The subsystem "exploration, production and processing" is connected to the natural gas chain via the input of *raw gas* (resource, in Nm^3) and the output *produced natural gas* (in Nm^3).

6.2 Exploration

Recent drilling statistics were found for Norway, Russia and Germany. For the Netherlands older but nevertheless precise data are available as well.

On the Norwegian continental shelf 172 wells of a total length of 709'265 m were drilled in 2010[5]. 82 of these drillings were drillings in existing boreholes (about 123'006 m). The new boreholes drilled in 2010 amount to 586'259 m. For this study only the new drilling meters are considered, per Nm3 of natural gas produced this amounted to 5.2E-06 m of well.

For the Russian Federation drilling statistics were available from the main producers (see Section 6.3.8) which cover 92% of the natural gas market and together report 5326 km of boreholes drilled. Extrapolated to 100% of the market this amounts to 5803 km or 1.01E-6 m per Nm3 of natural gas produced.

The Dutch drilling statistic (MEZ 2000) presents specific drilling data covering more than 20 years (exploration and production 1980-1999). It reports 7 mm/Nm^3 o.e. for offshore drillings and 1.2 mm/Nm^3 o.e. for onshore drillings. For the onshore drillings in 1999 40 % of the drilled meters were for the production, 60 % for the exploration. For offshore 33 % of the drilling meters were for production and 67 % for exploration.

In Germany 51'411 meters of wells were drilled in 2010 (WEG 2011). The success rate of the drillings was rather high with 61 %, however only one of six drillings reached a new reservoir (17 %). This reflects that it is difficult to discover new gas fields in Germany.

Tab. 6.3 shows the drilling meters for various countries. No distinction is made between production and exploration drilling. Since there is no specific data available for Northern Africa and the Middle East the value of the Russian Federation is applied for these two regions.

[5] Email by Alf B Stensøy, Norwegian Petroleum Directorate (NPD), 26.Sept. 2011.

Tab. 6.3 Specific drilling data for various countries (Gazprom 2011; Lukoil 2011; MEZ 2000; OLF 2011; Rosneft 2011b; WEG 2011).

	Reference year	Total hydrocarbon production MJ NCV	Borehole meters m/a	Specific demand in borehole meters [1)] m/kg oil	m/Nm^3 Gas
Netherlands	1980 – 1999 [2)]	38 E+08	224 000	83 E-7	25 E-07
Netherlands onshore	1980 – 1999 [2)]	29 E+08	84 000		12 E-07
Netherlands offshore	1980 – 1999 [2)]	9 E+08	140 000		70 E-07
Germany	2010	57 E+10	51 000	39 E-07	33 E-07
Norway	2010	87 E+11	586 000	29 E+07	24 E-07
Russian Federation	2010	43 E+12	281 000	20 E-06 [3)]	32 E-07 [3)]

[1)] Allocated based on energy content (NCV)

[2)] Average values

[3)] Weighted average extrapolated to 100 % (The corporations examined cover 92 % of the natural gas and 47 % of the oil production.)

The energy and material flows for exploration and production drilling are described in Jungbluth (2003, Kap. 6). Since the technologies used are very similar they are also used for natural gas. The linkage of the values of (Jungbluth 2003, Kap. 6) is done via the specific drilling data in Tab. 6.4.

Tab. 6.4 Specific drilling data for exploration and production activities in this study (m/Nm^3 produced natural gas)

	Onshore	Offshore
Germany	33 E-07	-
Middle East	32 E-07	32 E-07
The Netherlands	12 E-07	70 E-07
North Africa	32 E-07	
Norway	-	24 E-07
Russian Federation	32 E-07	-

6.3 Production and processing

6.3.1 Overview

The transition point from the exploration to the actual production phase takes place when the conveying line is installed in the borehole and the wellhead is connected to the Christmas tree (also called production tree, Cerbe et al. 1999, S. 12).

Usually a first cleansing of the natural gas takes place immediately after the production (processing in the field). This is especially necessary for natural gas containing hydrogen sulphides and/or water. Free liquids are separated with cyclone cutters, expansion vessels and cooling equipment. In some cases further unwanted gases (H_2S) are separated before the gas is fed into the pipeline for further transport.

To reach the required final quality the natural gas sometimes needs to be processed in a further treatment plant before it is fed into the transport pipelines and the supply network.

The following processing stages are distinguished:

- Separation of free water and oil
- Separation of higher hydrocarbons
- Natural gas drying
- Desuphurisation and recovery of elementary sulphur by means of a Claus plant

- (possibly) additional drying of higher hydrocarbons

The choice of the treatments and their sequence depends mainly on the composition of the raw gas, which can vary considerably.

The natural gas drying and desulphurisation (also called sweetening) are explained in more detail in the modules “Drying, natural gas” and “Sweetening, natural gas”.

The amount of processing needed depends on the quality of the produced gas. In general sour gas is more complex to process because of the additional desulphurisation step. Tab. 6.5 shows statistical data of the applied processing stages in different producing countries. Since no official statistics are available the given information is uncertain.

Tab. 6.5 Share of raw gas desulphurisation and raw gas drying (values used in this study are in bold letters). The values relate to the total input of produced gas

Country of origin	Share with desulphurisation	Share with drying	Source
Algeria (North Africa)	**0%**	**100%**	<Landolt Börnstein 1972>
Germany	60% 40% **50%**	N.a. the expenditures are included in the total values.	(Cerbe et al. 1999, S. 12) (WEG 2001a) (Fischer 2001)
Russian Federation	16% **20%**	**100%**	<DGMK 1992> (Krewitt 1997)
Norway	0% **0%**	- **60%**	<DGMK 1992> (Statoil 2001b)
Netherlands	**0%**	N.a. the expenditures are included in the total values.	<DGMK 1992>

In the natural gas processing about 2 to 20 % mole content is separated from the gas <Cerbe 1988, Grimm et al. 1983>. The higher hydrocarbonsand sulphur are partially sold as by-products. The Natural Gas Liquids NGL (mixture of ethane, propane, butane and pentane) are traded on an international market. In the combined production NGL are attributed to the oil production.

Energy consumption

In the early stages of the operation of natural gas fields the pressure of the reservoir is in general high enough for directly feeding the natural gas into the pipeline. With increasing age of the gas field the pressure decreases and additional compression of the natural gas becomes necessary. This is also the case for gas from combined oil and gas production. The gas processing immediately following the production of natural gas partly takes place by decompression of the gas which leads to considerable pressure losses which need to be compensated with compression.

For the compression mostly gas turbines are used (in 90 % of the cases according to (OLF 2001)). They are in a capacity range of 10 to 20 MW <Husdal 1992>. A small share of waste heat is used for in-field gas processing (dehydration).

Chemicals

In the combined oil and gas production various chemicals are used. Mostly only information about the total amount is available. In accordance with (Jungbluth 2003) it is assumed that non defined chemicals in the production consist of 43 % organic and 57 % inorganic chemicals.

Process related emissions to air

The most important process-related emissions to air from the natural gas production are, according to <Fürer 1991> and (OGP 2010):

- Emissions from the flaring of natural gas

- Gas leakages of the plants
- Gas emissions from venting and from repair works

Most of the production plants as well as some drilling rigs have a utility to flare superfluous gas. For safety reasons the flaring takes place at a certain distance from the well. The utility serves to flare natural gas during the drilling and the starting of a new field, during maintenance, accidents and to relieve the processing plant at the occurrence of pressure peaks <Klitz 1980>.

Process-related emissions to water

The most important process-related emissions to water and soil are <Fürer 1991>:

- Emissions from the discharge of produced water
    - Onshore: Injection into old oil/natural gas reservoirs or discharge into surface water
    - Offshore: Direct discharge into the sea, injection into old oil/natural gas reservoirs or transport and disposal on the mainland.
- Pollution of the soil (onshore) or the sea (offshore) with lubricating oils, fats or detergents (often via rain water)
- Emissions from sludge disposal or other pollutants that are separated from the process water. They are disposed in sludge dumps or treated as hazardous waste.

Reservoir water from natural gas production (also called produced water) can be harmful to the environment. Especially in the latest stage of the exploitation of gas fields large volumes of water are dragged up with the gas stream. The produced water has to be separated from the gas and needs to be disposed.

In (MILJOSOK 1996) it is stated that the volume of produced water is a factor 100 to 1000 smaller than the volume of produced water from oil production relative to the amount of natural gas and crude oil produced (expressed in energy equivalents). Statoil (2001b) allocates the whole produced water to the oil production. In this study it is assumed that per MJ oil produced 100 times more produced water is produced than in natural gas production. The composition of the produced water varies from country to country. The before mentioned allocation key is also used for the allocation of heavy metals and other emissions from the produced water.

Onshore production

The disposal methods used vary greatly from region to region. Precise statistics are not available. Legal regulations in Germany are very strict, so that the discharge into surface water bodies is only permitted in rare cases <Fürer 1991>. In CIS states (former Soviet Union) this practice is likely to be more common. For Northern Africa and Russia it is assumed that 10 resp 30 % of the produced water are discharged to surface water (Tab. 6.6). The discharged produced water is considered negligible for natural gas produced onshore in Germany and the Netherlands.

Offshore production

In the offshore oil and natural gas production the produced water is generally discharged to the sea or sometimes reinjected into the reservoir. In the combined production the free oil is usually separated so that the oil content is below 40 ppm (see siehe Jungbluth 2003). It is assumed that 100 % of the produced water in offshore production in the Netherlands is discharged to the sea. In Norway 21 % of the produced water is reinjected and 79 % is discharged to sea (OLF 2011).

Tab. 6.6 shows the assumed disposal routes for produced water used in this study.

Tab. 6.6 Assumed disposal of produced water in this study

	Discharge to surface water	Reinjection into reservoirs
Offshore Middle East (default)	100 %	
Offshore Norway [1)]	79 %	21 %
Onshore Russian Federation [2)]	30 %	70 %
Onshore North Africa [2)]	10 %	90 %
Onshore Europe	0 %	100 %

[1)] Source: OLF 2011

[2)] Assumption

Waste

Various kinds of wastes are produced in the course of production and processing of natural gas. This paragraph describes the wastes from production while the wastes from the processing are described in the section on drying (section 6.3.4). The most detailed data can be found in the environmental reports of the Norwegian Oil Association (OLF). Due to lack of data from other producing regions this information is used for all countries. Basis for the conversion is the net calorific value of the produced energy. The production datasets that are not updated in the current report (DE, NL), waste data from OLF (2000) are used (see Tab. 6.7). For the updated datasets waste data from OLF 2011 was used which is presented in the section on the Norwegian production (see Tab. 6.15, p. 30).

The distance to the disposal site is estimated to be 50 km (Germany, The Netherlands), for Norway, North Africa, The Middle East and Russia (all updated and new processes) the transport distance is estimated to be 100 km.

Tab. 6.7 Waste from the combined oil and natural gas production in Norway (OLF 2000; 2001)

	Amount	Substances		Disposal technology
	kg		kg/MJ [2)]	
Municipal waste				
Wood	1 468 000		1.71E-07	MWI (assumption)
Municipal waste / mixed waste	6 740 000	Residual waste	7.84E-07	Landfill
Rest	10 596 000	Paper, cardboard, glass, steel, organic waste, plastic	N. a.	Recycling
Hazardous waste				
Oily waste	3 589 000	Used motor oil (80 % [1)]), hydraulic oil (7% [1)]), drainage water, filter etc.	4.17E-07	Hazardous waste incineration(assumption)
Fluorescent tubes & bulbs	29 000		N. a.	Recycling
Chemicals etc.	8 857 000	Chemical mixtures, pure chemicals, acids	1.06E-06	Underground storage (assumption)
Solid hazardous waste	53 963 [1)]	N. a.	6.27E-09	Underground storage (assumption)
Anti-freeze	20 631 [1)]		2.40E-09	HWI (assumption)
Varnish	91 000	2-component adhesives, varnish	1.06E-08	HWI (assumption)
Produced water [3)]	3 980 000		4.63E-07	HWI (assumption)
Asbestos	35 012 [1)]		4.07E-09	Underground storage (assumption)
Batteries	50 000		N. a.	Recycling
Sand from sand-blasting	12 000		1.40E-09	Underground storage (assumption)
Other hazardous waste	158 000		1.84e-08	Underground storage (assumption)

[1)] Data for 1999

[2)] Total produced hydrocarbons (oil and natural gas): 8.6 E+12 MJ

[3)] The composition of produced water varies greatly. It consists mostly of oil contaminated water (EWC code 165074) and brine (EWC code 165073) [6]. Here it is consided as oily waste.

n.a.: not applicable

Gas drying

Water and water vapour contained in raw gas have to be eliminated, because otherwise at certain pressures and temperatures they would form crystalline, snow-like compounds – so-called gas hydrates – that can lead to a clogging of pipelines and equipment. Gas hydrates can further cause corrosion. Water vapour can be separated by one of the following tested methods:

- Deep freezing by expansion cooling (Joule-Thomson effect) or external cooling
- Drying with liquid organic absorption agents
- Drying with solid absorption agents

For the separation of water by cooling large amounts of heat are necessary. Therefore the preferred way is to profit from the Joule-Thomson-Effect, where the natural gas has a sufficiently high pressure at the drill hole. This is the case for most offshore fields in the North Sea.

The most common drying procedure is the absorption on the basis of glycol. This is used e.g. in the Groningen gas field in the Netherlands <Cerbe 1988>. A high pressure separator withdraws some of

6 Personal information of Mr. Furuholt, Statoil, 11.9.2002

the humidity. In the following step a small amount of glycol is added which absorbs free water. It is separated after the throttling point, is regenerated and reused afterwards.

Gas drying with solid adsorption agents (silica gel or aluminium gel) is used where small volumes of natural gas are cleaned or at extremely low temperatures. In extreme cases also molecular sieves (zeolites) are used.

The drying of natural gas is described in the module “Drying, natural gas” (see section 6.3.2).

Desulphurisation

Raw gas is classified as “sour gas” (also called lean gas) or “sweet gas” based on the sulphur content. Natural gas with more than 1 vol. % H_2S-content is sour, sweet gas has a lower H_2S content (see also fuel data in Tab. 3.4).

The most commonly used desulphurisation process is the chemical gas scrubbing. The used suds contain very reactive compounds such as Purisol, Sulfinol, Rectisol (trade marks) and ethanolamine. After decompression and pre-heating, the suds are regenerated by adding steam. The separated H_2S is directed to a sulphur production plant (Claus plant). In the Claus plant the H_2S is transformed to SO_2 with partial combustion and in the following catalytic reaction of H_2S/SO_2 transformed to elementary sulphur. Various flue gases are burned in a production flare, often with the addition of natural gas or vapour. Hereby the SO_2 emissions are of special interest.

The desulphurisation is described in the module “Sweetening, natural gas” (see section 6.3.6).

6.3.2 Infrastructure of the offshore production

The energy and material flows of production drillings are included in the exploration activities. This section describes the material and energy needs of offshore platforms needed for oil and natural gas production (see Tab. 6.8).

In the offshore production steel and concrete platforms are used. In depths of less that 100 metres steel platforms have advantages over the concrete platforms thus there are more steel than concrete platforms being used today (assumption: 80 % steel-, 20 % concrete platforms, according to <Chilingarian et al. 1992>).

For the natural gas production only few data are available. <Klitz 1980> documents the materials and energy used for the construction in the English offshore gas fields Leman (larger field with 26 production islands, Tab. 6.8). This field produced a total of $2.9*10^{11}$ m^3 natural gas up to the late 1980ies.

Further information was published in the course of discussions concerning the decommissioning of the platform Odin, in the Norwegian Continental Shelf (Greenpeace 1996, Tab. 6.8). The platform was operated by Esso Norway. It is a platform with a gas installation with a steel mantle. Drilling equipment and residential quarters were built upon it. The rather small platform (40x40x112 metres) was built in 1983 and shut down in 1994. The production volume amounted to 27.7 E+09 Nm^3 of natural gas within eleven years. In 1996 the platform was transported to the mainland for disassembly.

Tab. 6.8 shows the data representing the energy and material requirements to erect offshore platforms. Data from Burger (2004) are used to approximate the amount of paints used. For wind power plants this source records 5.5 g epoxy paint per kg of steel. In this study 1.5 mg paint per m^3 natural gas produced are used.

Steel platforms are protected from corrosion by the use of sacrificial anodes. Here the composition of often used aluminium zinc anodes is used. Roughly 85 % of the anodes are used up in the course of the lifetime of the platform and are balanced as emissions to the sea (Peters 2003; Tridentalloys 2003). The basic uncertainty is estimated with 10, since there are considerable uncertainties, e.g. with reference to the used amounts (shown in Tab. 6.9).

Standard transport distances are assumed for the transport of the materials.

The platform has a surface of 1'600 m^2, over eleven years of operation which results in 17'600 m^2a. It is assumed that the surface is restored after the disassembly of the platform on land. Further we assume that all platforms are disposed of either dismantled or not. The disassembly itself is not included in the inventory.

Tab. 6.8 Material and energy use to erect offshore natural gas platforms

	Unit	Natural Gas <Klitz 1980>	Odin (Greenpeace 1996)	**This study**
		Per m^3 natural gas	Per m^3 natural gas	Per m^3 natural gas
INPUT:				
Non-energetic resources:				
Water	kg	1.0E-04		1.0E-04
Energetic resources:				
Electricity, medium voltage, production UCTE, at grid	kWh	7.6E-04		7.6E-04
Diesel, burned in building machine	MJ	4.0E-03		4.0E-03
Land use:				
Industrial area, benthos	m^2a		6.35E-07	6.35E-07
Materials (infrastructure):				
Steel	kg	2.7 E-04	4.74E-04	
Steel low-alloyed	kg			4.74E-04
Concrete	kg		3.25E-04	3.25E-04
PVC	kg		1.08E-06	1.08E-06
Aluminium	kg		9.13E-06	9.13E-06
Zinc	kg		2.82E-07	2.82E-07
Epoxy resin, liquid, at plant	kg			1.50E-06

Summary of the unit process raw data

Tab. 6.9 shows the inventory data for “Plant, offshore, natural gas, production”. The plant has a service life time of eleven years, with a total production of 27.7 bcm natural gas.

Data quality

The data is based on information about a platform in the North Sea. The quantity of steel used is in a similar range like older data (see Tab. 6.8).

Tab. 6.9 Unit process raw data of „plant, offshore, natural gas, production“

Explanations	Name	Location	InfrastructureProcess	Unit	*plant offshore, natural gas, production*	UncertaintyType	StandardDeviation95%	GeneralComment
	Location				*OCE*			
	InfrastructureProcess				*1*			
	Unit				*unit*			
Resources, land	Transformation, from sea and ocean	-	0	m2	1.60E+3	1	2.03	(2,4,2,1,1,4); Greenpeace report, one platform
	Transformation, to sea and ocean	-	0	m2	1.60E+3	1	2.03	(2,4,2,1,1,4); Greenpeace report, one platform
	Transformation, from industrial area, benthos	-	0	m2	1.60E+3	1	2.03	(2,4,2,1,1,4); Greenpeace report, one platform
	Transformation, to industrial area, benthos	-	0	m2	1.60E+3	1	2.03	(2,4,2,1,1,4); Greenpeace report, one platform
	Occupation, industrial area, benthos	-	0	m2a	1.76E+4	1	1.54	(2,4,2,1,1,4); Greenpeace report, one platform
Technosphere	diesel, burned in building machine	GLO	0	MJ	1.16E+8	1	1.28	(3,4,4,1,1,4); calculated based on data from 1980
	tap water, at user	RER	0	kg	2.83E+6	1	1.28	(3,4,4,1,1,4); calculated based on data from 1980
	electricity, medium voltage, production UCTE, at grid	UCTE	0	kWh	2.12E+7	1	1.28	(3,4,4,1,1,4); calculated based on data from 1980
	steel, low-alloyed, at plant	RER	0	kg	1.31E+7	1	1.27	(2,4,2,1,3,4); Greenpeace report, one platform, standard module
	epoxy resin, liquid, at plant	RER	0	kg	7.30E+4	1	1.61	(3,4,3,2,4,5); Data for wind turbines
	polyvinylchloride, bulk polymerised, at plant	RER	0	kg	3.00E+4	1	1.27	(2,4,2,1,3,4); Greenpeace report, one platform, standard module
	aluminium, production mix, at plant	RER	0	kg	2.53E+5	1	1.27	(2,4,2,1,3,4); Greenpeace report, one platform, standard module
	cast iron, at plant	RER	0	kg	3.03E+2	1	10.43	(5,5,1,1,1,na); Estimation for aluminium anode, basic uncertainity estimated = 10
	MG-silicon, at plant	NO	0	kg	3.79E+2	1	10.43	(5,5,1,1,1,na); Estimation for aluminium anode, basic uncertainity estimated = 10
	copper, at regional storage	RER	0	kg	1.52E+1	1	10.43	(5,5,1,1,1,na); Estimation for aluminium anode, basic uncertainity estimated = 10
	zinc for coating, at regional storage	RER	0	kg	7.82E+3	1	1.27	(2,4,2,1,3,4); Greenpeace report, one platform, standard module
	concrete, normal, at plant	CH	0	m3	4.09E+3	1	1.27	(2,4,2,1,3,4); Greenpeace report, one platform, standard module
	transport, lorry 32t	RER	0	tkm	1.80E+6	1	2.09	(4,5,na,na,na,na); standard distance
	transport, freight, rail	RER	0	tkm	2.70E+6	1	2.09	(4,5,na,na,na,na); standard distance 600km
	transport, transoceanic freight ship	OCE	0	tkm	2.81E+6	1	2.09	(4,5,na,na,na,na); standard distance
	Heat, waste	-		MJ	7.62E+7	1	1.17	(2,4,2,1,1,4); Greenpeace report, one platform, standard module
emission water, ocean	Aluminum	-	-	kg	2.15E+5	1	10.43	(5,5,1,1,1,na); Estimation 85% utilisation of anode
	Iron, ion	-	-	kg	2.58E+2	1	10.43	(5,5,1,1,1,na); Estimation 85% utilisation of anode
	Silicon	-	-	kg	3.22E+2	1	10.43	(5,5,1,1,1,na); Estimation 85% utilisation of anode
	Copper, ion	-	-	kg	1.29E+1	1	10.43	(5,5,1,1,1,na); Estimation 85% utilisation of anode
	Zinc, ion	-	-	kg	6.65E+3	1	10.43	(5,5,1,1,1,na); Estimation 85% utilisation of anode
	Titanium, ion	-	-	kg	5.37E+1	1	10.43	(5,5,1,1,1,na); Estimation 85% utilisation of anode
Outputs	plant offshore, natural gas, production	OCE	1	unit	1.00E+0			
	weigth				2.25E+7			

6.3.3 Onshore production infrastructure

In the onshore production up to several hundred production plants form one field. This circumstance requests that the steel of the collection pipes is taken into consideration when describing the material needs of natural gas production plants. With the assumption of an average production per field of 1'500 bcm natural gas <MEZ 1992>, for the Netherlands, 100 drillings per field in a distance of 300 m from a comb-shaped collection pipe, the steel input needed results in the range of 0.001 kg steel per m^3 produced natural gas. In <DOE 1983> a higher value of 0.04 kg/ m^3 is given. <Fritsche et al. 1989> calculate with a demand for steel of 0.0008 kg/ m^3 (onshore) and 0.0013 kg/ m^3 (offshore), respectively. In this study an average steel demand of 0.001 kg/ m^3 is used for onshore production.

The construction of the collection pipes is of minor importance since the pipes are either placed directly on the ground, or laid into the ground at shallow depths (about 0.5 m). The energy requirement of the construction is estimated at 0.001 MJ/ m^3 produced natural gas, represented with the module „Diesel, burned in building machine”.

Standard distances are used for the transport of the steel.

The onshore production requires space for the drilling tower, cleaning processes, pipelines and energy production. <Fritsche et al. 1989> and <DOE 1983> indicate a land use of 0.0003 resp. 0.0001 m^2a / m^3. In this study a land use of 7'500 m^2 is used for the field. Usually production plants are constructed predominantly on grassland and pastures.

The pipes inserted in drilling holes and the collection pipes are left behind when operation is ceased. Thus they are disposed of dispersedly. Wether the steel of the plant is recycled or left behind depends on the political and economic conditions. It is assumed that all offshore plants are disassembled and disposed. The disassembly is not considered in this inventory.

It is assumed that the surface area is restored to the original state.

Tab.6.10 Material inputs, construction expenditures and land use of onshore production plants

Per m^3 natural gas produced	Unit	Combined production 1)	Natural gas 3)	**This study** 2)
INPUT:				
Energetic resources:				
Electricity, medium voltage, production UCTE, at grid	kWh	5.3E-04		5.5 E-04
Diesel, burned in building machine	MJ	1.0 E-03	1 E-03	1 E-03
Land use:				
Transformation, from pasture and meadow	m^2		1 E-04	5 E-06
Materials (infrastructure):				
Steel unalloyed	kg	1.3E-03	1 E-03	1 E-03

1) Values according to (Frischknecht et al. 1996, Tab. IV.7.11), converted to the calorific value of natural gas – NCV of crude oil: 42.6 MJ/kg, Natural gas: 40.9 MJ/kg.

2) Roughly 10 % from combined production and 90 % from natural gas production

3) See remarks in text

Summary of the unit process raw data

Tab. 6.11 shows the inventory data of "Plant onshore, natural gas, production". The plant has a life-time of 50 years with a total production volume of 1.5 bcm natural gas.

Tab. 6.11 Unit process raw data of „Plant onshore, natural gas, production"

Explanations	Name	Location	InfrastructureProcess	Unit	*plant onshore, natural gas, production*	UncertaintyType	Standard Deviation 95%	GeneralComment
	Location				*GLO*			
	InfrastructureProcess				*1*			
	Unit				*unit*			
Resources, land	Transformation, from pasture and meadow	-	0	m2	7.50E+3	1	2.10	(3,4,3,3,3,4); qualified estimates for NL gas field
	Transformation, to pasture and meadow	-	0	m2	7.50E+3	1	2.10	(3,4,3,3,3,4); qualified estimates for NL gas field
	Transformation, from industrial area	-	0	m2	7.50E+3	1	2.10	(3,4,3,3,3,4); qualified estimates for NL gas field
	Transformation, to industrial area	-	0	m2	7.50E+3	1	2.10	(3,4,3,3,3,4); qualified estimates for NL gas field
	Occupation, industrial area	-	0	m2a	3.75E+5	1	1.62	(3,4,3,3,3,4); qualified estimates for NL gas field, 50 years occupation
Technosphere	diesel, burned in building machine	GLO	0	MJ	1.50E+6	1	1.36	(4,4,3,3,3,4); qualified estimates for NL gas field
	electricity, medium voltage, production UCTE, at grid	UCTE	0	kWh	8.25E+5	1	1.36	(4,4,3,3,3,4); qualified estimates for NL gas field
	reinforcing steel, at plant	RER	0	kg	1.50E+6	1	1.36	(4,4,3,3,3,4); qualified estimates for NL gas field
	transport, lorry 32t	RER	0	tkm	1.50E+5	1	2.09	(4,5,na,na,na,na); standard distance
	transport, freight, rail	RER	0	tkm	3.00E+5	1	2.09	(4,5,na,na,na,na); standard distance
	Heat, waste	-		MJ	2.97E+6	1	1.31	(3,4,3,3,3,4); qualified estimates for NL gas field
Outputs	plant onshore, natural gas, production	GLO	1	unit	1.00E+0			

Data quality

The data used is mostly based on assumptions and estimations. There are considerable uncertainties.

6.3.4 Gas treatment plants

The inventory data for material use and construction expenditures as well as the land use is shown in Tab. 6.12. The comparison with onshore production shows that the amount of steel needed for the treatment plants is roughly twice as high (see Section 6.3.2). This seems plausible since the treatment plants are of rather high complexity.

This section summarises data from two gas treatment plants. The described plants process 1.52E+12 MJ gaseous hydrocarbons per year.

The energy needed for the construction processes is assumed to be twice as high as the energy needed to erect onshore production equipment. The transport is estimated with standard transport distances according to (Frischknecht et al. 2004).

The land use is based on data characterising the Norwegian gas treatment plants Kollsnes and Kårstø.

Tab. 6.12 Material inputs, construction expenditures and land use to erect natural gas treatment plants

Per m^3 produced		<Fritsche et al. 1989>	Norway [1), 7)]	**This study**
		m^3 prod	m^3 prod	m^3 prod
Aluminium	kg	4E-05		
Steel	kg	2E-03		2E-03 [2):]
Concrete	kg	1E-03 [3), 5)]		1E-03 [3)]
Transport lorry 32t Transport rail electric	tkm tkm			2E-04 4E-04
Diesel, burned in building machine Electricity, medium voltage, production UCTE, at grid	MJ kWh			2.0E-03 [4)] 1.1E-03 [4)]
Land use, 60 years operation (industrial site)	m^2a		6.75E-05	6.75E-05

1) For this calculation the total surface area of both plants (2.1E+06 m^2 resp. 7.5E+05 m^2) is divided by the total production (1.52E+12 MJ gases, expressed as m^3 natural gas 4.23 E+10 Nm^3) and the service lifetime (60 years[8]).

2) Transport of steel 200 km rail and 100 km lorry 32 t

3) Transport of concrete 50 km with lorry 32 t

4) Analogue to Tab.6.10

5) Data for "cement" is interpreted as concrete

Summary of the unit process raw data

Tab. 6.13 shows the inventory data of„Production plant, natural gas". The production plant described processes 1.52E+12 MJ of gaseous hydrocarbons per year. The lifetime is 60 years.

Data quality

The figures representing the area of the plant are based on rather current data. Unfortunately no data was available for the materials and drilling needed for this specific plant. Therefore these values are based on extrapolations and are subject to considerable uncertainties.

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7 Personal communication by Mr. Furuholt, Statoil, 16.04.2002

8 Personal communication by Mr. Furuholt, Statoil, 16.04.2002

Tab. 6.13 Unit process raw data of „Production plant, natural gas“

Explanations	Name	Location	Category	SubCategory	InfrastructureProcess	Unit	production plant, natural gas	UncertaintyType	Standard Deviation 95%	GeneralComment
	Location						GLO			
	InfrastructureProcess						1			
	Unit						unit			
Resources, land	Transformation, from pasture and meadow	-	resou	land	0	m2	2.86E+06	1	2.06	(2,3,1,3,1,5); personal communication, Statoil
	Transformation, to pasture and meadow	-	resou	land	0	m2	2.86E+06	1	2.06	(2,3,1,3,1,5); personal communication, Statoil
	Transformation, from industrial area	-	resou	land	0	m2	2.86E+06	1	2.06	(2,3,1,3,1,5); personal communication, Statoil
	Transformation, to industrial area	-	resou	land	0	m2	2.86E+06	1	2.06	(2,3,1,3,1,5); personal communication, Statoil
	Occupation, industrial area	-	resou	land	0	m2a	1.71E+08	1	1.57	(2,3,1,3,1,5); personal communication, Statoil
Technosphere	diesel, burned in building machine	GLO	-	-	0	MJ	5.07E+09	1	1.64	(3,3,5,3,3,5); extrapolation from German data
	electricity, medium voltage, production UCTE, at grid	UCTE	-	-	0	kWh	2.82E+09	1	1.64	(3,3,5,3,3,5); extrapolation from German data
	reinforcing steel, at plant	RER	-	-	0	kg	5.07E+09	1	1.64	(3,3,5,3,3,5); extrapolation from German data
	concrete, normal, at plant	CH	-	-	0	m3	9.82E+05	1	1.64	(3,3,5,3,3,5); extrapolation from German data
	transport, lorry 32t	RER	-	-	0	tkm	6.15E+08	1	2.09	(4,5,na,na,na,na); standard distance
	transport, freight, rail	RER	-	-	0	tkm	1.01E+09	1	2.09	(4,5,na,na,na,na); standard distance
	Heat, waste	-	air	low popula		MJ	1.01E+10	1	1.64	(3,3,5,3,3,5); extrapolation from German data
Outputs	production plant, natural gas	GLO	-	-	1	unit	1.00E+00			

6.3.5 Production in Norway

In Norway oil and gas are produced offshore on the Norwegian Continental Shelf (NCS). The emissions and discharges as well as the energy use are well documented. The Norwegian Oil Association releases environmental reports on an annual basis (OLF 2011). The 2011 report contains data from all production fields on the NCS up to the year 2010. The emissions and expenditures from oil and natural gas production rise with increasing age of the fields; therefore the 2010 data was used for this study. Emission data covering construction and installation, marine support services and helicopter traffic are not included in the OLF report.

The data provided in the environmental report are given for the combined production of natural gas and crude oil. The data used in this study are also presented for the combined production. Allocation is applied according to the energy content (net calorific value) of the hydrocarbons. Unless stated otherwise, the source of information is the OLF environmental report (OLF 2011).

Tab. 6.14 shows the total hydrocarbon production in Norway in the year 2010. Condensates and natural gas liquids are attributed to the crude oil production.

Tab. 6.14 Norwegian hydrocarbon production in 2010 and allocation factors

Production of	Nm^3	kg	Net calorific value (MJ)	Allocation factor
Natural gas	1.12E+11		4.1E+12	47%
Crude oil	1.10E+08	9.5E+10	4.1E+12	53%
Condensates	4.35E+06	3.7E+09	1.6E+11	
Natural gas liquids (NGL)	1.63E+07	8.1E+09	3.5E+11	

[1)] net calorific values used: crude oil: XX MJ/kg; natural gas: XX MJ/Nm^3; condensates: XX MJ/kg; NGL: XX MJ/kg

Infrastructure

The infrastructure is represented by the modules “Plant offshore, natural gas, production” and “Platform, crude oil, offshore” (Jungbluth 2003). The specific demand is based on the amounts of natural gas and oil produced (net calorific value).

Exploration and production drilling

In 2010 a total of 586’259 m new boreholes were drilled (see also subchapter 6.2). The drilling meters from combined production are allocated to crude oil and natural gas based on the net calorific value of the total production, resulting in 24 E-7 meters drilled per Nm^3 natural gas and 29 E-7 per kg crude oil.

Waste

Drilling wastes are covered in the module “Well for exploration and production, offshore”. For other wastes produced in the Norwegian oil and gas production the modules “Waste, non-hazardous, from combined oil and gas production, offshore“ and “Hazardous waste, from combined oil and gas production, offshore” (in kg) are used which are based on data from OLF (OLF 2011). They are shown in Tab. 6.15. The waste is assumed to be transported over 100 km to the treatment facilities. This is taken into account in the dataset “natural gas, at production” (NO).

Tab. 6.15: Unit process raw data of waste from combined offshore oil and natural gas production in Norway

Name	Location	InfrastructureProcess	Unit	Waste, non-hazardous, from combined oil and gas production, offshore	Hazardous waste, from combined oil and gas production, offshore	
Location				NO	NO	
InfrastructureProcess				0	0	
Unit				kg	kg	
Waste, non-hazardous, from combined oil and gas production, offshore	NO	0	kg	1.00E+00	0	
Hazardous waste, from combined oil and gas production, offshore	NO	0	kg	0	1.00E+00	Source, Remarks
disposal, municipal solid waste, 22.9% water, to sanitary landfill	CH	0	kg	7.58E-1		OLF 2011. Residual waste, wet organic waste, contaminated food and other waste.
disposal, industrial devices, to WEEE treatment	CH	0	kg	4.00E-2		OLF 2011. EE waste
disposal, wood untreated, 20% water, to municipal incineration	CH	0	kg	1.62E-1		OLF 2011
disposal, plastics, mixture, 15.3% water, to municipal incineration	CH	0	kg	4.04E-2		OLF 2011
disposal, hazardous waste, 25% water, to hazardous waste incineration	CH	0	kg		9.63E-1	OLF 2011. Blasting sand, chemicals, light bulbs, oil contaminated waste and spray cans.
disposal, emulsion paint remains, 0% water, to hazardous waste incineration	CH	0	kg		3.70E-2	OLF 2011

Emissions to air

In the OLF environmental report the yearly amounts of air pollutants (carbon dioxide, nitrogen oxides, sulphur oxides, methane and non-methane volatile organic compounds (nmVOC)) from turbine, engine, boiler, flare, well test and “other sources” are declared separately. The yearly amounts of PAHs, PCB, dioxins, fuel gas emissions and liquid fuels emitted to the air are declared without specifying the source of emission.

The emissions from natural gas burned in turbines and diesel burned in various equipments are covered in the subsection on fuel consumption. One major source of air emissions is the flaring of natural gas. On the Norwegian Continental Shelf 370 million Nm^3 of natural gas were flared in 2010. This is represented by the dataset “natural gas, sweet, burned in production flare”.

The emissions of ethane, propane and butane were calculated based on the methane emissions (excluding the emissions from turbines, flaring and well testing) and the composition of Norwegian natural gas.

The mercury and radon emissions were calculated based on the amount of gas flared and the natural gas composition (see Tab. 3.5).

Fuel consumption

In 2010 a total of 3.7 bcm of natural gas were burned in turbines and an equivalent of 12 PJ of diesel was burned in the combined production of oil and natural gas in Norway, represented by the datasets “sweet gas, burned in gas turbine, production” and “diesel, burned in diesel-electric generating set”. The fuel used in the well testing is excluded, since this is covered in the dataset on natural gas exploration.

Chemicals

In 2010 72'400 t of chemicals for purposes other than exploratory drillings were used (excluding chemicals for well drilling). Gthe production of these chemicals is represented by the dataset “chemicals organic, at plant”.

Emissions to water

The most important sources for operational discharges to the sea are drilling process and well operation, including the discharge of produced water. Other sources of pollutant emissions are acute discharges of oil and chemicals.

In 2010 95 t of oil was spilled to the sea in acute discharges on the NCS.

The heavy metal discharges and oil discharges from drilling activities are covered in the exploration module “Well for exploration and production, offshore” (OCE). The heavy metal discharges with the produced water in 2010 are displayed in Tab. 6.16.

Tab. 6.16 Discharge of heavy metals and other compounds with produced water in 2010 (OLF 2011)

	unit	As	Ba	Pb	Fe	Cd	Cu	Cr	Hg	Ni	Zn
Total	kg	895	7’071’530	239	825’822	22	89	225	9	200	6’948
Per kg produced water	kg	15 E-4	12	41 E-5	1.4	38 E-6	15 E-5	38 E-5	15 E-6	34 E-5	12 E-3

Summary of the unit process raw data

In Tab. 6.17 the annual figures for the combined oil and gas production are presented. Allocation factors for the oil and natural gas production are shown in the columns 10 and 11. Basis for the allocation is the net calorific value of the oil and natural gas produced. 47 % of the emissions are allocated to natural gas. More produced water is created in the oil production than in natural gas production (a factor 100 is used in this study) thus the allocation factor for heavy metal emission in natural gas production is only 0.9 %.

Data quality

Most of the data used is from the environmental report of the Norwegian oil and gas production for the year 2010 (OLF 2011). The report is of good quality and provides a lot of specific information. These data are partially supplemented by assumptions e.g. regarding mercury and radon emissions. The data used are specific for the region and are representative for the technology described.

Tab. 6.17 Unit process raw data of "combined offshore gas and oil production" (NO)

Name	Location	InfrastructureProcess	Unit	combined offshore gas and oil production	Uncertainty	StandardDeviation95%	GeneralComment	crude oil, at production offshore	natural gas, at production offshore
Location				NO				NO	NO
InfrastructureProcess				0				0	0
Unit				a				kg	Nm3
crude oil, at production offshore	NO	0	kg	1.07E+11				1	0
natural gas, at production offshore	NO	0	Nm3	1.12E+11				0	1
Oil, crude, in ground	-	-	kg	1.07E+11	1	1.05	(1,1,1,1,1,1,BU:1.05); OLF 2011. Oil (96.2%) and Condensates (3.8%) production.	1.00	
Gas, natural, in ground	-	-	Nm3	1.12E+11	1	1.05	(1,1,1,1,1,1,BU:1.05); OLF 2011. Excluding gas flared and burned in turbine.		1.00
Water, salt, ocean	-	-	m3	1.66E+8	1	1.05	(1,1,1,1,1,1,BU:1.05); OLF 2011. Injected seawater. Conversion factor for Sm3 to Nm3: 1.05	0.53	0.47
Water, salt, sole	-	-	m3	1.73E+8	1	1.05	(1,1,1,1,1,1,BU:1.05); OLF 2011. Produced water.	0.99	0.01
chemicals organic, at plant	GLO	0	kg	7.24E+7	1	1.65	(4,4,3,3,4,5,BU:1.05); Consumption of chemicals, without chemicals for well drilling (OLF 2011, table 19).	0.53	0.47
sweet gas, burned in gas turbine, production	NO	0	Nm3	3.78E+9	1	1.05	(1,1,1,1,1,1,BU:1.05); Environmental report for Norway (OLF 2011). Gas burned in turbine for well tests is excluded.	0.53	0.47
natural gas, sweet, burned in production flare	GLO	0	Nm3	3.72E+8	1	1.05	(1,1,1,1,1,1,BU:1.05); OLF 2011, p.42 (table 4)	0.53	0.47
diesel, burned in diesel-electric generating set	GLO	0	MJ	1.17E+10	1	1.65	(4,4,3,3,4,5,BU:1.05);	0.53	0.47
transport, lorry >16t, fleet average	RER	0	tkm	1.66E+6	1	2.11	(4,4,2,3,1,5,BU:2); Waste transport, 100km (estimation).	0.53	0.47
well for exploration and production, offshore	OCE	1	m	5.86E+5	1	3.00	(1,1,1,1,1,1,BU:3); NPD 2011, personal communication	0.53	0.47
drying, natural gas	NO	0	Nm3	6.74E+10	1	1.30	(4,5,2,1,1,1,BU:1.05);	0.53	0.47
platform, crude oil, offshore	OCE	1	unit	5.44E+0	1	3.05	(2,2,1,1,3,3,BU:3);	1.00	0.00
plant offshore, natural gas, production	OCE	1	unit	4.09E+0	1	3.06	(3,1,2,1,1,5,BU:3);	0.00	1.00
Waste, non-hazardous, from combined oil and gas production, offshore	NO	0	kg	1.48E+7	1	1.24	(3,1,2,1,1,5,BU:1.05);	0.53	0.47
Hazardous waste, from combined oil and gas production, offshore	NO	0	kg	1.81E+6	1	1.24	(3,1,2,1,1,5,BU:1.05);	0.53	0.47
Methane, fossil	-	-	kg	1.97E+7	1	1.50	(1,1,1,1,1,1,BU:1.5); OLF 2011. Without emissions from turbines, flaring and well testing.	0.53	0.47
Ethane	-	-	kg	2.03E+6	1	1.56	(1,2,1,1,3,3,BU:1.5); Calculated based on gas composition	0.53	0.47
Propane	-	-	kg	5.22E+5	1	1.56	(1,2,1,1,3,3,BU:1.5); Calculated based on gas composition	0.53	0.47
Butane	-	-	kg	1.65E+5	1	1.56	(1,2,1,1,3,3,BU:1.5); Calculated based on gas composition	0.53	0.47
Carbon dioxide, fossil	-	-	kg	1.13E+9	1	1.22	(1,2,1,1,3,3,BU:1.05); OLF 2011. Without emissions from turbines, flaring and well testing.	0.53	0.47
NMVOC, non-methane volatile organic compounds, unspecified origin	-	-	kg	2.67E+6	1	1.56	(1,2,1,1,3,3,BU:1.5); OLF 2011. Without emissions from turbines, flaring and well testing.	0.53	0.47
Nitrogen oxides	-	-	kg	1.70E+4	1	1.56	(1,2,1,1,3,3,BU:1.5); OLF 2011. Without emissions from turbines, flaring and well testing.	0.53	0.47
Sulfur dioxide	-	-	kg	3.99E+5	1	1.22	(1,2,1,1,3,3,BU:1.05); OLF 2011. Without emissions from turbines, flaring and well testing.	0.53	0.47
PAH, polycyclic aromatic hydrocarbons	-	-	kg	9.00E+1	1	3.05	(1,2,1,1,3,3,BU:3); OLF 2011, table 28	0.53	0.47
Polychlorinated biphenyls	-	-	kg	1.70E+0	1	3.05	(1,2,1,1,3,3,BU:3); OLF 2011, table 28	0.53	0.47
Dioxins, measured as 2,3,7,8-tetrachlorodibenzo-p-dioxin	-	-	kg	8.00E-5	1	3.05	(1,2,1,1,3,3,BU:3); OLF 2011, table 28	0.53	0.47
Mercury	-	-	kg	2.75E-1	1	5.06	(1,2,1,1,3,3,BU:5); Estimation	0.53	0.47
Radon-222	-	-	kBq	1.10E+7	1	3.05	(1,2,1,1,3,3,BU:3); Estimation	0.53	0.47
Methane, bromochlorodifluoro-, Halon 1211	-	-	kg		1	1.56	(1,2,1,1,3,3,BU:1.5); Estimation	0.53	0.47
Oils, unspecified	-	-	kg	9.55E+4	1	1.56	(1,2,1,1,3,3,BU:1.5); Acute discharge to sea (OLF 2011, Tab.27).	0.53	0.47
Arsenic, ion	-	-	kg	8.95E+2	1	5.06	(1,2,1,1,3,3,BU:5); Heavy metals from	0.99	0.01
Barite	-	-	kg	7.07E+6	1	5.06	(1,2,1,1,3,3,BU:5); Heavy metals from	0.99	0.01
Cadmium, ion	-	-	kg	2.20E+1	1	3.05	(1,2,1,1,3,3,BU:3); Heavy metals from	0.99	0.01
Chromium, ion	-	-	kg	2.25E+2	1	3.05	(1,2,1,1,3,3,BU:3); Heavy metals from	0.99	0.01
Copper, ion	-	-	kg	8.90E+1	1	3.05	(1,2,1,1,3,3,BU:3); Heavy metals from	0.99	0.01
Lead	-	-	kg	2.39E+2	1	5.06	(1,2,1,1,3,3,BU:5); Heavy metals from	0.99	0.01
Mercury	-	-	kg	9.00E+0	1	5.06	(1,2,1,1,3,3,BU:5); Heavy metals from	0.99	0.01
Nickel, ion	-	-	kg	2.00E+2	1	5.06	(1,2,1,1,3,3,BU:5); Heavy metals from	0.99	0.01
Zinc, ion	-	-	kg	6.95E+3	1	5.06	(1,2,1,1,3,3,BU:5); Heavy metals from	0.99	0.01
Iron, ion	-	-	kg	8.26E+5	1	5.06	(1,2,1,1,3,3,BU:5); Heavy metals from produced water (OLF 2011, Tab.27)	0.99	0.01

6.3.6 Production in the Netherlands

The Netherland (NL) has onshore and offshore combined production of crude oil and natural gas. Roughly 70 % of the production takes place onshore (Tab. 6.18). If not stated otherwise the data from (NAM 2001) served as basis for calculations for the production in the Netherlands. NAM (Nederlandse Aardolie Maatschappij B.V.) has a market share of about 73 % of the Dutch oil and natural gas production.

Due to lack of more recent publications data representing the production in 2000 are used in this study. The data include the processing of the raw gas. Therefore drying is not accounted for separately.

Tab. 6.18 Onshore- and offshore natural gas and oil production of NAM (2001) in million Nm^3 oil equivalents for the year 2000. In 1999 NAM had a market share of the oil and natural gas production in the Netherlands of 73 %.

Production (in million Nm^3 o.e.)	Total	Offshore	Onshore
Natural gas	4.89E+01	1.39E+01	3.50E+01
Share of total		*28.4%*	*72%*
Oil	1.15E+00	3.80E-01	7.70E-01
Share of total		*33%*	*67%*
Condensates	7.40E-04	2.45E-04	4.95E-04
Share of total		*33%*	*67%*
Total	5.01E+01	1.43E+01	3.58E+01
Share of total		*28.5%*	*71.5%*

The net calorific value of the oil and natural gas serves as basis for the allocation to off- and onshore production. 28.5 % of the natural gas produced stem from offshore, 71.5 % from onshore production. Emissions to sea are allocated entirely to the offshore production.

Infrastructure

The infrastructure is represented by the datasets "Plant offshore, natural gas, production" and "Plant onshore, natural gas, production", as well as "Production plant crude oil, onshore" (Jungbluth 2003). The specific demand is based on the amounts of natural gas and oil produced (net calorific value).

Energy consumption

Similar to Norway the fuels used in the Netherlands are natural gas and diesel. Additionally electricity from the grid is used. The total energy consumption per m^3 of produced natural gas adds up to 2.9 MJ_{th}/m^3 [9].

Tab. 6.19 Energy use at the onshore and offshore combined production in the Netherlands

Energy use		Total use 2000	Offshore	Onshore
Natural gas	MJ	8.10E+09	2.31E+09	5.79E+09
Diesel	MJ	4.00E+08	1.14E+08	2.86E+08
Electricity	MJ_{th}	6.00E+09	1.71E+09	4.29E+09

9 For the comparison a conversion efficiency coefficient of 35 % was used for the conversion of MJ_{th} to MJ_e.

Chemicals

In NAM (2000) the amount of chemicals used in 1999 is declared for the different production types. This amount is extrapolated for the year 2000 based on the production volumes (see Tab. 6.20).

Tab. 6.20 Use of chemicals in 1999 in the Dutch combined production (NAM 2000; 2001)

	Unit	Various (oil production) 1)	Glycol (Natural gas prod.)	Methanol (Natural gas prod.)
Total 1999	kg	130'000	1'174'480	1'880'200
Specific amounts 2)	kg/kg; kg/Nm^3	1.22E-04	2.23E-05	3.57E-05
Total 2000 3)	kg	**117'726**	**1'083'981**	**1'747'943**

1) 43 % organic, 57 % inorganic according to (Jungbluth 2003)

2) Production in 1999: 1.07 E+09 kg crude oil, 5.26 E10 Nm^3 natural gas

3) Calculated based on specific values. Production in 2000: 9.67 E+08 kg crude oil, 4.89 E10 Nm^3 natural gas

Emissions to air

In the year 2000 a total of 58 million Nm^3 of natural gas were flared and vented (see Tab. 6.21).

Tab. 6.21 Volumes of natural gas flared and vented in the Netherlands in 2000 (**NAM 2000**)

		Total 2000	**Total Offshore**	**Total Onshore**
Flared natural gas	Nm^3	4.49E+07	1.28E+07	3.21E+07
Vented natural gas	Nm^3	1.31E+07	3.74E+06	9.36E+06

The emissions from natural gas flaring and venting are calculated by subtracting the emission factors reported in the datasets "sweet gas, burned in gas turbine, production" and „diesel, burned in diesel-electric generating set"(Tab. 6.19) from the total production emissions (see Tab. 6.22).

Tab. 6.22 Emissions to air of NAM in 2000. The emissions are allocated to onshore and offshore production based on the production volumes. Emission factors of the datasets „Sweet gas, burned in gas turbine, production " and „ diesel, burned in diesel-electric generating set " are documented in Section 6.3.4.

Air emissions		**Total emissions 2000**	Offshore	Onshore	**Total offshore ex-cluding natural gas burned in turbines**	**Total onshore ex-cluding natural gas burned in turbines**
CO_2	kg	6.60E+08	1.88E+08	4.72E+08	2.54E+07	6.35E+07
CO	kg	1.60E+06	4.57E+05	1.14E+06	4.57E+05	1.14E+06
SO_2	kg	1.00E+05	2.85E+04	7.15E+04	1.55E+04	3.89E+04
NO_x	kg	2.00E+06	5.71E+05	1.43E+06	8.21E+03	2.06E+04
CH_4	kg	9.70E+06	2.77E+06	6.93E+06	2.71E+06	6.80E+06
Aliphatic C/H (C_2H_6, C3+)	kg	2.30E+06	6.56E+05	1.64E+06	6.40E+05	1.60E+06
Aromatic C/H (BTEX)	kg	1.20E+06	3.42E+05	8.58E+05	3.34E+05	8.36E+05
CFC 1)	kg	4.00E+01	1.14E+01	2.86E+01	1.14E+01	2.86E+01
H-CFC 2)	kg	4.00E+03	1.14E+03	2.86E+03	1.14E+03	2.86E+03
Hg	kg	3.00E+01	8.56E+00	2.14E+01	2.14E+00	5.36E+00

1) In the laboratory; assumption: CFC-12

2) Gas cooling and air conditioning. Assumption: H-CFC-22

The radon-222 emissions are calculated with the volume of natural gas vented and the gas composition. The emissions from flaring are considered by linking to the dataset „Natural gas, sweet, burned in production flare“.

The produced water is allocated on the same basis as in the Norwegian production. The reinjected produced water is not taken into account. It is further assumed that a third of the water used comes each from the tap, from ground water and surface water (see Tab. 6.23).

Tab. 6.23 Volumes of produced water and water used in 2000 (**NAM 2001**)

Water		Total use	Per Nm^3 natural gas
Produced water discharged to sea [1)]	m^3	1.55E+05	1.09E-05
Produced water reinjected [2)]	m^3	1.80E+06	3.60E-05
Use of drinking water, ground water and surface water [2), 3)]	m^3	2.10E+05	4.20E-06

[1)] Allocated only to offshore production.

[2)] Allocated to total production.

[3)] Assumption: 1/3 drinking water, ground water, and surface water each

Emissions to water

NAM (2001) only declares emissions to the sea (see Tab. 6.24 and Tab. 6.25). At onshore production only insignificant volumes of water are discharged to surface water bodies. The water is treated beforehand (van Eslen 2002). The emission of the remaining pollutants is not considered due to lack of data.

Water emissions are allocated to the production of oil and natural gas, with oil causing more produced water than the natural gas production (factor 100, see Tab. 6.35). 26.8 % of the total produced water are thus allocated to the natural gas production.

The emissions of BOD, COD, DOC and TOC are calculated based on the emission of hydrocarbons to water.

Tab. 6.24 Additives discharged to the sea with effluents in the year 2000 (allocated to offshore production)

Additive		**Total emissions**	**Per total Nm3 o.e.**	**Per litre water**
Corrosion inhibitors	kg	3.00E+02	2.10E-05	1.94E-06
Glycol	kg	1.08E+05	7.56E-03	6.97E-04
Methanol	kg	1.44E+05	1.01E-02	9.29E-04
Oil in water	kg	2.60E+03	1.82E-04	1.68E-05

Tab. 6.25 Heavy metals discharged to the sea with effluents in the year 2000 (allocated to offshore production)

		Total emissions	Per total Nm^3 o.e.	per Nm^3 natural gas	per litre water
Zinc	kg	3.66E+02	2.56E-05	2.56E-08	2.36E-06
Mercury	kg	4.00E-01	2.80E-08	2.80E-11	2.58E-09
Cadmium	kg	1.60E+00	1.12E-07	1.12E-10	1.03E-08
Lead	kg	1.08E+02	7.56E-06	7.56E-09	6.97E-07
Nickel	kg	1.20E+01	8.40E-07	8.40E-10	7.74E-08

Waste

Wastes are represented using the standard data shown in Tab. 6.7.

Summary of the unit process raw data

The following tables (Tab. 6.26 and Tab. 6.27) show the annual values of the combined production. The allocation to oil and natural gas is conducted according to the allocation factors presented in the columns 10 and 11. Allocation factors are based on the net calorific values of the produced oil and natural gas. About 97 % of the expenditures and emissions of offshore production and 98 % of the expenditures and emissions of onshore production are thus allocated to natural gas. For the allocation of the produced water the fact is taken into account, that a lot more produced water is created in the production of oil compared to natural gas (100:1). Therefore only 26.8 % of the total amount is allocated to offshore gas production.

Data quality

The data used stem mostly from the NAM environmental report (2001) for the year 2000 and describes about 73 % of the Dutch natural gas production. They are considered to be of good quality. In addition some well justified assumptions are used e.g. for the composition of nmVOC and the infrastructure. The data used are specific for the examined region and appropriate to represent the technology used. No specific data were available about the emission of radioactive substances (radon 222).

Tab. 6.26 Unit process raw data of „combined offshore gas and oil production“ (NL)

Explanations	Name	Location	InfrastructureProcess	Unit	combined offshore gas and oil production	UncertaintyType	StandardDeviation95%	GeneralComment	natural gas, at production offshore	crude oil, at production offshore
	Location				NL				NL	NL
	InfrastructureProcess				0				0	0
	Unit				a				Nm3	kg
Resources, in ground	Oil, crude, in ground	-	0	kg	3.19E+8	1	1.07	(1,2,1,1,1,3); Environmental report for 75% of gas produced in NL	0.0	100.0
	Gas, natural, in ground	-	0	Nm3	1.39E+10	1	1.07	(1,2,1,1,1,3); Environmental report for 75% of gas produced in NL	100.0	0.0
Resources, in water	Water, salt, sole	-	0	m3	1.55E+5	1	1.12	(2,2,1,1,1,3); Environmental report for 75% of gas produced in NL	26.8	73.2
	Water, salt, ocean	-	0	m3	5.99E+4	1	1.12	(2,2,1,1,1,3); Environmental report for 75% of gas produced in NL	26.8	73.2
Technosphere	chemicals organic, at plant	GLO	0	kg	1.44E+4	1	1.07	(1,2,1,1,1,3); Environmental report for 75% of gas produced in NL	98.2	1.8
	chemicals inorganic, at plant	GLO	0	kg	1.91E+4	1	1.07	(1,2,1,1,1,3); Environmental report for 75% of gas produced in NL	97.3	2.7
	ethylene glycol, at plant	RER	0	kg	3.09E+5	1	1.07	(1,2,1,1,1,3); Environmental report for 75% of gas produced in NL	98.2	1.8
	methanol, at regional storage	CH	0	kg	4.99E+5	1	1.07	(1,2,1,1,1,3); Environmental report for 75% of gas produced in NL	98.2	1.8
	sweet gas, burned in gas turbine, production	NO	0	Nm3	6.42E+7	1	1.22	(1,2,1,1,3,3); Environmental report for 75% of gas produced in NL, standard module	97.3	2.7
	diesel, burned in diesel-electric generating set	GLO	0	MJ	1.14E+8	1	1.22	(1,2,1,1,3,3); Environmental report for 75% of gas produced in NL, standard module	97.3	2.7
	electricity, medium voltage, at grid	NL	0	kWh	1.66E+8	1	1.22	(1,2,1,1,3,3); Environmental report for 75% of gas produced in NL, standard module	97.3	2.7
	transport, lorry 32t	RER	0	tkm	8.38E+4	1	2.32	(5,1,1,3,3,5); estimates for waste transport	97.3	2.7
	transport, freight, rail	RER	0	tkm	6.04E+4	1	2.09	(4,5,na,na,na,na); standard distance	97.3	2.7
	well for exploration and production, offshore	OCE	1	m	1.00E+5	1	1.22	(1,2,1,1,3,3); Environmental report for 75% of gas produced in NL, standard module	97.3	2.7
	platform, crude oil, offshore	OCE	1	unit	1.63E-2	1	3.14	(4,1,1,3,3,5); based on UK platform infrastructure and production	0.0	100.0
	plant offshore, natural gas, production	OCE	1	unit	5.02E-1	1	3.26	(2,4,2,3,4,4); Environmental report for 75% of gas produced in NL, standard module	100.0	0.0
	disposal, used mineral oil, 10% water, to hazardous waste incineration	CH	0	kg	4.47E+5	1	1.22	(1,1,1,3,3,3); Norwegian environmental report	97.3	2.7
	disposal, municipal solid waste, 22.9% water, to sanitary landfill	CH	0	kg	3.98E+5	1	1.22	(1,1,1,3,3,3); Norwegian environmental report	97.3	2.7
	disposal, wood untreated, 20% water, to municipal incineration	CH	0	kg	8.66E+4	1	1.22	(1,1,1,3,3,3); Norwegian environmental report	97.3	2.7
	disposal, hazardous waste, 0% water, to underground deposit	DE	0	kg	5.38E+5	1	1.22	(1,1,1,3,3,3); Norwegian environmental report	97.3	2.7
	disposal, antifreezer liquid, 51.8% water, to hazardous waste incineration	CH	0	kg	1.22E+3	1	1.22	(1,1,1,3,3,3); Norwegian environmental report	97.3	2.7
	disposal, emulsion paint remains, 0% water, to hazardous waste incineration	CH	0	kg	5.37E+3	1	1.22	(1,1,1,3,3,3); Norwegian environmental report	97.3	2.7
	low active radioactive waste	CH	0	m3	6.37E+1	1	1.22	(2,1,1,3,3,3); data for GB	0.0	100.0
Emissions, in air, low population density	Methane, fossil	-		kg	2.71E+6	1	1.51	(1,2,1,1,1,3); Environmental report for 75% of gas produced in NL	97.3	2.7
	Carbon dioxide, fossil	-		kg	2.54E+7	1	1.07	(1,2,1,1,1,3); Environmental report for 75% of gas produced in NL	97.3	2.7
	Carbon monoxide, fossil	-		kg	4.57E+5	1	1.07	(1,2,1,1,1,3); Environmental report for 75% of gas produced in NL	97.3	2.7
	Nitrogen oxides	-		kg	8.21E+3	1	1.51	(1,2,1,1,1,3); Environmental report for 75% of gas produced in NL	97.3	2.7
	Hydrocarbons, aliphatic, alkanes, unspecified	-		kg	6.40E+5	1	1.51	(1,2,1,1,1,3); Environmental report for 75% of gas produced in NL, reduced for combustion emissions	97.3	2.7
	Hydrocarbons, aromatic	-		kg	3.34E+5	1	1.51	(1,2,1,1,1,3); Environmental report for 75% of gas produced in NL, reduced for combustion emissions	97.3	2.7
	Sulfur dioxide	-		kg	1.55E+4	1	1.07	(1,2,1,1,1,3); Environmental report for 75% of gas produced in NL	97.3	2.7
	Mercury	-		kg	2.14E+0	1	1.51	(1,2,1,1,1,3); Environmental report for 75% of gas produced in NL	97.3	2.7
	Radon-222	-		kBq	7.47E+5	1	3.15	(4,1,3,3,3,5); data calculated on the basis of gas composition	97.3	2.7
	Methane, chlorodifluoro-, HCFC-22	-		kg	1.14E+3	1	1.56	(1,2,1,1,3,3); Environmental report for 75% of gas produced in NL	97.3	2.7
	Methane, dichlorodifluoro-, CFC-12	-		kg	1.14E+1	1	1.56	(1,2,1,1,3,3); Environmental report for 75% of gas produced in NL	97.3	2.7
	Heat, waste	-		MJ	5.99E+8	1	1.22	(2,2,1,1,3,3); Environmental report for 75% of gas produced in NL, standard module	97.3	2.7
Emissions, in water, ocean	Triethylene glycol	-		kg	1.08E+5	1	3.00	(1,2,1,1,1,3); Environmental report for 75% of gas produced in NL	100.0	0.0
	Methanol	-		kg	1.44E+5	1	3.00	(1,2,1,1,1,3); Environmental report for 75% of gas produced in NL	100.0	0.0
	Oils, unspecified	-		kg	2.60E+3	1	3.00	(1,2,1,1,1,3); Environmental report for 75% of gas produced in NL	26.8	73.2
	Lead	-		kg	1.08E+2	1	5.00	(1,2,1,1,1,3); Environmental report for 75% of gas produced in NL	26.8	73.2
	Cadmium, ion	-		kg	1.60E+0	1	5.00	(1,2,1,1,1,3); Environmental report for 75% of gas produced in NL	26.8	73.2
	Mercury	-		kg	4.00E-1	1	5.00	(1,2,1,1,1,3); Environmental report for 75% of gas produced in NL	26.8	73.2
	Radon-222	-		kBq	7.47E+5	1	3.15	(4,1,3,3,3,5); data calculated on the basis of gas composition	97.3	2.7
	Methane, chlorodifluoro-, HCFC-22	-		kg	1.14E+3	1	1.56	(1,2,1,1,3,3); Environmental report for 75% of gas produced in NL	97.3	2.7
	Methane, dichlorodifluoro-, CFC-12	-		kg	1.14E+1	1	1.56	(1,2,1,1,3,3); Environmental report for 75% of gas produced in NL	97.3	2.7
	Heat, waste	-		MJ	5.99E+8	1	1.22	(2,2,1,1,3,3); Environmental report for 75% of gas produced in NL, standard module	97.3	2.7
Emissions, in water, ocean	Triethylene glycol	-		kg	1.08E+5	1	3.00	(1,2,1,1,1,3); Environmental report for 75% of gas produced in NL	100.0	0.0
	Methanol	-		kg	1.44E+5	1	3.00	(1,2,1,1,1,3); Environmental report for 75% of gas produced in NL	100.0	0.0
	Oils, unspecified	-		kg	2.60E+3	1	3.00	(1,2,1,1,1,3); Environmental report for 75% of gas produced in NL	26.8	73.2
	Lead	-		kg	1.08E+2	1	5.00	(1,2,1,1,1,3); Environmental report for 75% of gas produced in NL	26.8	73.2
	Cadmium, ion	-		kg	1.60E+0	1	5.00	(1,2,1,1,1,3); Environmental report for 75% of gas produced in NL	26.8	73.2
	Mercury	-		kg	4.00E-1	1	5.00	(1,2,1,1,1,3); Environmental report for 75% of gas produced in NL	26.8	73.2
	Nickel, ion	-		kg	1.20E+1	1	5.00	(1,2,1,1,1,3); Environmental report for 75% of gas produced in NL	26.8	73.2
	Zinc, ion	-		kg	3.66E+2	1	5.00	(1,2,1,1,1,3); Environmental report for 75% of gas produced in NL	26.8	73.2
	BOD5, Biological Oxygen Demand	-		kg	3.81E+5	1	1.58	(3,na,na,3,1,5); Extrapolation for sum parameter	26.8	73.2
	COD, Chemical Oxygen Demand	-		kg	3.81E+5	1	1.58	(3,na,na,3,1,5); Extrapolation for sum parameter	26.8	73.2
	DOC, Dissolved Organic Carbon	-		kg	1.08E+5	1	1.58	(3,na,na,3,1,5); Extrapolation for sum parameter	26.8	73.2
	TOC, Total Organic Carbon	-		kg	1.08E+5	1	1.58	(3,na,na,3,1,5); Extrapolation for sum parameter	26.8	73.2
	AOX, Adsorbable Organic Halogen as Cl	-		kg	2.68E-2	1	1.58	(3,na,na,3,1,5); Extrapolation for sum parameter	26.8	73.2
	Nitrogen	-		kg	2.01E+0	1	1.58	(3,na,na,3,1,5); Extrapolation for sum parameter	26.8	73.2
	Sulfur	-		kg	6.96E+0	1	1.58	(3,na,na,3,1,5); Extrapolation for sum parameter	26.8	73.2
Outputs	natural gas, at production offshore	NL	0	Nm3	1.39E+10				100.0	0.0
	crude oil, at production offshore	NL	0	kg	3.19E+8				0.0	100.0

Tab. 6.27 Unit process raw data of „combined onshore gas and oil production“ (NL)

Explanations	Name	Location	InfrastructureProcess	Unit	combined onshore gas and oil production	UncertaintyType	StandardDeviation95%	GeneralComment	natural gas, at production onshore	crude oil, at production onshore
	Location				NL				NL	NL
	InfrastructureProcess				0				0.00	0.00
	Unit				a				Nm3	kg
Resources, in ground	Oil, crude, in ground	-	0	kg	6.47E+8	1	1.11	(1,2,1,1,1,3); Environmental report for 75% of gas produced in NL	0.00	100.00
	Gas, natural, in ground	-	0	Nm3	3.50E+10	1	1.11	(1,2,1,1,1,3); Environmental report for 75% of gas produced in NL	100.00	0.00
Resources, in water	Water, river	-	0	m3	5.25E+4	1	1.12	(2,2,1,1,1,3); Environmental report for 75% of gas produced in NL	97.85	2.15
Resources, in water	Water, salt, sole	-	0	m3	5.25E+4	1	1.12	(2,2,1,1,1,3); Environmental report for 75% of gas produced in NL	97.85	2.15
	Water, salt, ocean	-	0	m3	5.25E+4	1	1.12	(2,2,1,1,1,3); Environmental report for 75% of gas produced in NL	97.85	2.15
Technosphere	chemicals organic, at plant	GLO	0	kg	3.62E+4	1	1.11	(1,2,1,1,1,3); Environmental report for 75% of gas produced in NL	98.20	1.80
	chemicals inorganic, at plant	GLO	0	kg	4.80E+4	1	1.11	(1,2,1,1,1,3); Environmental report for 75% of gas produced in NL	97.85	2.15
	ethylene glycol, at plant	RER	0	kg	7.75E+5	1	1.11	(1,2,1,1,1,3); Environmental report for 75% of gas produced in NL	98.20	1.80
	methanol, at regional storage	CH	0	kg	1.25E+6	1	1.11	(1,2,1,1,1,3); Environmental report for 75% of gas produced in NL	98.20	1.80
	tap water, at user	RER	0	kg	5.25E+7	1	1.12	(2,2,1,1,1,3); Environmental report for 75% of gas produced in NL	97.85	2.15
	sweet gas, burned in gas turbine, production	NO	0	Nm3	1.61E+8	1	1.23	(1,2,1,1,3,3); Environmental report for 75% of gas produced in NL, standard module	97.85	2.15
	diesel, burned in diesel-electric generating set	GLO	0	MJ	2.86E+8	1	1.23	(1,2,1,1,3,3); Environmental report for 75% of gas produced in NL, standard module	97.85	2.15
	electricity, medium voltage, at grid	NL	0	kWh	4.17E+8	1	1.23	(1,2,1,1,3,3); Environmental report for 75% of gas produced in NL, standard module	97.85	2.15
	transport, lorry 32t	RER	0	tkm	2.10E+5	1	2.32	(5,1,1,3,3,5); estimates for waste transport	97.85	2.15
	transport, freight, rail	RER	0	tkm	1.51E+5	1	2.09	(4,5,na,na,na,na); standard distance	97.85	2.15
	well for exploration and production, onshore	GLO	1	m	4.29E+4	1	1.23	(1,2,1,1,3,3); Environmental report for 75% of gas produced in NL, standard module	97.85	2.15
	production plant crude oil, onshore	GLO	1	unit	8.93E-2	1	3.03	(3,4,1,3,1,3); Data for RU	0.00	100.00
	plant onshore, natural gas, production	GLO	1	unit	2.33E+1	1	3.25	(2,4,2,3,4,3); Environmental report for 75% of gas produced in NL, standard module	100.00	0.00
	disposal, used mineral oil, 10% water, to hazardous waste incineration	CH	0	kg	1.12E+6	1	1.23	(1,1,1,3,3,3); Norwegian environmental report	97.85	2.15
	disposal, municipal solid waste, 22.9% water, to sanitary landfill	CH	0	kg	9.96E+5	1	1.23	(1,1,1,3,3,3); Norwegian environmental report	97.85	2.15
	disposal, wood untreated, 20% water, to municipal incineration	CH	0	kg	2.17E+5	1	1.23	(1,1,1,3,3,3); Norwegian environmental report	97.85	2.15
	disposal, hazardous waste, 0% water, to underground deposit	DE	0	kg	1.35E+6	1	1.23	(1,1,1,3,3,3); Norwegian environmental report	97.85	2.15
	disposal, antifreezer liquid, 51.8% water, to hazardous waste incineration	CH	0	kg	3.05E+3	1	1.23	(1,1,1,3,3,3); Norwegian environmental report	97.85	2.15
	disposal, emulsion paint remains, 0% water, to hazardous waste incineration	CH	0	kg	1.34E+4	1	1.23	(1,1,1,3,3,3); Norwegian environmental report	97.85	2.15
	low active radioactive waste	CH	0	m3	1.29E+2	1	1.23	(1,1,1,3,3,3); Norwegian environmental report	0.00	100.00
Emissions, in air, low population density	Methane, fossil	-		kg	6.80E+6	1	1.51	(1,2,1,1,1,3); Environmental report for 75% of gas produced in NL	97.85	2.15
	Carbon dioxide, fossil	-		kg	6.35E+7	1	1.11	(1,2,1,1,1,3); Environmental report for 75% of gas produced in NL	97.85	2.15
	Carbon monoxide, fossil	-		kg	1.14E+6	1	1.11	(1,2,1,1,1,3); Environmental report for 75% of gas produced in NL	97.85	2.15
	Nitrogen oxides	-		kg	2.06E+4	1	1.51	(1,2,1,1,1,3); Environmental report for 75% of gas produced in NL	97.85	2.15
	Hydrocarbons, aliphatic, alkanes, unspecified	-		kg	1.60E+6	1	1.51	(1,2,1,1,1,3); Environmental report for 75% of gas produced in NL, reduced for combustion emissions	97.85	2.15
	Hydrocarbons, aromatic	-		kg	8.36E+5	1	1.51	(1,2,1,1,1,3); Environmental report for 75% of gas produced in NL, reduced for combustion emissions	97.85	2.15
	Sulfur dioxide	-		kg	3.89E+4	1	1.11	(1,2,1,1,1,3); Environmental report for 75% of gas produced in NL	97.85	2.15
	Mercury	-		kg	5.36E+0	1	1.51	(1,2,1,1,1,3); Environmental report for 75% of gas produced in NL	97.85	2.15
	Radon-222	-		kBq	1.87E+6	1	3.15	(4,1,3,3,3,5); data calculated on the basis of gas composition	97.85	2.15
	Methane, chlorodifluoro-, HCFC-22	-		kg	2.86E+3	1	1.56	(1,2,1,1,3,3); Environmental report for 75% of gas produced in NL	97.85	2.15
	Methane, dichlorodifluoro-, CFC-12	-		kg	2.86E+1	1	1.56	(1,2,1,1,3,3); Environmental report for 75% of gas produced in NL	97.85	2.15
	Heat, waste	-		MJ	1.50E+9	1	1.24	(2,2,1,1,3,3); Environmental report for 75% of gas produced in NL, standard module	97.85	2.15
Outputs	natural gas, at production onshore	NL	0	Nm3	3.50E+10				100.00	0.00
	crude oil, at production onshore	NL	0	kg	6.47E+8				0.00	100.00

6.3.7 Production in Germany

In Germany half of the natural gas is produced by BEB (11.3E+9 Nm^3 in 2000, 56.5 % of the production), owned to each 50 % by Shell and Esso. The remaining production is provided by Mobil Erdgas-Erdöl GmbH (21.3 %), RWE-DEA AG (11.5 %), Wintershall AG (4.3 %), Preussag Energie GmbH (3.1%) and EEG-Erdgas Erdöl GmbH (3.4%) (WEG 2001b).

Natural gas is produced mainly onshore, the first offshore field started operation in October 2000. With a production of 373 million m^3 it is amongst the biggest German natural gas fields. Since it is only 1 % of the production volume the offshore share is neglected for the German natural gas production. In this study mostly data from (BEB 2001) are used.

Infrastructure

The infrastructure is represented by the modules “Plant onshore, natural gas, production”. The specific demand is based on the amounts of natural gas produced (net calorific value).

Energy and material use

The BEB environmental report provides information about the water and energy use, as well as the air emissions of the natural gas production and processing, as well as the ancillary sulphur production (2001) (see Tab. 6.28). The data are provided per Nm^3 of natural gas produced. Due to lack of data no distinction is made between the emissions from flaring and from energy consumption.

Tab. 6.28 Energy and water use in the German natural gas and oil production (**BEB 2001**)

		2000	1999
CH_4 in flare	kg / Nm^3	2.00E-04	2.00E-04
Energy use [1)]	MJ / Nm^3	1.76E-01	1.76E-01
Water use [2)]	kg / Nm^3	8.00E-04	8.00E-04

[1)] Natural gas and electricity. In accordance with the RWE environmental report (2001) it is assumed that 20 of the used electricity are taken from the grid.

[2)] Produced water in closed cycle (reinjected)

According to (Fischer 2001) about 50 % of the natural gas produced by BEB is sour. The natural gas may contain up to 25 vol. % H_2S. The desulphurisation of the natural gas is modelled in the dataset“Sweetening, natural gas”.

Chemical use

No specific data was available with regard to the chemicals used in the German natural gas production. Therefore the specific consumption of glycol and methanol is quantified using information from the Dutch natural gas production (see Tab. 6.20).

Emissions to air

The air emission data provided in (BEB 2001) are not differentiated with regard to their source (flare, venting etc.). The total air emissions of the German natural gas production are shown in Tab. 6.29. The German production statistics (WEG 2001b) state, that about 0.13 vol. % (0.09-0.17 vol. %) of the raw gas is flared immediately after production. Tab. 6.29 shows the overall methane emissions given in (BEB 2001).

Tab. 6.29 Air emissions from the natural gas production (**BEB 2001**) per Nm^3 of natural gas produced

	2000	1999
	kg/Nm^3	kg/Nm^3
CH_4	2.64E-04	2.80E-04
CO_2	1.14E-02	9.71E-03
SO_2	1.00E-04	6.67E-05
NO_x	1.28E-05	1.60E-05
CO	8.00E-05	8.00E-05
nmVOC	1.80E-05	1.80E-05

The mercury and radon emissions shown in Tab. 6.30 are calculated based on the volumes of natural gas flared and vented and the natural gas composition.

Tab. 6.30 Volumes of natural gas vented and flared per Nm^3 natural gas produced, emission factors of mercury and radon-222 and total emissions for 2000 (calculated)

	Flaring and venting	Concentration	Emissions from flaring and venting
Natural gas	Nm^3 8.36E-04		
Hg		kg/Nm^3 2.00E-07	kg 1.67E-10
Rn		kBq/Nm^3 4.00E-01	kg 3.34E-04

1) calculated based on CH_4 emissions and CH_4 flared as well as on the CH_4 concentration in the German raw gas (see Tab. 3.4)

The waste heat from the flare is added to the waste heat from electricity use.

Emissions to water

The produced water is reinjected to the reservoir (BEB 2001). In line with the Dutch data it is assumed that the emissions to water are negligible for onshore production.

Waste

Amounts of wastes and their characteristics are modelled according to the data shown in Tab. 6.7.

Exploration and production wells

The amount of meters of well drilled is taken from the Annual Report 2010 of the German Oil and Gas Producer's Association (WEG 2011). In 2010 the drilling for exploration and production of natural gas amounted to 51’411 m. This corresponds to 4.05E-6 m per cubic metre of produced gas. The energy and material use associated with drilling wells is represented by the dataset “well for exploration and production, onshore”.

Summary of the unit process raw data

Tab. 6.31 shows the inventory data of “Natural gas, at production onshore” in Germany.

Data quality

The data of this dataset are mostly taken from the BEB environmental report for the year 2000 (BEB 2001) and describe about 57 % of the German natural gas production. They are considered to be of good quality. These data are complemented by well justifiable assumptions (e.g. composition of nmVOCs and assumptions regarding the infrastructure). The data used are specific for Germany and are representative for the technology used in Germany.

Tab. 6.31 Unit process raw data of “Natural gas, at production onshore” in Germany

Explanations	Name	Location	InfrastructureProcess	Unit	natural gas, at production onshore	UncertaintyType	StandardDeviation95%	GeneralComment
	Location				DE			
	InfrastructureProcess				0			
	Unit				Nm3			
	Gas, natural, in ground	-	0	Nm3	1.005E+00	1	1.06	(1,2,1,1,1,2); environmental report for 50% market share in Germany.
	ethylene glycol, at plant	RER	0	kg	2.23E-05	1	1.22	(1,2,1,3,3,3); Dutch environmental report
	methanol, at regional storage	CH	0	kg	3.57E-05	1	1.22	(1,2,1,3,3,3); Dutch environmental report
	electricity, medium voltage, at grid	DE	0	kWh	9.77E-03	1	1.08	(2,2,1,1,1,2); environmental report for 50% market share in Germany, standard energy type
	transport, lorry 32t	RER	0	tkm	1.10E-05	1	2.32	(5,1,1,3,3,5); estimates for waste transport
	transport, freight, rail	RER	0	tkm	3.48E-05	1	2.09	(4,5,na,na,na,na); standard distance
	well for exploration and production, onshore	GLO	1	m	2.02E-06	1	1.05	(1,1,1,1,1,1); environmental report for whole Germany
	sweetening, natural gas	DE	0	Nm3	5.00E-01	1	1.05	(1,2,1,1,1,1); environmental report for 50% market share in Germany, standard module for Germany
	plant onshore, natural gas, production	GLO	1	unit	6.67E-10	1	3.26	(2,4,2,3,4,4); environmental report for 50% market share in Germany, standard module
	disposal, used mineral oil, 10% water, to hazardous waste incineration	CH	0	kg	3.17E-05	1	1.22	(2,1,1,3,3,3); Norwegian environmental report
	disposal, municipal solid waste, 22.9% water, to sanitary landfill	CH	0	kg	2.82E-05	1	1.22	(2,1,1,3,3,3); Norwegian environmental report
	disposal, wood untreated, 20% water, to municipal incineration	CH	0	kg	6.14E-06	1	1.22	(2,1,1,3,3,3); Norwegian environmental report
	disposal, hazardous waste, 0% water, to underground deposit	DE	0	kg	3.82E-05	1	1.22	(2,1,1,3,3,3); Norwegian environmental report
	disposal, antifreezer liquid, 51.8% water, to hazardous waste incineration	CH	0	kg	8.64E-08	1	1.22	(2,1,1,3,3,3); Norwegian environmental report
	disposal, emulsion paint remains, 0% water, to hazardous waste incineration	CH	0	kg	3.81E-07	1	1.22	(2,1,1,3,3,3); Norwegian environmental report
Emissions, in air, low population density	Methane, fossil	-		kg	2.64E-04	1	1.50	(1,2,1,1,1,2); environmental report for 50% market share in Germany
	Ethane	-		kg	7.92E-06	1	1.51	(2,2,1,1,1,2); environmental report for 50% market share in Germany, standard break down of NMVOC in different types
	Propane	-		kg	7.20E-06	1	1.51	(2,2,1,1,1,2); environmental report for 50% market share in Germany, standard break down of NMVOC in different types
	Carbon dioxide, fossil	-		kg	1.14E-02	1	1.06	(1,2,1,1,1,2); environmental report for 50% market share in Germany
	Carbon monoxide, fossil	-		kg	8.00E-05	1	5.00	(1,2,1,1,1,2); environmental report for 50% market share in Germany
	NMVOC, non-methane volatile organic compounds, unspecified origin	-		kg	2.88E-06	1	2.00	(2,2,1,1,1,2); environmental report for 50% market share in Germany, standard break down of NMVOC in different types
	Nitrogen oxides	-		kg	1.28E-05	1	1.51	(2,2,1,1,1,2); environmental report for 50% market share in Germany
	Sulfur dioxide	-		kg	1.00E-04	1	1.06	(1,2,1,1,1,2); environmental report for 50% market share in Germany
	Mercury	-		kg	1.67E-10	1	1.69	(4,1,3,3,3,5); data calculated on the basis of losses and gas composition
	Radon-222	-		kBq	3.34E-04	1	3.15	(4,1,3,3,3,5); data calculated on the basis of losses and gas composition
	Heat, waste	-		MJ	8.26E-02	1	1.08	(2,2,1,1,1,2); environmental report for 50% market share in Germany, standard module
Outputs	natural gas, at production onshore	DE	0	Nm3	1.00E+00			

6.3.8 Production in Russia

The data of the Russian natural gas production process is derived mostly from annual reports and other information supplied by Russian oil and natural gas producers. Gazprom and Novatek are the largest natural gas producers in Russia, Rosneft and Lukoil are the two largest oil producers and have considerable production of associated petrol gas (APG). Together, these four companies cover more than 98 % of the Russian gas production volume (see Tab. 6.32). In 2010 the total hydrocarbon production in the Russian Federation amounted to 588.9 billion cubic meters of natural gas and 505.1 Mio t of oil (BP 2011). The share of associated natural gas of the total natural gas production is only 4% of the total production volume (calculation, see Tab. 6.32).

Twenty per cent of the Russian natural gas is classified as sour gas <Krewitt 1997>.

Tab. 6.32: Russian oil and natural gas production by the most important companies in 2010 (calculated)

		Gazprom	**Lukoil**		**Rosneft**	**Novatek**	**Total**	**This study**
		Mostly natural gas only	Combined Oil and natural gas	Natural gas only	Combined Oil and natural gas	Natural gas only		
Share of Russian natural gas production		86.4 %	1.0 %	2.3 %	2.1 %	6.4 %	98.2 %	
Crude oil production	Mio. t	32	90	0	116	0		
Natural gas production	bcm	508.6	5.8	13.6	12.3	37.8		
of which	**Natural gas production**	98.5 % 1)	0 %	100 %	0 %	100 %		**96 %**
	Combined oil and natural gas production	1.5 % 1)	100 %	0 %	100 %	0 %		**4 %**
Source		(Gazprom 2011)	(Lukoil 2011)	(Lukoil 2011)	(Rosneft 2011)	(Novatek 2011)		

1) Estimated

Infrastructure

The infrastructure is represented by the dataset "Plant onshore, natural gas, production". The specific demand is based on the amounts of natural gas produced (net calorific value).

Emissions to air

The most relevant sources for air emissions are flaring, venting, combustion from diesel engines and gas turbines as well as fugitive gases. Combustion from diesel engines and gas turbines are discussed in the subsection on energy and material use.

In Russia almost half of the Associated Petrol Gas (APG) is flared. For the year 2007 a World Bank study estimates that 45 % of the APG or 5 % of the total natural gas produced in Russia is flared (PFC 2007). For the year 2010 Rosneft, Russia's largest oil producer, reported an APG recovery rate of 52.6 %. This is lower than in the two previous years (63.2 and 67 % recovery, respectively, Rosneft 2011a). For this study an APG recovery rate of 55 % (45 % flared) is applied.

In Russia's national inventory reporting to the UNFCCC the volume of gas flared is reported to be 1.5 bcm for the year 2009, which equals 0.3 % of the natural gas production in Russia (UNFCCC 2011a). The flaring of APG is allocated to the oil and gas based on the net calorific value of the produced hydrocarbons. 72 % of the flared gas allocated to the produced natural gas stems from natural gas production and 28 % from combined oil and gas production.

Further information concerning air emissions was found in various sources. . Overall methane emissions of all Gazprom activities are 0.1 % of the produced natural gas volume and leakages during extraction and production amount to 0.02 % (Akopova 2010). In the Gazprom environmental report data is available for 2010. Some of the data are however difficult to assign to only the natural gas processes since Gazprom is also involved in other business activities such as energy production and water supply. Novatek provides some data in its sustainability report (Novatek 2010).

Tab. 6.33 sives an overview on the available data about air emissions and the data used in this study. To avoid double counting, emissions covered by other datasets (flaring, natural gas burned in turbines, natural gas drying, sweetening and diesel burned in engine) were deduced where applicable.

Tab. 6.33: Air Emissions of the Russian natural gas extraction, processing and storage per m^3 natural gas produced

		Gazprom			Novatek	Russian GHG Inventory [4]	Total air emissions covered in other modules	**This study**
		Environmental Report [1]	Emissions from gas extraction and processing w/o leakage [2]	Leakage in gas extraction and processing [2]	Sustainability Report [3]			Additional emissions for process gas, prod RU
Methane	kg	2.62E-04	5.88E-04	1.18E-04	1.56E-05	**3.6E-03**	**2.9E-05**	**3.60E-03**
Ethane	kg		5.40E-05	1.08E-05		**3.3E-04**		**3.33E-04**
Propane	kg		2.00E-05	4.00E-06		**1.2E-04**		**1.23E-04**
Carbon monoxide	kg	**4.34E-04**			2.34E-04		**1.1E-04**	**3.22E-04**
Carbon dioxide	kg		3.60E-05	**7.20E-06**		2.22E-04	8.1E-02	**7.20E-06**
nmVOC	kg		4.00E-05	**8.00E-06**		3.77E-04	8.7E-04	**8.00E-06**
Sulphur dioxide	kg	1.46E-04			7.32E-08	7.16E-04	1.1E-03	
Hydrogen sulphide	kg		1.80E-05	**3.60E-06**		1.11E-04		**1.11E-04**
Nitrogen oxides	kg	5.97E-05			5.29E-05	7.2E-04	9.9E-05	**6.17E-04**
Mercury [5]	kg		2.00E-10	4.00E-11		1.23E-09	1.6E-09	
Radon-222 [5]	kBq		4.00E-04	8.00E-05		2.47E-03	3.2E-03	

[1] (Gazprom 2011), reference year 2010; includes emissions from production, processing and underground storage.

[2] Methane emission factors from (Akopova 2010), 2005-2008 data. Other emissions calculated based on Russian raw gas composition.

[3] (Novatek 2010), data from 2008-2009.

[4] (UNFCCC 2011a), reference year 2009

[5] Standard factors for mercury and radon-222 (see Tab. 3.4)

Energy and material use

The specific amounts of natural gas burned in turbines and of diesel consumed during natural gas production are calculated based on information in the Novatek Annual Review (Novatek 2011). The natural gas burned in turbines amounts to 0.5 % of the natural gas production. 0.02 MJ of diesel are burned in generators per Nm^3 of natural gas produced.

The water use in 2010 was 22 mg per m^3 natural gas produced. This is modelled with “tap water, at user” (RER) (Novatek 2010).

Exploration and production drilling

All of Russia’s largest gas and oil producers report about their exploration and production drilling activities. They are shown in Tab. 6.34. The drilling meters are allocated to the natural gas and oil produced according to the net calorific value. The value used in this study is a weighted average, based on the relative market share of the producers.

Tab. 6.34 Exploration and production drilling in 2010 (Gazprom 2011; Lukoil 2011; Rosneft 2011b) **(grey: calculated values)**

		Gazprom Mostly natural gas production 1)	Lukoil Combined oil and natural gas 2)	Natural gas production	Rosneft Combined oil and natural gas 3)	This study
Natural gas market share (RUS)		86.4%	1.0%	2.3%	2.1%	100.0%
Share of Russian crude oil production		6.3%	17.8%	0.0%	22.9%	
Exploration drilling	km		102			
	wells	18	28			
Production drilling	km		2286		2726	
	wells	64	901	3	837	
Drilling total	km	204.9	2388	8	2726	
	wells	82	929	3	837	
Well length	m/well	2499	2571	2571	3257	**2519**
NG production	bcm	509	6	14	12	
Crude oil production	Mio. t	32	90	0	116	
Meters of well drilled per m^3 natural gas produced	**m/m^3**	**3.7E-07**	**2.1E-05**	**5.7E-07**	**1.8E-05**	**1.01E-06**
Meters of well drilled per kg crude oil produced	m/kg	4.5E-07	2.5E-05	0.0E+00	2.2E-05	

1) Source: (Gazprom 2011)
2) Source: (Lukoil 2011)
3) Source: (Rosneft 2011b)

Processing

It is assumed that all produced gas is dried. The chemical use is included in the dataset “drying, natural gas“. 20 % of the natural gas produced in Russia is considered to be sour gas <Krewitt 1997>. The sweetening process is modelled with the dataset “sweetening, natural gas”.

Emissions to water

The discharge of produced water is modelled using standard values. A differentiation is made for natural gas production and combined oil and gas production (see Tab. 6.35 and Tab. 6.36).

Specifications about the incurred produced water are displayed in Tab. 6.35. There is a strong variability in the data and thus there are considerable uncertainties.

The amount of produced water varies considerably from natural gas production and combined oil and natural gas production. In the combined production the water is polluted with crude oil and various hydrocarboncompounds. Before the water can be discharged to surface water bodies it is cleaned by means of a strainer. A thorough discussion of the composition of produced water can be found in (Jungbluth 2003, Kap. 7.7).

Tab. 6.35 Amounts of produced water from natural gas production

Region	l/m³ produced natural gas	Source
Northern Germany	0.001 - 1	<Fürer 1991>
Northern Germany	0.0008	(BEB 2001)
Norway	0.0012 [1)]	<Statoil 1992>, <BP 1992> for production volumes
Norway	0.0051 [1)]	(OLF 2001)
Norway	0.0131 [1)]	(OLF 2011)
Netherlands	0.003 [1)]	(NAM 2001)
Amount from natural gas production	**0.001**	**This study (assumption)**
Amount from combined oil and natural gas production	**0.003**	**This study (assumption)**

[1)] For the allocation on produced oil and natural gas it is assumed that the production of crude oil produces 100 times more water (per net calorific value) than the production of natural gas. The increase of the produced water in Norway from 1992 until 2010 is probably due to the increased age of the natural gas fields.

The emissions of water pollutants with discharged produced water are modelled with the dataset "discharge, produced water, onshore" (Jungbluth 2003, Tab. 7.32, Modul „discharge, produced water, onshore"). The composition of produced water is based on information provided by the US Environmental Protection Agency <EPA 1987>. The data is shown in Tab. 6.36.

Tab. 6.36 Emissions from produced water in natural gas production in the United States <EPA 1987>, kg per liter produced water discharged

		Data for the USA
Benzene in water	kg/l	4.7 E-07
Chloride	kg/l	7.3 E-03
Arsenic Ion	kg/l	2.0 E-08

Waste

Gazprom and Novatek provide some data on waste (Gazprom 2011, Novatek 2010). The amount of waste generated per cubic meter of natural gas produced is considerably higher for Gazprom (6.19E-4 kg/m^3 in 2010) than for Novatek (7.71E-7 kg/m^3 in 2008/2009). While Novatek claims to use 50 % of its waste at their facilities (e.g. reinjection and recycling) this doesn't account for the whole difference. 90 % of the waste amounts reported by Novatek are low-hazardous, 0.03 % high-hazardous and 10 % other waste. While it is not stated specifically, it can be assumed that (at least) the drilling wastes are excluded in the amounts reported by Novatek.

For this study the specific amounts of waste reported by Gazprom are used (392 thousand tons resp. 7.71E-04 kg per m^3 natural gas produced). The drilling wastes as considered in the dataset "Well for exploration and production" (1.5E-4 kg/m^3 natural gas produced) are deducted from the value provided by Gazprom, resulting in 6.19E-4 kg per m^3 natural gas produced. It is assumed that 10 % of the waste is hazardous waste, which is the share of hazardous waste on total Norwegian production waste. A transport distance of 100 km to the disposal site is assumed.

Summary of the unit process raw data

Tab. 6.37 shows the inventory data of "Natural gas, at production onshore" in Russia.

Data quality

The data about production and processing of natural gas in Russia are mostly based on information provided by Russian natural gas producers. The data are specific for the region and the technology used. Since there are only very limited official data available a basic uncertainty remains.

Tab. 6.37 Unit process raw data of „Natural gas, at production onshore“ (RU)

	Name	Location	Infrastru	Unit	natural gas, at production onshore	UncertaintyType	StandardDeviation95%	GeneralComment
	Location				RU			
	InfrastructureProcess				0			
	Unit				Nm3			
	natural gas, at production onshore	RU	0	Nm3	1			
technosphere	sour gas, burned in gas turbine, production	NO	0	Nm3	1.36E-3	1	1.05	(1,1,1,1,1,1,BU:1.05); ; Novatek 2011
	sweet gas, burned in gas turbine, production	NO	0	Nm3	4.01E-3	1	1.05	(1,1,1,1,1,1,BU:1.05); ; Novatek 2011
	natural gas, sweet, burned in production flare	GLO	0	Nm3		1	1.05	(1,1,1,1,1,1,BU:1.05); Official statistics and literature, partly for RU.; MATET 2010; PFC 2007
	natural gas, sweet, burned in production flare	GLO	0	Nm3	2.06E-3	1	1.05	(1,1,1,1,1,1,BU:1.05); Official statistics and literature.; UNFCC 2011; PFC 2007
	natural gas, sour, burned in production flare	GLO	0	Nm3	5.15E-4	1	1.05	(1,1,1,1,1,1,BU:1.05); ;
	diesel, burned in diesel-electric generating set	GLO	0	MJ	2.11E-2	1	1.05	(1,2,1,1,1,1,BU:1.05); ; Novatek 2011
	well for exploration and production, onshore	GLO	1	m	1.01E-6	1	3.10	(2,3,1,1,3,5,BU:3); Data from NG and combined Oil and NG producers with
	drying, natural gas	NO	0	Nm3	1.00E+0	1	1.24	(2,4,1,1,1,5,BU:1.05); ;
	sweetening, natural gas	DE	0	Nm3	2.00E-1	1	1.24	(2,4,1,1,1,5,BU:1.05); ;
	plant onshore, natural gas, production	GLO	1	unit	3.21E-11	1	3.10	(2,3,1,1,3,5,BU:3); ;
	Waste, non-hazardous, from combined oil and gas production, offshore	NO	0	kg	5.57E-4	1	1.31	(2,3,1,1,3,5,BU:1.05); From Russian gas producer with 6% market share
	Hazardous waste, from combined oil and gas production, offshore	NO	0	kg	6.19E-5	1	1.31	(2,3,1,1,3,5,BU:1.05); From Russian gas producer with 6% market share
	transport, lorry >16t, fleet average	RER	0	tkm	6.19E-2	1	2.06	(2,4,1,1,1,5,BU:2); Assumption: 100 km to disposal site;
	discharge, produced water, onshore	GLO	0	kg	1.09E-3	1	1.24	(2,4,1,1,1,5,BU:1.05); From combined production 0.003 l/m3 natural gas produced, from mere natural gas production 0.001 l/m3.; NAM 2001, BEB 2001, other
	tap water, at user	RER	0	kg	2.17E-5	1	1.31	(2,3,1,1,3,5,BU:1.05); From Russian gas producer with 6% market share
resource, in ground	Gas, natural, in ground	-	-	Nm3	1.00E+0	1	1.31	(2,3,1,1,3,5,BU:1.05); ;
emission air, low population density	Methane, fossil	-	-	kg	3.60E-3	1	1.62	(2,3,1,1,3,5,BU:1.5); Calculations based on raw gas composition,
	Ethane	-	-	kg	3.33E-4	1	1.62	(2,3,1,1,3,5,BU:1.5); Calculations based on raw gas composition,
	Propane	-	-	kg	1.23E-4	1	1.62	(2,3,1,1,3,5,BU:1.5); Calculations based on raw gas composition,
	Butane	-	-	kg		1	1.62	(2,3,1,1,3,5,BU:1.5); Calculations based on raw gas composition,
	Carbon dioxide, fossil	-	-	kg	7.20E-6	1	1.31	(2,3,1,1,3,5,BU:1.05); Calculations based on raw gas composition,
	NMVOC, non-methane volatile organic compounds, unspecified origin	-	-	kg	8.00E-6	1	1.62	(2,3,1,1,3,5,BU:1.5); Calculations based on raw gas composition,
	Hydrogen sulfide	-	-	kg	1.11E-4	1	1.62	(2,3,1,1,3,5,BU:1.5); Calculations based on raw gas composition,
	Mercury	-	-	kg	4.00E-11	1	5.11	(2,3,1,1,3,5,BU:5); Calculations based on raw gas composition, industry
	Radon-222	-	-	kBq	8.00E-5	1	3.10	(2,3,1,1,3,5,BU:3); Calculations based on raw gas composition, industry
	Methane, fossil	-	-	kg		1	1.62	(2,3,1,1,3,5,BU:1.5); Literature. Calculations based on raw gas
	Ethane	-	-	kg		1	1.62	(2,3,1,1,3,5,BU:1.5); Literature. Calculations based on raw gas
	Propane	-	-	kg		1	1.62	(2,3,1,1,3,5,BU:1.5); Literature. Calculations based on raw gas
	Butane	-	-	kg		1	1.62	(2,3,1,1,3,5,BU:1.5); Literature. Calculations based on raw gas
	Carbon dioxide, fossil	-	-	kg		1	1.31	(2,3,1,1,3,5,BU:1.05); Literature. Calculations based on raw gas
	NMVOC, non-methane volatile organic compounds, unspecified origin	-	-	kg		1	1.62	(2,3,1,1,3,5,BU:1.5); Literature. Calculations based on raw gas
	Hydrogen sulfide	-	-	kg		1	1.62	(2,3,1,1,3,5,BU:1.5); Literature. Calculations based on raw gas
	Mercury	-	-	kg		1	5.11	(2,3,1,1,3,5,BU:5); Literature. Calculations based on raw gas
	Radon-222	-	-	kBq		1	3.10	(2,3,1,1,3,5,BU:3); Literature. Calculations based on raw gas
emission water, river	Benzene	-	-	kg	5.12E-10	1	3.10	(2,3,1,1,3,5,BU:3); Based on US Data; EPA 1987
	Chloride	-	-	kg	7.95E-6	1	3.10	(2,3,1,1,3,5,BU:3); Based on US Data; EPA 1987
	Arsenic, ion	-	-	kg	2.18E-11	1	5.11	(2,3,1,1,3,5,BU:5); Based on US Data; EPA 1987

6.3.1 Production in Northern Africa

In 2010 the largest share of natural gas exported from Northern African Countries (NAC) to Europe was from Algeria (about 78 %) with shares from Libya (15 %) and Egypt (7 %).

For the Northern African countries just few specific data are available. As most of the natural gas is produced from natural gas fields (about 96 %) and not from combined oil and gas production, the production situation is similar to that of the Russian Federation. Therefore, unless specified otherwise, the Russian data are used to model North African natural gas production. The Algerian natural gas is classified as sweet gas.

Emissions to air

In the Second National Communication of Algeria on Climate Change to the hands of the UNFCCC the flaring from combined oil and gas production are given for the year 2000 (MATET 2010). However, there are no numbers available on the flaring from mere natural gas production which makes up the larger part of the flaring in the case of Russia (about 72 %).

In 2000 a total of 1.2 bcm associated gas were flared in Algeria (MATET 2010). It was assumed that the APG recovery rate is 55 % like in Russia (PFC 2007) and thus 1.3 bcm of the produced natural gas are APG.

The emissions from APG flaring are attributed to the produced oil and the produced APG based on the energy content (net calorific value). For the flaring in natural gas production the factor of Russian natural gas production is used (0.2 %). The total share of flaring per unit of natural gas produced is therefore 0.27 %.

The amount of gas burned in turbines per natural gas produced is approximated with the specific demand of the Russian natural gas production. It is represented by the dataset "sweet gas, burned in gas turbine, production".

Emissions from fugitive gases and venting in the Algerian natural gas production are reported for the year 2000 (MATET 2010). Fugitive gases and venting make up 1.8 % relative to the total amount of natural gas produced. The emissions are calculated based on the raw gas composition (see Table 3.4).

Summary of the unit process raw data

Tab. 6.38 shows the inventory data of „natural gas, at production onshore" in Northern Africa.

Data quality

The data for production and processing of natural gas in Northern Africa are mostly based on Russian data. Therefore there are considerable uncertainties.

6.3.1 Production in the Middle East

Due to lack of specific data the natural gas production in the Region Middle East is modelled with data representing natural gas production in Northern Africa. It is assumed that these two regions have a similar technology standard. Since oil and gas are mostly produced offshore in the Middle East, using North African data (where the production takes place onshore) is a rough approximation.

Tab. 6.38 Unit process raw data of “Natural gas, at production onshore” in Northern Africa (NAC) and the Middle East (RME)

	Name	Location	Infrastru	Unit	natural gas, at production onshore	natural gas, at production	UncertaintyType	StandardDeviation95%	GeneralComment
	Location				NAC	RME			
	InfrastructureProcess				0	0			
	Unit				Nm3	Nm3			
	natural gas, at production onshore	NAC	0	Nm3	1	0			
	natural gas, at production	RM		Nn	0	1			
	sweet gas, burned in gas turbine, production	NO	0	Nm3	5.37E-3	5.37E-3	1	1.05	(1,1,1,1,1,1,BU:1.05); ; Novatek 2011
	natural gas, sweet, burned in production flare	GLO	0	Nm3	2.12E-3	2.12E-3	1	1.05	(1,1,1,1,1,1,BU:1.05); Official statistics and literature, partly for RU.; MATET 2010; PFC 2007
	diesel, burned in diesel-electric generating set	GLO	0	MJ	2.11E-2	2.11E-2	1	1.05	(1,2,1,1,1,1,BU:1.05); ; Novatek 2011
	well for exploration and production, onshore	GLO	1	m	1.01E-6	1.01E-6	1	3.10	(2,3,1,1,3,5,BU:3); Data from NG and combined Oil and NG producers with 91%
	drying, natural gas	NO	0	Nm3	1.00E+0	1.00E+0	1	1.24	(2,4,1,1,1,5,BU:1.05); ;
	plant onshore, natural gas, production	GLO	1	unit	3.21E-11	3.21E-11	1	3.10	(2,3,1,1,3,5,BU:3); ;
	Waste, non-hazardous, from combined oil and gas production, offshore	NO	0	kg	5.57E-4	5.57E-4	1	1.31	(2,3,1,1,3,5,BU:1.05); From Russian gas producer with 6% market share (Novatek
	Hazardous waste, from combined oil and gas production, offshore	NO	0	kg	6.19E-5	6.19E-5	1	1.31	(2,3,1,1,3,5,BU:1.05); From Russian gas producer with 6% market share (Novatek
	transport, lorry >16t, fleet average	RER	0	tkm	6.19E-2	6.19E-2	1	2.06	(2,4,1,1,1,5,BU:2); Assumption: 100 km to disposal site;
	discharge, produced water, onshore	GLO	0	kg	1.03E-3	1.03E-3	1	1.24	(2,4,1,1,1,5,BU:1.05); From combined production 0.003 l/m3 natural gas produced, from mere natural gas production 0.001 l/m3.; NAM 2001, BEB 2001, other
	tap water, at user	RER	0	kg	2.17E-5	2.17E-5	1	1.31	(2,3,1,1,3,5,BU:1.05); From Russian gas producer with 6% market share (Novatek
resource, in ground	Gas, natural, in ground	-	-	Nm3	1.00E+0	1.00E+0	1	1.31	(2,3,1,1,3,5,BU:1.05); ;
	Methane, fossil	-	-	kg	5.74E-3	5.74E-3	1	1.62	(2,3,1,1,3,5,BU:1.5); Literature. Calculations based on raw gas composition.; MATET
	Ethane	-	-	kg	3.76E-4	3.76E-4	1	1.62	(2,3,1,1,3,5,BU:1.5); Literature. Calculations based on raw gas composition.; MATET
	Propane	-	-	kg	0	0	1	1.62	(2,3,1,1,3,5,BU:1.5); Literature. Calculations based on raw gas composition.; MATET
	Butane	-	-	kg	2.48E-4	2.48E-4	1	1.62	(2,3,1,1,3,5,BU:1.5); Literature. Calculations based on raw gas composition.; MATET
	Carbon dioxide, fossil	-	-	kg	1.88E-4	1.88E-4	1	1.31	(2,3,1,1,3,5,BU:1.05); Literature. Calculations based on raw gas
	NMVOC, non-methane volatile organic compounds, unspecified origin	-	-	kg	3.76E-4	3.76E-4	1	1.62	(2,3,1,1,3,5,BU:1.5); Literature. Calculations based on raw gas composition.; MATET
	Hydrogen sulfide	-	-	kg	0	0	1	1.62	(2,3,1,1,3,5,BU:1.5); Literature. Calculations based on raw gas composition.; MATET
	Mercury	-	-	kg	1.88E-9	1.88E-9	1	5.11	(2,3,1,1,3,5,BU:5); Literature. Calculations based on raw gas composition.; MATET
	Radon-222	-	-	kBq	3.76E-3	3.76E-3	1	3.10	(2,3,1,1,3,5,BU:3); Literature. Calculations based on raw gas composition.; MATET
emission water, river	Benzene	-	-	kg	4.86E-10	4.86E-10	1	3.10	(2,3,1,1,3,5,BU:3); Based on US Data; EPA 1987
	Chloride	-	-	kg	7.54E-6	7.54E-6	1	3.10	(2,3,1,1,3,5,BU:3); Based on US Data; EPA 1987
	Arsenic, ion	-	-	kg	2.07E-11	2.07E-11	1	5.11	(2,3,1,1,3,5,BU:5); Based on US Data; EPA 1987

6.3.2 Production in the United Kingdom

The inventory of natural gas production in the United Kingdom is represented by the dataset „Natural gas, at production offshore“.This dataset is documented in (Jungbluth 2003, Kap. 7) and is not repeated here.

6.3.3 Production in Nigeria

The natural gas production in Nigeria is documented in the the section on Oil in the corresponding ecoinvent report (Jungbluth 2004).

6.3.4 Gas turbines in the production

The emission factors of gas turbines used in natural gas production are shown in Tab. 6.39. The values are mainly based on data from the Norwegian Continental Shelf. The data consist of average weighted emissions from gas turbines (97 % of the gas used on the NCS), gas boilers and gas motors (remaining 3 %) (OLF 2001). This mix is used in this study.

“Sour” raw gas with roughly 6 vol. % H_2S leads to elevated SO_2 emissions. It is assumed that the hydrogen sulphide content is reduced to 3 vol. % by cleaning measures on the field (most often pressure relief). The European supply mix contains about 5 % (originally) sour gas (see Tab. 6.5 and Tab. 6.1).

Tab. 6.39 summarises the available data about air emissions from gas turbines in natural gas production. Data from (OLF 2001) for Norway are used in the datasets “Sweet gas, burned in gas turbine, production" and "Sour gas, burned in gas turbine, production". They are supplemented with data from the natural gas composition prior to processing (last row in Tab. 6.39).

Tab. 6.39 Air emissions of gas turbines in the production, sweet and sour gas. Values used in this study are bold.; n.a.: not available

Fuel →		Natural gas at consumer	Combined production	Produced natural gas mix	Natural gas prior to processing	
				Norway	Sour gas	Sweet gas
Output class	MW	10	n.a.			
Source		(Frischknecht et al. 1996), Anhang 1-Erdgas	(Frischknecht et al. 1996), Tab. IV.7.43	(OLF 2001) 2)	Tab. 3.4 and columns left	(Frischknecht et al. 1996: Tab. V.3.3)
		m^3	m^3	m^3	m^3	m^3
SO_2	kg	n.a.	0	0	**9E-02**	0
NO_X		4.7E-03	7E-03	**7.2E-03**	n.a.	n.a.
N_2O					**1 E-5** 3)	**1 E-5** 3)
Particles		0	0	n.a.	n.a.	n.a.
CO		1.4E-03	1E-02	n.a.	**0.005** 3)	**0.005** 3)
CH_4		2E-04	4E-04	**8.9E-04**	n.a.	n.a.
NMVOC		4E-04	2E-04	**1.1E-04**	n.a.	n.a.
N_2O		**1E-05**	5E-05	n.a.	n.a.	n.a.
CO_2		**1.98**	2.14	2.45	1.98	1.98
Mercury		n.a.		n.a.	**1.0E-07** 1)	**1.0E-07** 1)
Radon-222	kBq	n.a.		n.a.	**0.2** 1)	**0.2** 1)
Waste heat	MJ	27		n.a.		

1) Conditioning of the natural gas in the field. Assumption: reduction of the emission factor by 50 %.

2) Average 1999-2000.

3) Assumption with data about gas turbine emissions(Frischknecht et al. 1996)

The infrastructure demand is modelled with the manufacture of a 10 MW turbine. It is assumed that the turbine has a service lifetime of 15 years and is operated 5'500 hours per year.

Summary of the unit process raw data

The following tables (Tab. 6.40 und Tab. 6.41) show the inventory data of the gas turbines.

Data quality

The emission data are based on an environmental report covering all of the Norwegian offshore production. The data are supplemented with older values and assumptions, which are based on the natural gas composition.

Tab. 6.40 Unit process raw data of "Sweet gas, burned in gas turbine, production"

Explanations	Name	Location	InfrastructureProcess	Unit	*sweet gas, burned in gas turbine, production*	UncertaintyType	StandardDeviation95%	GeneralComment
	Location				*NO*			
	InfrastructureProcess				*0*			
	Unit				*MJ*			
Technosphere	Gas, natural, in ground	-	0	Nm3	2.78E-02	1	1.07	(1,1,1,1,1,3); environmental report for Norway
	gas turbine, 10MWe, at production plant	RER	1	unit	3.37E-10	1	1.22	(1,1,1,1,3,3); environmental report for Norway
Emissions, in air, low population density	Methane, fossil	-		kg	2.43E-05	1	1.50	(1,1,1,1,1,3); environmental report for Norway
	Carbon dioxide, fossil	-		kg	6.69E-02	1	1.07	(1,1,1,1,1,3); environmental report for Norway
	Carbon monoxide, fossil	-		kg	1.39E-04	1	5.00	(1,1,1,1,1,3); environmental report for Norway
	NMVOC, non-methane volatile organic compounds, unspecified origin	-		kg	3.07E-06	1	2.00	(1,1,1,1,1,3); environmental report for Norway
	Nitrogen oxides	-		kg	1.99E-04	1	1.50	(1,1,1,1,1,3); environmental report for Norway
	Dinitrogen monoxide	-		kg	2.50E-07	1	1.52	(3,1,2,2,1,3); based on assumptions
	Mercury	-		kg	2.78E-09	1	1.52	(3,1,2,2,1,3); based on assumptions
	Radon-222	-		kBq	5.56E-03	1	3.02	(3,1,2,2,1,3); based on assumptions
	Heat, waste	-		MJ	1.11E+00	1	1.09	(2,1,1,1,1,3); environmental report for Norway
Outputs	sweet gas, burned in gas turbine, production	NO	0	MJ	1.00E+00			

Tab. 6.41 Unit process raw data of „Sour gas, burned in gas turbine, production"

Explanations	Name	Location	InfrastructureProcess	Unit	*sour gas, burned in gas turbine, production*	UncertaintyType	StandardDeviation95%	GeneralComment
	Location				*NO*			
	InfrastructureProcess				*0*			
	Unit				*MJ*			
Technosphere	Gas, natural, in ground	-	0	Nm3	2.78E-02	1	1.07	(1,1,1,1,1,3); environmental report for Norway
	gas turbine, 10MWe, at production plant	RER	1	unit	3.37E-10	1	1.22	(1,1,1,1,3,3); environmental report for Norway
Emissions, in air, low population density	Methane, fossil	-		kg	2.43E-05	1	1.50	(1,1,1,1,1,3); environmental report for Norway
	Carbon dioxide, fossil	-		kg	6.69E-02	1	1.07	(1,1,1,1,1,3); environmental report for Norway
	Carbon monoxide, fossil	-		kg	1.39E-04	1	5.00	(1,1,1,1,1,3); environmental report for Norway
	NMVOC, non-methane volatile organic compounds, unspecified origin	-		kg	3.07E-06	1	2.02	(1,1,3,1,1,3); environmental report for Norway
	Nitrogen oxides	-		kg	1.99E-04	1	1.50	(1,1,1,1,1,3); environmental report for Norway
	Dinitrogen monoxide	-		kg	2.50E-07	1	1.52	(3,1,2,2,1,3); based on assumptions
	Sulfur dioxide	-		kg	4.86E-03	1	1.12	(3,1,1,1,1,3); calculated
	Mercury	-		kg	2.78E-09	1	1.52	(3,1,2,2,1,3); based on assumptions
	Radon-222	-		kBq	5.56E-03	1	3.02	(3,1,2,2,1,3); based on assumptions
	Heat, waste	-		MJ	1.11E+00	1	1.09	(2,1,1,1,1,3); environmental report for Norway
Outputs	sour gas, burned in gas turbine, production	NO	0	MJ	1.00E+00			

6.3.5 Natural gas drying

Natural gas drying (dataset „Drying, natural gas") is modelled mainly based on information about emissions and resource use at the Norwegian processing plants in Kollsnes und Kårstø (Statoil 2001a). These plants treat roughly 60 % of the Norwegian natural gas.

Kårstø started operation in 1985, Kollsnes in 1996. In Kollsnes the raw gas from the Troll platforms is treated which contains fewer higher hydrocarbons and is relatively dry. In Kårstø raw gas of other fields with higher contents of higher hydrocarbons is treated. In 2000 a total of 2.95E+07 Nm^3 o.e. natural gas, 4.99 E+06 Nm^3 o.e. condensates and 2.82 E+11 MJ other gases were treated in these two facilities (1.52E+12 MJ[10] in total). This corresponds to 4.2E+10 Nm^3 natural gas (basis for calculation: 36 MJ/Nm^3).

The energy use of the processing is mainly due to the distillation. In this process the raw gas is heated up and distilled into the various components. The emissions of the flaring and the combustion of energy carriers are included in the inventory data but are not declared separately due to lack of detailed information.

Infrastructure

The infrastructure needs are modelled with the dataset„Production plant, natural gas". The amount of production plant needed per Nm^3 natural gas dried is calculated based on the annual production volume (quantified in net calorific values) and the life time of the plant.

Auxiliary materials

The used auxiliary materials can be distinguished as: <Hudgins 1991>

- Inhibitors to the formation of hydrates
- Adsorption agents for drying
- Adsorption agents for desulphurisation
- Sometimes as well corrosion inhibitors

The formation of hydrates (water crystals) is feared in gas industry. Especially in processing facilities with excessive drops in pressure it can happen that the temperature falls below the dew point. In this case inhibitors are added to the natural gas, especially methanol and in some cases also ethylene glycol. According to <Hudgins 1991> the separated water needs to contain 10 to 50 % methanol by weight in order to avoid the formation of hydrates. A further treatment is only considered when large amounts of water (moist natural gas) incur.

The most commonly used adsorption agent for drying is triethyl glycol. It is used in a closed adsorption/desorption process. A small part of the glycol can be dragged along by the natural gas and is later found in the condensate of the collecting lines of the facility; typically between 0.01 and 0.04 ml/m^3 produced natural gas according to <Hudgins 1991>. The values used in this study are based on (Statoil 2001a) and are summarised in Tab. 6.42.

Tab. 6.42: Chemical use at the processing plants Kollsnes and Kårstø in 2000 (**Statoil 2001a**)

		Total / year	Per m^3 natural gas	Remark
Monoethylene glycol	kg	7.70E+04	1.82E-06	
Other chemicals	kg	2.24E+05	5.30E-06	50 % as organic, 50 % as inorganic chemicals (assumption)
acid/caustic soda	kg	8.90E+04	2.11E-06	

Emissions to air

Data on air emissions are taken from (Statoil 2001a).

10 Basis for the conversion: 1 Nm^3 o.e. = 0.84 t o.e., 1 t o.e. = 42'300 MJ.

Emissions to water

There is only little information available about waste water and wastes from natural gas processing. According to <Sostek 1984> the processing of natural gas produces roughly 0.07 l slightly toxic and 0.001 l highly toxic waste water per m^3 processed natural gas.

According to <Statoil 1992b> their own processing plants in the North Sea produce about 22 l slightly polluted waste water (cooling and cleaning water with TOC 51 mg/l) and 0.02 mg highly toxic waste per m^3 produced natural gas. The sum parameters BSB_5, CSB, DOC and TOC are calculated with the elementary composition of the discharged hydrocarbons.

Studies by <Kumar 1987> and <Speight 1990> show that the water content of raw gas is 0 to 30 g/m^3. Moist and dry natural gases typically have a water content of 6 to 8 g/m^3 and 0 to 1 g/m^3, respectively. In pipeline specifications the threshold limit is set at 0.1 g/m^3.

The natural gas is conditioned to a moisture content of 1 g/ m^3 by separating free water in the field before entering the natural gas processing plant (see Subchapter 6.3). Hence, at gas processing plants roughly 0.9 g water is produced per m^3 produced natural gas to comply with the pipeline threshold limit of 0.1 g/m^3.

Data of the total water emissions (TOC, glycol, methanol, phenol, oil, ammonium) per year are available in (Statoil 2001a) for the plants Kollsnes and Kårstø. These values are normed to the annual production and used in this study. The emissions of BOD, COD und DOC are calculated theoretically based on the emission of hydrocarbons to water.

Waste

Norwegian data are used to represent the wastes produced at natural gas processing[11].

Tab. 6.43 Waste amounts 2001 in the plants Kårstø und Kollsnes (natural gas processing Norway)

	Kårstø	Kollsnes	Type of disposal (assumption)
	kg	kg	
Oily wastes	105965	74247	Hazardous waste incineration
Solvents	1684	27500	Hazardous waste incineration
Varnish	1711		Hazardous waste incineration
Municipal waste	880	86821	Landfill
Wood	47	15820	MWI
Ashes from combustion and residues of flue gas treatment	894		Landfill
Anti-freeze	19680	146655	Hazardous waste incineration
Mixture of chemicals	2525		# presumably physico-chemical treatment
Absorber, filter, Textiles	3691	2035	MWI
Batteries, lamps	3911		Recycling
Rest sorted waste (paper, cardboard, glass, metal, organic waste, plastics)			Recycling

Summary of the unit process raw data

Tab. 6.44 shows the inventory data of the dataset "Drying, natural gas".

[11] Personal communication with Mr. Furuholt, Statoil, Email 10.05.2002 and 15.05.2002: Waste amounts in Karsto and Kollsnes.

Data quality

The data about natural gas drying are based on an environmental report of the processing plants Kårstø and Kollsnes (Statoil 2001a). Data are of good quality. However it is not possible to distinguish the different processes (separation of higher hydrocarbons, drying etc.). Therefore this dataset represents an average of the natural gas processing in Norway.

Tab. 6.44 Unit process raw data of „Drying, natural gas“

Explanations	Name	Location	Infrastructure	Unit	*drying, natural gas*	Uncertainty	StandardDeviation	GeneralComment
	Location				*NO*			
	InfrastructureProcess				*0*			
	Unit				*Nm3*			
Technosphere	diesel, at regional storage	RER	0	kg	5.99E-6	1	1.22	(1,1,1,1,3,3); environmental report, aggregation of different processes
Technosphere	chemicals organic, at plant	GLO	0	kg	2.65E-6	1	1.22	(1,1,1,1,3,3); environmental report
	chemicals inorganic, at plant	GLO	0	kg	2.65E-6	1	1.22	(1,1,1,1,3,3); environmental report
	ethylene glycol, at plant	RER	0	kg	1.82E-6	1	1.22	(1,1,1,1,3,3); environmental report
	soda, powder, at plant	RER	0	kg	2.11E-6	1	1.22	(1,1,1,1,3,3); environmental report
	natural gas, at production offshore	NO	0	Nm3	7.46E-3	1	1.22	(1,1,1,1,3,3); environmental report, aggregation of different processes
	electricity, medium voltage, at grid	NO	0	kWh	2.04E-2	1	1.22	(1,1,1,2,3,3); environmental report, standard module
	transport, lorry 32t	RER	0	tkm	1.52E-6	1	2.32	(5,1,1,3,3,5); estimates for waste transport
	transport, freight, rail	RER	0	tkm	5.54E-6	1	2.09	(4,5,na,na,na,na); standard distance
	production plant, natural gas	GLO	1	unit	3.94E-13	1	1.21	(1,1,1,1,3,1); environmental report, standard module
	disposal, used mineral oil, 10% water, to hazardous waste incineration	CH	0	kg	4.38E-6	1	1.22	(2,1,1,3,3,3); Norwegian data
	disposal, municipal solid waste, 22.9% water, to sanitary landfill	CH	0	kg	2.13E-6	1	1.22	(2,1,1,3,3,3); Norwegian data
	disposal, wood untreated, 20% water, to municipal incineration	CH	0	kg	3.85E-7	1	1.22	(2,1,1,3,3,3); Norwegian data
	disposal, average incineration residue, 0% water, to residual material landfill	CH	0	kg	2.17E-8	1	1.22	(2,1,1,3,3,3); Norwegian data
	disposal, antifreezer liquid, 51.8% water, to hazardous waste incineration	CH	0	kg	4.04E-6	1	1.22	(2,1,1,3,3,3); Norwegian data
	disposal, textiles, soiled, 25% water, to municipal incineration	CH	0	kg	1.39E-7	1	1.22	(2,1,1,3,3,3); Norwegian data
	disposal, solvents mixture, 16.5% water, to hazardous waste incineration	CH	0	kg	7.09E-7	1	1.22	(2,1,1,3,3,3); Norwegian data
	disposal, emulsion paint remains, 0% water, to hazardous waste incineration	CH	0	kg	4.16E-8	1	1.22	(2,1,1,3,3,3); Norwegian data
Emissions, in air, low population density	Methane, fossil	-	-	kg	1.64E-5	1	1.56	(1,1,1,1,3,1); environmental report, aggregation of different processes
	Carbon dioxide, fossil	-	-	kg	1.67E-2	1	1.21	(1,1,1,1,3,1); environmental report, aggregation of different processes
	NMVOC, non-methane volatile organic compounds, unspecified origin	-	-	kg	6.72E-5	1	2.05	(1,1,1,1,3,1); environmental report, aggregation of different processes
	Nitrogen oxides	-	-	kg	1.54E-5	1	1.56	(1,1,1,1,3,1); environmental report, aggregation of different processes
	Sulfur dioxide	-	-	kg	4.73E-8	1	1.21	(1,1,1,1,3,1); environmental report, aggregation of different processes
	Heat, waste	-	-	MJ	7.36E-2	1	1.21	(1,1,1,1,3,1); environmental report, aggregation of different processes
Emissions, in water, ocear	TOC, Total Organic Carbon	-	-	kg	6.67E-7	1	1.56	(1,1,1,1,3,1); environmental report, aggregation of different processes
	DOC, Dissolved Organic Carbon	-	-	kg	6.67E-7	1	1.58	(3,na,na,3,1,5); Extrapolation for sum parameter
	BOD5, Biological Oxygen Demand	-	-	kg	2.72E-7	1	1.58	(3,na,na,3,1,5); Extrapolation for sum parameter
	COD, Chemical Oxygen Demand	-	-	kg	2.72E-7	1	1.58	(3,na,na,3,1,5); Extrapolation for sum parameter
	AOX, Adsorbable Organic Halogen as Cl	-	-	kg	9.24E-14	1	1.58	(3,na,na,3,1,5); Extrapolation for sum parameter
	Nitrogen	-	-	kg	6.93E-12	1	1.58	(3,na,na,3,1,5); Extrapolation for sum parameter
	Sulfur	-	-	kg	2.40E-11	1	1.58	(3,na,na,3,1,5); Extrapolation for sum parameter
Emissions, in water, ocean	Triethylene glycol	-	-	kg	1.21E-7	1	3.05	(1,1,1,1,3,1); environmental report, aggregation of different processes
	Methanol	-	-	kg	4.02E-8	1	3.05	(1,1,1,1,3,1); environmental report, aggregation of different processes
	Phenol	-	-	kg	4.73E-10	1	3.05	(1,1,1,1,3,1); environmental report, aggregation of different processes
	Oils, unspecified	-	-	kg	8.97E-9	1	3.05	(1,1,1,1,3,1); environmental report, aggregation of different processes
	Ammonium, ion	-	-	kg	9.47E-10	1	1.56	(1,1,1,1,3,1); environmental report, aggregation of different processes
Outputs	drying, natural gas	NO	0	Nm3	1.00E+0			

6.3.6 Desulphurisation

The desulphurisation of natural gas (dataset "Sweetening, natural gas") is modelled based on information from (BEB 2001) . The plant in Grossenkneten (DE) started operation in 1972 and, according to BEB, is one of the biggest and most environmentally friendly desulphurisation plants in the world.

99.99 % of the Sulphur compounds are removed from the raw gas. Together with the waste gas treatment the connected sulphur recovery units reach a conversion efficiency of 99.8 %. Of the roughly 6 E9 m^3 sulphur containing natural gas that reach the desulphurisation plant per year, 4.8E9 m^3 cleaned gas are fed into the natural gas network. The co-produced elementary sulphur is considered a by-product leaving the plant without burdens.

Various suds are used to adsorb the sulphur, such as Purisol, Sulfinol, Rectisol (trade marks) and ethanolamine. Losses may occur due to dragging on of droplets. They are not specified further. There is no information available about the chemicals used in the desulphurisation. Therefore the manufacture of the chemicals needed in desulphurisation are approximated with “organic chemicals”.

Process-related emissions to air

The state of the art desulphurisation methods are very efficient in selectively extracting H_2S from the produced natural gas and transforming it to elementary sulphur. The total efficiency of modern desulphurisation plants is more than 99 %. The remaining sulphur is emitted with flue gas in the flaring utility.

Tab. 6.45 shows the total efficiency of desulphurisation plants and SO_2 emission factors.

Tab. 6.45 Total efficiency of the desulphurisation (sour gas with 6 vol. % H_2S according to Tab. 3.4) and SO_2 emission factors of the flare at desulphurisation plants.

Source	Description	Total efficiency of desulphurisation %	SO_2-emission factor of the flare g/m^3 prod. Natural gas
Schnitzler et al. 1989	Plants in North America	95 - 99.8	8.5 - 0.35
Taylor et al. 1991	Newer plants in NL, for produced gas with H_2S > 15 % vol.	> 99.8	< 0.35
(BEB 2001)	Plant in Grossenkneten, DE	99.99	7.2E-4
This study		99.99	**7.2E-4**

According to <EPA 1976> other emissions from the flare in processing plants are of little importance (Tab. 6.46). However, estimations show that NO_X-, CO- and particle emissions from the flare are in the same order of magnitude as in the energy supply chain. Therefore they are taken into consideration in this study. VOC emissions however can be neglected since the amounts released are very small in comparison with emissions from leakage in the plants. The average values given in Tab. 6.46 are valid both for sweet and sour gas, the values of the Grossenkneten plant only for sour gas. It is notable that the CO_2 emissions are considerably higher than the value assumed for the gas composition in this study (0.1 kg/Nm^3). The CO_2 emissions from the combustion are deduced from the total emissions. The methane emissions are taken from an environmental report (BEB 2001).

Tab. 6.46 Average emissions from the flare of processing plants in the U.S.A. <EPA 1976> and the plant in Grossenkneten (**BEB 2001**)

	Emission factors from flare [1)]	**Plant in Grossenkneten (BEB 2001)**
	kg/m^3 prod. natural gas	**kg/m^3 prod. natural gas**
CO_2		**2.12E-01**
CO	4.0E-04	**3.26E-04**
NO_x	2.0E-03	**3.49E-05**
VOC	0.1E-03	**4.00E-03**
Particles	0.3E-03	

1) with shares from drying, separation and Claus units

The natural gas fuel data from before and after the treatment shows additionally that roughly 95 % of the mercury and 100 % of the radon are removed from the natural gas stream (Tab. 3.4 und Tab. 3.5).

<Achterberg et al. 1972> traced the fate of mercury in processing plants of the Groningen gas field. Only 40 µg Hg/m^3 Of the initial 180 µg Hg/m^3 were still in the natural gas stream after the adsorption with glycol. Most of the separated mercury can be found in the condensate (NGL). Only traces are contained in the separated water. In the following filter unit the mercury content is lowered down to 12 µg Hg/ m^3.

Radon-222 suffers a similar fate. It is mostly separated in the LPG component (especially propene, propane and butane <Gesell 1975, Summerlin et al. 1985>. This can be explained by the similar vapour pressures of radon-222 and the LPG components. From a toxicological point of view the long-lived decay products of radon-222 are of interest: Pb-210, Bi-210 und Po-210.

Measurements of heavy metal emissions in the flue gases of 10 desulphurisation plant flares confirm that no detectable mercury emissions to air take place <Achterberg et al. 1972, Pierre et al. 1989>. The gas burned in the flare is mostly already processed gas as well as flue gases from the plant.

Summary of the unit process raw data

Tab. 6.47 shows the inventory data of "Sweetening, natural gas".

Data quality

The data about desulphurisation are based on an environmental report of one large German plant covering the year 2000. The data are of high quality. Data on chemical use, waste and waste water are missing though.

Tab. 6.47 Inventory data for „Sweetening, natural gas"

Explanations	Name	Location	Infrastructure	Unit	*sweetening, natural gas*	UncertaintyT	Standard Deviation 95%	GeneralComment
	Location				*DE*			
	InfrastructureProcess				*0*			
	Unit				*Nm3*			
Technosphere	chemicals organic, at plant	GLO	0	kg	2.65E-6	1	2.33	(5,5,2,3,5,5); estimate
	natural gas, at production onshore	DE	0	Nm3	3.25E-2	1	1.05	(1,2,1,1,1,1); environmental report
	sour gas, burned in gas turbine, production	NO	0	MJ	9.44E-1	1	1.05	(1,2,1,1,1,1); environmental report
	transport, lorry >16t, fleet average	RER	0	tkm	2.65E-7	1	2.09	(4,5,na,na,na,na); standard distance
	transport, freight, rail	RER	0	tkm	1.59E-6	1	2.09	(4,5,na,na,na,na); standard distance
	production plant, natural gas	GLO	1	unit	3.94E-13	1	1.05	(1,2,1,1,1,1); environmental report
Emissions, in air, low population density	Methane, fossil	-	-	kg	2.00E-5	1	1.50	(1,2,1,1,1,1); environmental report
	Carbon dioxide, fossil	-	-	kg	1.49E-1	1	1.05	(1,2,1,1,1,1); environmental report, emissions from energy use subtracted
	Carbon monoxide, fossil	-	-	kg	3.26E-4	1	5.00	(1,2,1,1,1,1); environmental report
	NMVOC, non-methane volatile organic compounds, unspecified origin	-	-	kg	4.00E-3	1	2.00	(1,2,1,1,1,1); environmental report
	Nitrogen oxides	-	-	kg	3.49E-5	1	1.50	(1,2,1,1,1,1); environmental report
	Sulfur dioxide	-	-	kg	7.21E-4	1	1.05	(1,2,1,1,1,1); environmental report
Outputs	sweetening, natural gas	DE	0	Nm3	1.00E+0			

6.3.7 Flaring

Flaring is the controlled burning of natural gas which cannot be used for technical or commercial reasons in the course of exploration and production activities. . It may also occur as a safety measure during start-up, maintenance or upset in the normal processing and production operation.

The annual volumes of gas flared are estimated to 134 billion cubic metres for 2010 NOAA 2011. The geographical distribution of gas flaring worldwide is shown in Figure 6.1.

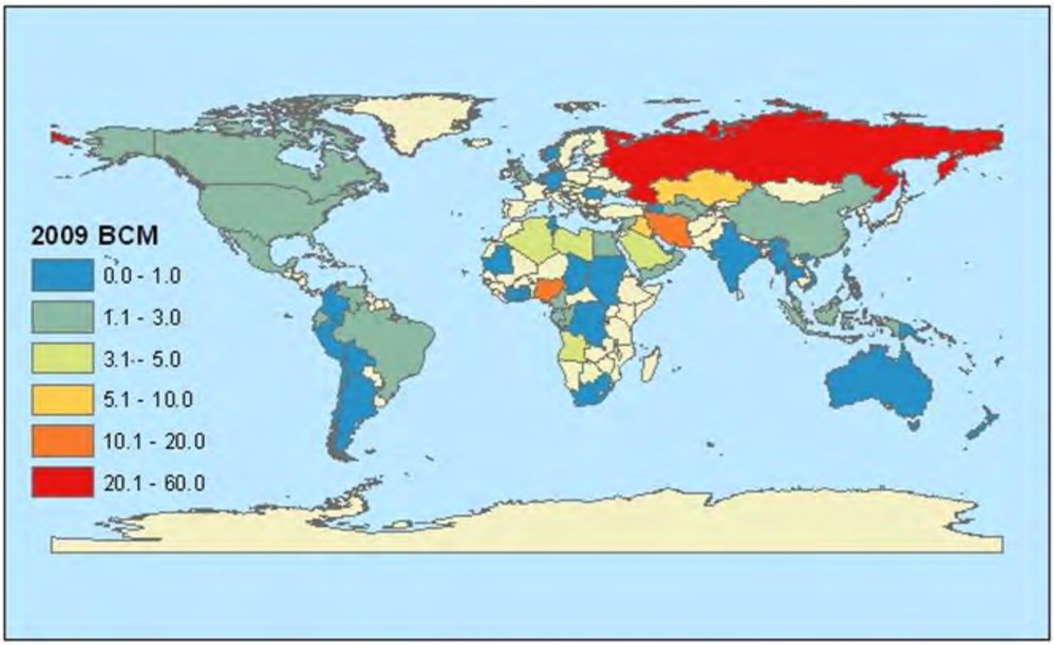

Figure 6.1 Gas flaring in 2009 (Source: www.ngdc.noaa.gov, retrieved 12.08.2011)

The emission factors of flaring are mainly taken from the Norwegian Environmental Report (OLF 2011). This report contains data about the Norwegian combined oil and gas production, thus representing Norwegian average technology. Some complementary data is taken from Frischknecht et al. (1996).

Tab. 6.48 Air emissions from flaring

Fuel →		Combined production 2)	Production mix Norway	General emission factors for flaring	Natural gas before treatment	**Output production flare**	
						Sour gas	**Sweet gas**
Source		(Frischknecht et al. 1996: chapter 13, part crude oil)	Environmental Report Norway (OLF 2011); UNFCCC country inventory Norway (UNFCC 2011)	(EFDB 2011)	Tab. 3.4	**This study**	**This study**
		m^3	m^3	m^3	m^3	m^3	m^3
SO_2	kg	n/a	8.07E-06	n/a	1)	1.7E-01	8.07E-6
NO_x	kg	1.2E-02	1.63E-03	1.20E-3		1.63E-3	1.63E-3
CO	kg	n/a	n/a	1.00E-3		1.00E-3	1.00E-3
CH_4	kg	8E-3	7.07E-04	2.00E-4		7.07E-4	7.07E-4
NMVOC	kg	4E-3	1.96E-04	1.00E-4		1.96E-4	1.96E-4
CO_2	kg	2.43E+0	3.71E+00	2.43E+0	1.98E+0	3.71E+0	3.71E+0
N_2O	kg	n/a	2.01E-05	2.00E-5	n/a	2.00E-5	2.00E-5
Particles	kg	n/a	n/a	n/a		5.4E-04 4)	2.0E-04 4)
Mercury	µg	1.5E+1	n/a	n/a	2.00E+2	2.00E+02	2.00E+02
Radon-222	kBq	1E-1	n/a		4E-1	4E-01	4E-01
Waste heat	MJ	n/a	n/a			36 E+0 3)	36 E+0 3)

1) 0.17 kg SO_2/ m^3 for sour gas (6 vol % H_2S) and 0 kg SO_2/ m^3 for sweet gas (0 vol % H_2S).

2) Average share of flaring technologies: 47% pipe flares, 53% newer systems

3) Estimation, lower heating value

4) Assumption. emission factor valid for refinery flare as reported in (Jungbluth 2003).

Summary of the unit process raw data

Tab. 6.49 and Tab. 6.50 show the inventory data of flaring natural gas.

Data quality

The data originate mainly from environmental reporting of the Norwegian offshore production and is of good quality. They represent the current flaring technology. The SO_2-emissions were calculated based on stoichiometry and assumptions with regards to the H_2S-content of sour gas.

Tab. 6.49 Unit process raw data of „Natural gas, sweet, burned in production flare”

	Name	Location	InfrastructureProcess	Unit	natural gas, sweet, burned in production flare	UncertaintyType	StandardDeviation95%	GeneralComment
	Location				GLO			
	InfrastructureProcess				0			
	Unit				Nm3			
product	natural gas, sweet, burned in production flare	GLO	0	Nm3	1			
	natural gas, sour, burned in production flare	GLO	0	Nm3	0			
resource, in ground	Gas, natural, in ground	-	-	Nm3	1.00E+0	1	1.07	(1,3,1,3,1,1,BU:1.05); OLF 2011, p.57 (table 29)
emission air, low population density	NMVOC, non-methane volatile organic compounds, unspecified origin	-	-	kg	1.96E-4	1	1.51	(1,3,1,3,1,1,BU:1.5); OLF 2011, p.57 (table 29)
	Methane, fossil	-	-	kg	7.07E-4	1	1.51	(1,3,1,3,1,1,BU:1.5); OLF 2011, p.57 (table 29)
	Sulfur dioxide	-	-	kg	8.07E-6	1	1.07	(1,3,1,3,1,1,BU:1.05); OLF 2011
	Sulfur dioxide	-	-	kg		1	1.07	(1,3,1,3,1,1,BU:1.05); Estimate
	Nitrogen oxides	-	-	kg	1.63E-3	1	1.51	(1,3,1,3,1,1,BU:1.5); OLF 2011, p.57 (table 29)
	Carbon dioxide, fossil	-	-	kg	3.71E+0	1	1.07	(1,3,1,3,1,1,BU:1.05); OLF 2011, p.57 (table 29)
	Carbon monoxide, fossil	-	-	kg	1.00E-3	1	5.00	(1,3,1,3,1,1,BU:5); Standard emission factor (EFDB 2011)
	Dinitrogen monoxide	-	-	kg	2.00E-5	1	1.51	(1,3,1,3,1,1,BU:1.5); Standard emission factor (EFDB 2011)
	Heat, waste	-	-	MJ	3.60E+1	1	1.09	(2,3,1,3,1,1,BU:1.05); Estimation, average value
	Mercury	-	-	kg	2.00E-7	1	5.00	(1,3,1,3,1,1,BU:5); Estimation, average value
	Particulates, < 2.5 um	-	-	kg	5.40E-4	1	3.00	(1,3,1,3,1,1,BU:3); Estimation for refinery flare from (Jungbluth 2003)
	Radon-222	-	-	kBq	4.00E-1	1	3.00	(1,3,1,3,1,1,BU:3); Estimation, average value

Tab. 6.50 Unit process raw data of „Natural gas, sour, burned in production flare”

	Name	Location	InfrastructureProcess	Unit	natural gas, sour, burned in production flare	UncertaintyType	StandardDeviation95%	GeneralComment
	Location				GLO			
	InfrastructureProcess				0			
	Unit				Nm3			
product	natural gas, sweet, burned in production flare	GLO	0	Nm3	0			
	natural gas, sour, burned in production flare	GLO	0	Nm3	1			
resource, in ground	Gas, natural, in ground	-	-	Nm3	1.00E+0	1	1.07	(1,3,1,3,1,1,BU:1.05); OLF 2011, p.57 (table 29)
emission air, low population density	NMVOC, non-methane volatile organic compounds, unspecified origin	-	-	kg	1.96E-4	1	1.51	(1,3,1,3,1,1,BU:1.5); OLF 2011, p.57 (table 29)
	Methane, fossil	-	-	kg	7.07E-4	1	1.51	(1,3,1,3,1,1,BU:1.5); OLF 2011, p.57 (table 29)
	Sulfur dioxide	-	-	kg		1	1.07	(1,3,1,3,1,1,BU:1.05); OLF 2011
	Sulfur dioxide	-	-	kg	1.70E-1	1	1.07	(1,3,1,3,1,1,BU:1.05); Estimate
	Nitrogen oxides	-	-	kg	1.63E-3	1	1.51	(1,3,1,3,1,1,BU:1.5); OLF 2011, p.57 (table 29)
	Carbon dioxide, fossil	-	-	kg	3.71E+0	1	1.07	(1,3,1,3,1,1,BU:1.05); OLF 2011, p.57 (table 29)
	Carbon monoxide, fossil	-	-	kg	1.00E-3	1	5.00	(1,3,1,3,1,1,BU:5); Standard emission factor (EFDB 2011)
	Dinitrogen monoxide	-	-	kg	2.00E-5	1	1.51	(1,3,1,3,1,1,BU:1.5); Standard emission factor (EFDB 2011)
	Heat, waste	-	-	MJ	3.60E+1	1	1.09	(2,3,1,3,1,1,BU:1.05); Estimation, average value
	Mercury	-	-	kg	2.00E-7	1	5.00	(1,3,1,3,1,1,BU:5); Estimation, average value
	Particulates, < 2.5 um	-	-	kg	5.40E-4	1	3.00	(1,3,1,3,1,1,BU:3); Estimation for refinery flare from (Jungbluth 2003)
	Radon-222	-	-	kBq	4.00E-1	1	3.00	(1,3,1,3,1,1,BU:3); Estimation, average value

6.4 Data quality

6.4.1 Production

The European supply mixes are based on statistical data. With the exemption of Italy (whose domestic production was not considered) the production countries considered in this study cover 99 % or more of the supply mixes.

For Norway and the Russian Federation specific and very recent data are available. Data of the most important producing Russian companies are used and extrapolated to model the Russian natural gas production. The Norwegian data covers the entire production.

The data of natural gas production in Germany, the Netherlands, the United Kingdom and Nigeria are not updated. The information stems to a large extent from natural gas producing companies. The uncertainty of the data may be elevated due to their age. .

Infrastructure information is taken from literature describing individual plants. These data are not very representative but due to the large production volumes the environmental impacts of infrastructure are of small overall importance.

6.4.2 Processing

Drying and desulphurisation of natural gas are modelled with data from reliable sources, however only from one source each and covering one specific country and the year 2000.

Material and land use is quantified based on only few data . The information provided regarding the separation and disposal of mercury and radon are subject to high uncertainties.

7 Life cycle inventory of long-distance transport

7.1 Overview

of Treated natural gas is mostly transported by long distance pipelines with compressors that are driven by gas turbines. For trans-ocean transport Natural gas is more and more being transported by ship as LNG (liquefied natural gas, see Subchapter 7.3). The well-established natural gas grid in Western Europe allows balancing peaks in demand (together with seasonal storage) and the dispatching of natural gas from different origins.

The infrastructure and construction needs play a decisive role; they are described in Subchapter 7.2. The seasonal storage of natural gas is included in the inventory of the long distance transport and is described in Section 7.2.4.

This chapter focuses on the long-distance transport from the countries of origin to Switzerland and Europe. Important parameters are the Swiss and European supply mixes (see Tab. 7.1) and the transport distances from the different origins to Switzerland and Europe, respectively.

Tab. 7.1 Supply mix of natural gas used in Switzerland (CH) and Europe (RER), see Chapter 4

	Name	Location	Infrastruct	Unit	natural gas, at long-distance pipeline	natural gas, at long-distance pipeline	UncertaintyType	StandardDeviation 95%	GeneralComment
	Location				CH	RER			
	InfrastructureProcess				0	0			
	Unit				Nm3	Nm3			
technosphere	natural gas, production DE, at long-distance pipeline	RER	0	Nm3	8.12E-2	1.35E-2	1	1.05	(1,1,1,1,1,1,BU:1.05); Natural gas statistics; BP 2011
	natural gas, production GB, at long-distance pipeline	RER	0	Nm3	2.21E-2	7.59E-2	1	1.05	(1,1,1,1,1,1,BU:1.05); Natural gas statistics; BP 2011
	natural gas, production NL, at long-distance pipeline	RER	0	Nm3	2.73E-1	1.51E-1	1	1.05	(1,1,1,1,1,1,BU:1.05); Natural gas statistics; BP 2011
	natural gas, production NO, at long-distance pipeline	RER	0	Nm3	2.65E-1	2.73E-1	1	1.05	(1,1,1,1,1,1,BU:1.05); Natural gas statistics; BP 2011
	natural gas, production RU, at long-distance pipeline	RER	0	Nm3	3.14E-1	2.40E-1	1	1.05	(1,1,1,1,1,1,BU:1.05); Natural gas statistics; BP 2011
	natural gas, production NAC, at long-distance pipeline	RER	0	Nm3	2.38E-2	1.20E-1	1	1.05	(1,1,1,1,1,1,BU:1.05); Natural gas statistics; BP 2011
	natural gas, production RME, at long-distance pipeline	RER	0	Nm3	8.54E-3	8.24E-2	1	1.05	(1,1,1,1,1,1,BU:1.05); Natural gas statistics; BP 2011
	natural gas, production NG, at long-distance pipeline	RER	0	Nm3	1.33E-2	4.45E-2	1	1.05	(1,1,1,1,1,1,BU:1.05); Natural gas statistics; BP 2011

The process "Long-distance transport" is connected to the supply chain via the input "Natural gas, production offshore/onshore (DE)" resp. NAC, GB, NL, NO, RU, RME and NG. The output (functional unit) is "Natural gas, production (DE), at long-distance pipeline" and NAC, GB, NL, NO, RU, RME and NG, respectively and "Natural gas, at long distance pipeline" (for CH and RER).

7.2 Pipeline transport

7.2.1 Infrastructure

Material

Steel pipes with a diameter between 750 and 1200 mm and a wall thickness between 5 and 25 mm are used for the pipelines. European natural gas pipelines have an average diameter of 900 mm at 65-100 bar (Ruhrgas 2001a). The long-distance pipelines in the Russian Federation have a maximal diameter of 1400 mm and a capacity of up to 3 million Nm^3/h (SWISSGAS 2001b).

The diameters of onshore pipelines with a low and high capacity are 950 mm and 1220 mm, respectively, with wall thicknesses of 10 mm and 12 mm, respectively. These data are based on information about the TENP pipeline from the Netherlands to Northern Italy which is relevant for Switzerland <Ercolani et al. 1991>, <Swissgas 1990> and on information about the Maghreb-Europe transport pipeline (Aróstegui 1997). These properties lead to specific steel needs of low and high capacity pipelines of about 240 t/km and 380 t/km, respectively. The types of steel used are StE 480.7 TM and StE 360.7 TM according to <Lübben et al. 1990>. Steel pipelines are sheathed with a plastic coating and protected with an electric field to prevent corrosion (Ruhrgas 2001a). It is assumed that the sheathing consists of 75 % LDPE (layer thickness 2.2 mm) and 25 % bitumen (layer thickness 3.0 mm). The electricity use for the electric field is very small and is neglected.

Tab. 7.2 Specific material use for the pipeline sheathing in the long-distance transport network

Material	Onshore pipelines	Share	Offshore pipelines	Share
	t/km		t/km	
LD-PE	6.2 [1)]	75%		
Bitumen	9.3 [2)]	25%		
Concrete			795	100%

[1)] 2.2 mm thick LDPE foil (density 0.92 t/m^3)

[2)] 3.0 mm thick bitumen layer (density 1.01 t/m^3)

[3)] 100 mm thick concrete layer (density 2.2 t/m^3)

Pipelines with larger diameters and thicker walls are used for the crossing of the strait between Tunisia and Sicily as well as the Northern Sea due to the higher operation pressure (up to 200 bar). In this study pipelines with a typical diameter of 1000 m and a wall thickness of 25 mm are used for offshore pipelines (average diameter of the most important offshore pipelines according to (durchschnittlicher Durchmesser der wichtigsten Offshore-Leitungen gemäss OED 2000; Statoil 2001b)). This geometry of offshore pipelines with a high capacity leads to a specific steel demand of about 610 t/km. These pipelines are protected with a concrete mantle (wall thickness 100 mm).

The pipeline load fluctuates in the course of the year. The average load im million m^3 per hour is of interest to determine the lifetime transportation capacity. The transit pipeline from the Netherlands to Northern Italy has an average load of 0.8 million m^3/h (average of the years 1990 and 1991 according to <Swissgas 1992>, <SVGW 95/96>). Te pipelines between Russia and Germany as well as between Algeria and Europe have an average load of 1.1 million m^3/h, in accordance with (Aróstegui 1997) and <Petrole 1986>. Data on the material use and the reference length can be found in Tab. 7.3. This table also shows information on the sand use for the bedding of the pipelines. The trench is assumed to be 1.5 m wide and 1.7 m high for pipelines with a low capacity and 1.75 m wide and 2.0 m high for pipelines with a high capacity. Sand is filled up to a height of about 50 cm.

Offshore pipelines are protected against corrosion by using sacrificial anodes. The anodes are assumed to weigh 3.5 t/km. Material use and emissions to water are quantified according to the approach used for offshore platforms.

There are hardly any reliable data available regarding the service lifetime of pipelines since most pipelines are no older than 40 years. Newer pipelines are licensed for 50 years <Fasler 1992>. The average planned lifetime of offshore pipelines is about 45 years (OED 2000). In the following an average lifetime of 50 years is assumed.

Tab. 7.3 Specific material use, transport capacity and lifetime of onshore and offshore pipelines as used in this study.

	Specific steel use	Specific sand use	Average transport capacity	Life time	Source
	t/km	t/km	Million Nm^3/h	Years	
Pipeline, Onshore, low capacity	240	1'950	0.8	50	Assumptions in the text, <Swissgas 1992, Petrole 1986>
Pipeline, Onshore, high capacity	380	2'280	1.1	50	(Aróstegui 1997)
Pipeline, Offshore, high capacity	610		1.6	50	(OED 2000)

[1)] Typical European pipeline

For the reference transport distances the average weighted export distance are used. Information about exported volumes and receiving European countries is taken from (BP 2011). An internet travel planner was used to determine the distance from the producing regions to the receiving countries[12]. The export distances in Tab. 7.4 represent the average weighted export distances for the countries considered. E.g. Germany exports to Belgium, Hungary, Luxemburg, Austria, Poland, Rumania and Switzerland. The average distance from Germany to these countries is weighted with the exported volumes.

Tab. 7.4 Reference distance (average weighted export distance to Euroepan countries) from the producing countries and regions

Reference distance		**Source**	**DE**	**NAC**	**GB**	**NG**	**NL**	**NO**	**RME**	**RU**
Onshore Pipeline										
High capacity	km	(BP 2011), distance estimations	-	2000	-		-	-		6000
Low capacity	km	(BP 2011), distance estimations	600	-	250	1200	700	800	600	-
Offshore Pipeline	km	(BP 2011), distance estimations	-	100	250		-	600		-

The transport of materials to and from the construction site is modelled with standard transport datasets in accordance with (Spielmann et al. 2004). Standard transport distances are applied (see s. Frischknecht et al. 2004). The materials needed to construct offshore pipelines need to be transported with a freight ship (assumption 300 km). The superfluous top soil can be utilised further and is thus a by-product of the pipeline construction.

Construction

The construction of high-pressure natural gas pipelines may have an impact on the environment and on the landscape. In most countries environmental impact assessments of natural gas pipeline projects are required. In general the following construction phases are distinguished:

- Preparation of the line: erosion of the topsoil. The top soil is piled up to the side of the trench (with skid-steer loaders). The construction site has a width of about 20 m.
- Pipe delivery (with lorry)
- Thrusting out and welding of the pipes. Radiographic testing of the weld, subsequent insulation.

[12] According to (Frischknecht et al. 2004) the homepage http://www.reiseplanung.de/index.jsp was used for the distance estimations on the 16.7.02 and 9.8.02. For the producting regions cities close by were entered, for the receiving countries the respective capitals.

- Excavation of the trench (with hydraulic diggers)
- Lowering of the pipeline into the trench (with side booms)
- Pipe mantling, replenishment of the trench, loosening of the ground, deposition of a top soil layer and rehabilitation

The construction site is organised like an assembly line and is 5 to 20 km long. <Ullmanns 1987> gives the following indications for the energy use of such a construction site:

- 28'000 l Diesel for construction machines and lorries per day
- 1'000 l Petrol for passenger cars per day

The pipeline length laid per day is in the range of 500 to 800 metres , depending on the type of landscape (typical value 700 m/d) <Ullmanns 1987>. This leads to a fuel use of about 40'000 l diesel and 1'400 l petrol per kilometre pipeline constructed. Data from the environmental report of (Saipem 2001) are used in this study (energy, water, waste; see Tab. 7.5 and s. auch Jungbluth 2003). The construction expenditures for offshore pipelines are approximated with diesel consumption, represented by the dataset “Diesel, burned in building machine”.

Tab. 7.5 Pipeline construction expenditures (**Saipem 2001**)

		Pipeline Onshore km	**Pipeline Offshore** km
Resources			
Water	m^3	1.87E+02	8.05E+02
Energy carriers			
Diesel	MJ	3.31E+06	2.53E+06
Disposal			
Municipal waste	kg	4.84E+03	1.26E+03
Hazardous waste	kg	3.53E+03	1.13E+03

Land use

The land use is especially relevant in the construction phase. After the construction the area is recultivated. During the operation of onshore pipelines a safety zone of 10 m to both sides of the pipeline has to remain accessible and can’t be used for further constructions. The area can be utilised for recreational or agricultural purposes. Forest areas are avoided as far as possible, however 15 % of the distribution pipelines are bordered by forest (according to Section 8.2.4). This share is likely lower in Germany and higher in the CIS states. As an average value 10 % forest along the pipeline length are assumed. After the construction they can’t be re forested due to safety reasons. It is assumed that these areas are transformed to agricultural land.

The construction site of 20 m^2/m pipeline is used during 2 months. This leads to 3'300 m^2a/km “Occupation, construction site” and 2'000 m^2/km land use change (10 % of the area being converted from forest to heterogeneous agricultural) which are included in the onshore pipeline construction inventory. It is assumed that the land is not reforested after the 50 years operation time.

Offshore pipelines are mostly covered (European Commission 1995). It is assumed that 90 % of the pipelines below sea level are covered and consequentially do not have land use. The land use during construction is neglected, as is the land use change. For the remaining 10 % “Occupation, industrial area, benthos” is used during the 50 years operation timeThe surface area is determined using the pipeline diameter leading to a land use of 5'500 m^2a/km.

Renaturation and disposal

At the end of life it is likely that a large share of the pipelines remains in the ground since the excavation would lead to considerable expenditures. In the following it is assumed that half of the material remains in the ground (resp. in the sea) and the other half of the pipelines are excavated, the steel and concrete are brought to inert landfills and the plastic and bitumen are burned in MWI.

Summary of the unit process raw data

The following tables show the inventory data of the construction and the disposal of natural gas pipelines. Onshore pipelines with a low and a high capacity are calculated with a typical diameter of 950 mm and 1220 mm, respectively, and a wall thickness of 10 mm and 12 mm, respectively. A typical diameter of 1000 mm and a wall thickness of 25 mm is applied on offshore pipelines. The life time of pipelines assumed in this study is 50 years.

Tab. 7.6 Unit process raw data of "Pipeline, natural gas, long distance, low capacity, onshore" (GLO)

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

Tab. 7.7 Unit process raw data of "Pipeline, natural gas, long distance, high capacity, onshore" (GLO)

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

Tab. 7.8 Unit process raw data of “Pipeline, natural gas, long distance, high capacity, offshore” (GLO)

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

Surveillance with helicopters

During the operation the pipelines need to be monitored regularly. According to <Fasler 1992> the pipelines are controlled with helicopters that fly along all pipelines. Some natural gas distributing companies fly over the pipelines every 2-3 weeks (Dutch gas distribution company 2002; Snam 2000). We assume helicopter checks every 2 weeks. This results in 1’300 km/km over the whole lifetime of the pipeline. With an average speed of 100 km/h a total of 13 h of helicopter flights are needed per km pipeline.

Information about the fuel use and emissions caused by helicopter flights are shown in Tab. 7.9 and Tab. 7.10, as reported in BUWAL (2000). The fuel use and emissions are different during LTO (landing and take-off) and the flying. Per flight one LTO cycle is needed. It is assumed that on average 250 km are flown per flight.

Tab. 7.9 Unit process raw data of "Transport, helicopter, LTO cycle" (GLO)

Explanations	Name	Location	InfrastructureProc	Unit	transport, helicopter, LTO cycle	UncertaintyType	StandardDeviation 95%	GeneralComment
	Location				GLO			
	InfrastructureProcess				0			
	Unit				unit			
Technosphere	kerosene, at regional storage	RER	0	kg	4.52E+01	1	1.09	(2,1,1,3,1,1); swiss extrapolated statistical data 2000
Emissions, air, low population density	Methane, fossil	-		kg	7.90E-5	1	1.51	(2,1,1,3,1,1); swiss extrapolated statistical data 2000
	Carbon dioxide, fossil	-		kg	1.42E+2	1	1.09	(2,1,1,3,1,1); swiss extrapolated statistical data 2000
	Carbon monoxide, fossil	-		kg	3.60E-4	1	5.01	(2,1,1,3,1,1); swiss extrapolated statistical data 2000
	NMVOC, non-methane volatile organic compounds, unspecified origin	-		kg	7.01E-5	1	1.51	(2,1,1,3,1,1); swiss extrapolated statistical data 2000
	Nitrogen oxides	-		kg	6.56E-4	1	1.51	(2,1,1,3,1,1); swiss extrapolated statistical data 2000
	Sulfur dioxide	-		kg	3.62E-1	1	1.09	(2,1,1,3,1,1); swiss extrapolated statistical data 2000
	Heat, waste	-		MJ	2.08E+3	1	1.09	(2,1,1,3,1,1); swiss extrapolated statistical data 2000
Outputs	transport, helicopter, LTO cycle	GLO	0	unit	1.00E+00			

Tab. 7.10 Unit process raw data of "Transport, helicopter" (GLO)

Explanations	Name	Location	InfrastructureProcess	Unit	transport, helicopter	UncertaintyType	StandardDeviation 95%	GeneralComment
	Location				GLO			
	InfrastructureProcess				0			
	Unit				h			
Technosphere	kerosene, at regional storage	RER	0	kg	2.64E+01	1	1.09	(2,1,1,3,1,1); swiss extrapolated statistical data 2000
	transport, lorry 32t	RER	0	tkm	0.00E+00	1	2.32	(5,1,1,3,3,5); estimates for waste transport
	helicopter	GLO	1	unit	1.00E-04	1	3.30	(5,4,1,3,3,4); estimates
Emissions, air, low population density	Methane, fossil	-		kg	3.76E-05	1	1.51	(2,1,1,3,1,1); swiss extrapolated statistical data 2000
	Carbon dioxide, fossil	-		kg	8.31E+01	1	1.09	(2,1,1,3,1,1); swiss extrapolated statistical data 2000
	Carbon monoxide, fossil	-		kg	2.32E-03	1	5.01	(2,1,1,3,1,1); swiss extrapolated statistical data 2000
	NMVOC, non-methane volatile organic compounds, unspecified origin	-		kg	3.34E-05	1	1.51	(2,1,1,3,1,1); swiss extrapolated statistical data 2000
	Nitrogen oxides	-		kg	4.03E-04	1	1.51	(2,1,1,3,1,1); swiss extrapolated statistical data 2000
	Sulfur dioxide	-		kg	2.11E-01	1	1.09	(2,1,1,3,1,1); swiss extrapolated statistical data 2000
	Heat, waste	-		MJ	1.21E+03	1	1.09	(2,1,1,3,1,1); swiss extrapolated statistical data 2000
Outputs	transport, helicopter	GLO	0	h	1.00E+00			

The weight of a helicopter is approximated with 1 ton (2 places, 50 % steel and 50 % aluminium) and the service life with 10'000 flight hours (see Tab. 7.11). The materials are recycled (assumption).

Tab. 7.11 Unit process raw data of "Helicopter" (GLO)

Explanations	Name	Location	InfrastructureProcess	Unit	helicopter	UncertaintyType	StandardDeviation95%	GeneralComment
	Location				*GLO*			
	InfrastructureProcess				*1*			
	Unit				*unit*			
	reinforcing steel, at plant	RER	0	kg	5.00E+02	1	1.60	(5,4,1,3,3,4); estimates
	aluminium, production mix, at plant	RER	0	kg	5.00E+02	1	1.60	(5,4,1,3,3,4); estimates
Outputs	helicopter	GLO	1	unit	1.00E+00			

7.2.2 Operational energy use

Every 100 to 200 km a turbo condenser with gas turbine propulsion balances the pressure loss in the network[13]. Usually several turbines make up a compressor station. The turbo compressor consists of a driving part, a power turbine and an energy generator, the gas turbine. The gas turbine is constructed like an aircraft engine. In some cases really modified jet engines are used. In airplanes the output of the hot combustion gas creates a thrust; in the power turbine it creates the rotation that drives the gas compressor. The efficiency is about 34 %-38 %. Per compression process with a typical compression ratio of 1.4 (initial/final pressure) about 0.27 % of the natural gas in Europe[13] is used, in the Russian Federation about 4.8 % (UNFCCC 2011a). The energy use for natural gas transport in the Russian Federation has decreased by 34 % since the 1990ies to 1.8 MJ per Nm^3 transported in 2009[14]. In this study an average transport distance of 2500 km is assumed for natural gas transport inside Russia[15]. This leads to an energy use of 0.7 MJ (1.9 %) per 1000 km and Nm^3 natural gas. The pipeline gas is used as combustible which is assumed to have end use quality.

Emissions and advance performances are calculated with the datasets "Natural gas, burned in gas turbine, for compressor station (DE)" and DZ, RU, NO, NL and UCTE, respectively. The Russian dataset is used to represent transports in the Middle East, the Algerian one (DZ) is used to model transports in Nigeria and North Africa.

The gas use of compressor stations is in the range of 1.4 % to 3 % per 1000 km transport distance (see Tab. 7.12). For this study a value of 1.8 % per 1000 km is used for pipeline transport in Europe, Middle East and North Africa, and 1.9 % per 1000 km in Russia.

[13] Personal Information by Mr. Fasold, Ruhrgas AG, 9.7.2001 and Mr. Meier, Swissgas, 22.8.2001

[14] Converted with a density of 0.73 kg/Nm^3, no information on the average distance is given in the source.

[15] This transport distance (average distance of all Russian gas transported within Russia) should not be mixed with the transport distance of Russian natural gas from Russian natural gas fields to the European border (see Section 7.2.3).

Tab. 7.12 Natural gas use of the compressor stations per 1000 km pipeline transport

Source	m^3 natural gas / m^3 transp. natural gas
Infras 1981	1.9 %
DOE 1983	3 %
Eberhard et al. 1990	2 %
DGMK 1992	2 %
Fritsche et al. 1993 (Westeuropa)	1.4 %
(Ruhrgas 2001a), Russian network	2.7 %
(Ruhrgas 2001a), European network	1.8 %
(Ruhrgas 2001c), Wolgotransgaz network[16]	2.15-2.23 %
(UNFCCC 2011a), Russian network [17]	1.9 %
This study	**Vol %**
Western Europe, Middle East and North Africa	**1.8**
Russian Federation	**1.9**

7.2.3 Natural gas leakages and other process related emissions

In the European natural gas networks losses occur mostly at barriers where venting is necessary. The values in literature vary between 0.001 % and 0.15 % of the transported natural gas <Jennervik 1991> <Okken 1990>. For the entire German network (including distribution) the losses are estimated to 0.4 % of the transported natural gas[18]. The losses in the transmission pipelines make up 5 % of the total losses, e.g. 0.02 % of the natural gas (Reichert & Schön 2000). Battelle Ingenieurtechnik GmbH (1994) assumes 240 Nm^3 natural gas losses[19] per kilometre pipeline and year. The compressors losses are quantified with 7750 Nm^3 per MW compressor capacity and year (Reichert & Schön 2000). Ruhrgas (2001b) discloses a total of 786 MW for 26 compressor stations, i.e. on average 30 MW per compressor station. We calculate with one compressor station every 150 km for the pipeline transport in Western Europe. With the assumed capacity (0.8 million Nm^3) this leads to 0.026 % losses per 1000 km for the transmission pipelines (including compressor stations).

The leakage data of the Russian Federation pipelines are taken from the official communication with the United Nations Framework Convention on Climate Change (UNFCCC 2011a). For the transmission pipelines the losses are 0.9 % of the transported natural gas. It is assumed that the average distance the natural gas is transported inside Russia corresponds to the distance from the production to the border with Europe (about 4200 km). The distance from the Russian-European border to the European consumer is estimated with 1800 km assuming the same emission factor. For the whole distance (6000 km) this leads to 1.31 % losses (value used in this study)[20].

The emissions in the Russian transmission network have fallen by about 15 % from 1999 to 2008 (Akopova 2010). In an older study the losses from the transport from Sibiria to Western Europe are estimated to be 1.4 % <Zittel 1998>. With a distance of 6000 km this results in 0.2 % loss per 1000 km transport distance, which is in a similar range like the value used in this study. This shows that earlier estimates were rather too low compared with actual measurements.

16 The Wolgotransgaz network runs over 800 km and transports almost 250 billion Nm^3 natural gas per year. Due to optimisation programs the energy use could be reduced from 45 Mio. MWh (445 Mio. Nm^3) to 1.5 Mio. MWh.

17 1.15E+12 MJ energy use fot pipeline transport, an average transport distance of 2500 km is assumed.

18 Personal information by Mr. Fasold, Ruhrgas AG, 9.7.2001

19 221 m^3 methane per km converted to natural gas with the factor 0.9184.

20 The distances were estimated with the Google Maps route planner: maps.google.ch

For the long distance pipeline transport from Nigeria and the Middle East the European leakage rates are used. The natural gas from these origins reaches the European mainland in the form of LNG and is transported in the European pipeline system to the destination following the evaporation.

Some of the leaked natural gas can be held back by the soil (depending on the soil type) or converted by bacteria <Nerger et al. 1987>. As a conservative approximation it is assumed that the entire volume of natural gas leaked reaches the atmosphere.

The composition of the natural gas changes slightly during the long distance transport. Small volumes of condensates (higher hydrocarbons) and water are collected in condensate separators. The volume of separated condensates is estimated to be 1.2 mg/tkm (Dutch gas distribution company 2002). In Subchapter 3.3 we assumed that alongside with the condensate also about 8 μg of mercury are excreted per m^3 transported natural gas. It is assumed that the accumulated condensate contaminated with mercury is disposed of as hazardous waste. This is approximated in the inventory with the dataset "Disposal, used mineral oil, 10% water, to hazardous waste incineration". A distance of 10 km to the treatment facility is assumed.

From the information provided in (Gasunie 1998; 2001) it becomes clear, that freon and halon are used for the cooling of the compressor stations. In 2000 a total of 850 kg Freon R22 and 275 kg halon 1211 and 1301 (assumption: only halon 1211) were used. With a total sales volume of 73 billion m^3 and an estimate average transport distance of 210 km that makes 6.93 E-08 kg/tkm Freon and 2.2 E-08 kg/tkm halon. These figures are used for the long distance transport in all countries considered.

7.2.4 Seasonal natural gas storage

The seasonal natural gas storage is an important part of the natural gas supply system. The storage tanks are filled during the summer period and emptied during the winter period. A share of the storage volume is reserved for strategic purposes. The volume of the strategic reserve varies depending on temperature changes.
Today roughly 10 % of the natural gas supply are temporarily stored (Ruhrgas 2001a), <Lübben et al. 1990>), which is about 230 million m^3 for the Swiss final consumption. Switzerland disposes of about 70 million m^3 storage capacity in caverns by Gaz de France in the French Jura[21].

The remaining storage capacity for Switzerland is covered mainly by cavern and aquifer storages of Ruhrgas in Germany. The Netherlands and Norway, both important suppliers for Switzerland, have large natural gas reserves.

Cavern storages are built in salt domes and salt deposits. A hole is drilled to a depth of 1000 m to 2000 m. A double pipe (steel pipe with inner pipe) is introduced in the borehole. Water is then pumped through the inner pipe which dissolves the salt, creating a cavern. The sole is pressed out through the outer pipe. This process can take up to a few months. The natural gas can then be stored in the cavern. On the surface a storage compressor station is built, a building with two to three compressor units. The energy use of the compressors depends of the cavern depth and the pressure; salt caverns are typically operated with a pressure of 200 bar, the energy use is about 1-2 % of the stored natural gas volumes. The losses are about 0.05 %[22].

Natural gas is also stored in pore storage, where the gas is deposited in permeable rock formations. Here losses can occur if the gas escapes to other horizons. In general the losses are a bit higher for this storage type (up to 0.5%, certainly <1%)[23].

(Battelle 1994) declares losses of 0.14 % of the working volume per year in large underground storage. In <Selzer et al. 1990> a gas leakage of 100'000 m^3 for a storage working volume of

[21] Personal information by Mr. B. Meier, Swissgas, June 2003.

[22] Personal information by Mr. Fasold, Ruhrgas AG, 9.7.2001

[23] Personal information by Mr. Fasold, Ruhrgas AG, 9.7.2001

220 million m^3 is communicated. This gives an annual average leakage of about 0.005 % relative to the transported natural gas. In IGU (2000b) an average loss of 0.1 % of the working fluid is reported which is used in this study and corresponds to 0.01 % of the transported natural gas.

The material and resource use to construct such a cavern is small and thus neglected here.

The energy expenditures and the losses at the storage are included in the inventory of the datasets „Natural gas, production (country), at long-distance pipeline".

7.2.5 Inventory of natural gas transport in pipelines

Description

Tab. 7.13 gives an overview of the inventory data of the transport datasets. The data of German natural gas transport are shown in more detail in Tab. 7.14 including uncertainties. The Tables "Transport, natural gas, pipeline, long distance" describe the energy use and the specific emissions per km transport of one ton natural gas (in the unit tkm). The transport dataset of Europe (RER) (see Tab. 7.15) uses the European natural gas mix according to Tab. 4.1 and.

The inventory data of the various countries differ with respect to the emissions since they are calculated based on the country specific natural gas composition. The losses are higher for Russia than for Europe. The amount of condensates and the occurring freon and halon emissions are assumed to be the same for all countries. Equally the emissions from offshore pipelines are assumed to be identical to the emissions from onshore pipelines.

The use of natural gas in Nm^3/tkm is calculated with the loss rate (% per 1'000 km) and the density of the natural gas (0.8 kg/Nm^3)[24].

Data quality

The energy use data are qualified estimates of industrial experts. The need for infrastructure is calculated based on the standard capacity. For the amount of condensates data of a Dutch company is used. The emissions are calculated based on the losses (qualified estimates) and the gas composition. The mercury content is estimated, for the other components published data are available. The freon and halon emissions are taken from the environmental report of a Dutch company.

[24] The calculation of losses in the German pipelines is as follows:
1 Nm^3 / 0.0008 t/Nm^3 * 0.026 / 1000 %/km = 3.22 E-04 Nm^3/tkm.

Tab. 7.13 Unit process raw data of the transport datasets (NAC, RU, RMG, NG and RER)

	Name	Location	InfrastructurePr	Unit	transport, natural gas, onshore pipeline, long distance	transport, natural gas, offshore pipeline, long distance	transport, natural gas, pipeline, long distance	transport, natural gas, pipeline, long distance	transport, natural gas, pipeline, long distance	transport, natural gas, pipeline, long distance
	Location				NAC	NAC	RU	RME	NG	RER
	InfrastructureProcess				0	0	0	0	0	0
	Unit				tkm	tkm	tkm	tkm	tkm	tkm
product	transport, natural gas, onshore pipeline, long distance	NAC	0	tkm	1	0	0	0	0	0
	transport, natural gas, offshore pipeline, long distance	NAC	0	tkm	0	1	0	0	0	0
	transport, natural gas, pipeline, long distance	RU	0	tkm	0	0	1	0	0	0
	transport, natural gas, pipeline, long distance	RME	0	tkm	0	0	0	1	0	0
	transport, natural gas, pipeline, long distance	NG	0	tkm	0	0	0	0	1	0
	transport, natural gas, pipeline, long distance	RER	0	tkm	0	0	0	0	0	1
technosphere	natural gas, burned in gas turbine, for compressor station	DZ	0	MJ	7.22E-1	7.22E-1			7.16E-1	
	natural gas, burned in gas turbine, for compressor station	RU	0	MJ			7.04E-1	7.22E-1		
	natural gas, burned in gas turbine, for compressor station	UCTE	0	MJ						6.62E-1
	natural gas, at production onshore	DE	0	Nm3						2.77E-6
	natural gas, at production offshore	GB	0	Nm3						1.57E-5
	natural gas, at production offshore	NL	0	Nm3						3.11E-5
	natural gas, at production onshore	NL	0	Nm3						4.03E-5
	natural gas, at production offshore	NO	0	Nm3						1.60E-5
	natural gas, at production onshore	NAC	0	Nm3	3.14E-4	3.14E-4				2.48E-5
	natural gas, at production onshore	RU	0	Nm3			2.98E-3			4.94E-5
	natural gas, at production	RME	0	Nm3				3.15E-4		1.70E-5
	natural gas, at production	NG	0	Nm3					3.20E-4	9.17E-6
	pipeline, natural gas, long distance, high capacity, onshore	GLO	1	km	2.59E-9		2.59E-9			
	pipeline, natural gas, long distance, high capacity, offshore	GLO	1	km		1.78E-9				5.95E-10
	pipeline, natural gas, long distance, low capacity, onshore	GLO	1	km				3.56E-9	3.56E-9	2.38E-9
	transport, lorry >16t, fleet average	RER	0	tkm	1.16E-7	1.16E-7	1.16E-7	1.16E-7	1.16E-7	1.16E-7
	disposal, used mineral oil, 10% water, to hazardous waste	CH	0	kg	1.16E-6	1.16E-6	1.16E-6	1.16E-6	1.16E-6	1.16E-6
emission air, low population density	Methane, fossil	-	-	kg	1.62E-4	1.62E-4	1.56E-3	1.66E-4	1.69E-4	1.80E-4
	Ethane	-	-	kg	3.14E-5	3.14E-5	1.31E-5	2.09E-5	1.60E-5	6.69E-6
	Propane	-	-	kg	1.14E-5	1.14E-5	4.37E-6	1.14E-5	1.24E-5	1.54E-6
	Butane	-	-	kg	4.18E-6	4.18E-6	2.19E-6	1.05E-5	9.06E-6	5.14E-7
	Carbon dioxide, fossil	-	-	kg	0	0	2.19E-6	0	0	1.54E-6
	NMVOC, non-methane volatile organic compounds,	-	-	kg	0	0	2.19E-6	0	0	2.57E-7
	Mercury	-	-	kg	2.57E-12	2.57E-12	2.19E-11	2.57E-12	2.57E-12	2.57E-13
	Methane, chlorodifluoro-, HCFC-22	-	-	kg	6.93E-8	6.93E-8	6.93E-8	6.93E-8	6.93E-8	6.93E-8
	Methane, bromochlorodifluoro-, Halon 1211	-	-	kg	2.24E-8	2.24E-8	2.24E-8	2.24E-8	2.24E-8	2.24E-8

Tab. 7.14 Unit process raw data of “Transport, natural gas, pipeline, long distance” (DE)

Explanations	Name	Location	InfrastructureProc	Unit	*transport, natural gas, pipeline, long distance*	UncertaintyType	StandardDeviation 95%	GeneralComment
	Location				*DE*			
	InfrastructureProcess				*0*			
	Unit				*tkm*			
Technosphere	natural gas, burned in gas turbine, for compressor station	DE	0	MJ	7.88E-1	1	1.23	(2,3,1,1,1,5); qualified estimates
	natural gas, at production onshore	DE	0	Nm3	3.22E-4	1	1.26	(2,3,3,1,1,5); published data 1994
	pipeline, natural gas, long distance, low capacity, onshore	GLO	1	km	3.57E-9	1	3.11	(3,3,1,1,3,5); based on estimated standard capacity
	transport, lorry 32t	RER	0	tkm	5.82E-8	1	2.32	(5,1,1,3,3,5); estimates for waste transport
	disposal, used mineral oil, 10% water, to hazardous waste incineration	CH	0	kg	1.16E-6	1	1.23	(2,3,1,3,1,5); based on dutch data
Emissions, air, low population density	Methane, fossil	-		kg	2.22E-4	1	2.11	(2,5,3,1,1,5); calculated based on leakage and gas composition
	Ethane	-		kg	2.57E-6	1	2.11	(2,5,3,1,1,5); calculated based on leakage and gas composition
	Propane	-		kg	3.22E-7	1	2.11	(2,5,3,1,1,5); calculated based on leakage and gas composition
	Carbon dioxide, fossil	-		kg	6.43E-7	1	1.33	(2,5,3,1,1,5); calculated based on leakage and gas composition
	Mercury	-		kg	3.22E-12	1	1.69	(4,5,3,2,1,5); calculated based on leakage and gas composition
	Methane, chlorodifluoro-, HCFC-22	-		kg	6.93E-8	1	1.52	(2,3,1,3,1,3); dutch environmental report + qualified estimates
	Methane, bromochlorodifluoro-, Halon 1211	-		kg	2.24E-8	1	1.52	(2,3,1,3,1,3); dutch environmental report + qualified estimates
Outputs	transport, natural gas, pipeline, long distance	DE	0	tkm	1.00E+0			

Tab. 7.15 Unit process raw data of "Transport, natural gas, pipeline, long distance" (RER)

	Name	Location	InfrastructureProcess	Unit	transport, natural gas, pipeline, long distance	UncertaintyType	StandardDeviation95%	GeneralComment
	Location				RER			
	InfrastructureProcess				0			
	Unit				tkm			
product	transport, natural gas, pipeline, long distance	RER	0	tkm	1			
technosphere	natural gas, burned in gas turbine, for compressor station	DZ	0	MJ		1	1.11	(1,1,3,1,1,1,BU:1.05); qualified estimates;
	natural gas, burned in gas turbine, for compressor station	RU	0	MJ		1	1.07	(2,1,1,1,1,1,BU:1.05); qualified estimates;
	natural gas, burned in gas turbine, for compressor station	UCTE	0	MJ	6.62E-1	1	1.07	(2,1,1,1,1,1,BU:1.05); qualified estimates;
	natural gas, at production onshore	DE	0	Nm3	2.77E-6	1	1.05	(1,1,1,1,1,1,BU:1.05); published data ;
	natural gas, at production offshore	GB	0	Nm3	1.57E-5	1	1.05	(1,1,1,1,1,1,BU:1.05); published data ;
	natural gas, at production offshore	NL	0	Nm3	3.11E-5	1	1.05	(1,1,1,1,1,1,BU:1.05); published data ;
	natural gas, at production onshore	NL	0	Nm3	4.03E-5	1	1.05	(1,1,1,1,1,1,BU:1.05); published data ;
	natural gas, at production offshore	NO	0	Nm3	1.60E-5	1	1.05	(1,1,1,1,1,1,BU:1.05); published data ;
	natural gas, at production onshore	NAC	0	Nm3	2.48E-5	1	1.05	(1,1,1,1,1,1,BU:1.05); published data ;
	natural gas, at production onshore	RU	0	Nm3	4.94E-5	1	1.05	(1,1,1,1,1,1,BU:1.05); published data ;
	natural gas, at production	RME	0	Nm3	1.70E-5	1	1.05	(1,1,1,1,1,1,BU:1.05); published data ;
	natural gas, at production	NG	0	Nm3	9.17E-6	1	1.05	(1,1,1,1,1,1,BU:1.05); published data ;
	pipeline, natural gas, long distance, high capacity, onshore	GLO	1	km		1	3.00	(1,1,1,1,1,1,BU:3); based on estimated standard capacity; Aróstegui 1997
	pipeline, natural gas, long distance, high capacity, offshore	GLO	1	km	5.95E-10	1	3.00	(1,1,1,1,1,1,BU:3); based on estimated standard capacity; Aróstegui 1997
	pipeline, natural gas, long distance, low capacity, onshore	GLO	1	km	2.38E-9	1	3.00	(1,1,1,1,1,1,BU:3); based on estimated standard capacity;
	transport, lorry >16t, fleet average	RER	0	tkm	1.16E-7	1	2.00	(1,1,1,1,1,1,BU:2); estimates for waste transport;
	disposal, used mineral oil, 10% water, to hazardous waste incineration	CH	0	kg	1.16E-6	1	1.05	(1,2,1,1,1,1,BU:1.05); mercury in condensate, based on dutch data; Dutch gas distribution company 2002
emission air, low population density	Methane, fossil	-	-	kg	1.80E-4	1	1.58	(2,4,1,1,1,5,BU:1.5); calculated based on leakage and gas composition;
	Ethane	-	-	kg	6.69E-6	1	1.62	(2,3,1,1,3,5,BU:1.5); calculated based on leakage and gas composition;
	Propane	-	-	kg	1.54E-6	1	1.58	(2,4,1,1,1,5,BU:1.5); calculated based on leakage and gas composition;
	Butane	-	-	kg	5.14E-7	1	1.58	(2,4,1,1,1,5,BU:1.5); calculated based on leakage and gas composition;
	Carbon dioxide, fossil	-	-	kg	1.54E-6	1	1.24	(2,4,1,1,1,5,BU:1.05); calculated based on leakage and gas composition;
	NMVOC, non-methane volatile organic compounds,	-	-	kg	2.57E-7	1	1.58	(2,4,1,1,1,5,BU:1.5); calculated based on leakage and gas composition;
	Mercury	-	-	kg	2.57E-13	1	5.07	(2,4,1,1,1,5,BU:5); calculated based on leakage and gas composition;
	Methane, chlorodifluoro-, HCFC-22	-	-	kg	6.93E-8	1	1.62	(2,3,1,1,3,5,BU:1.5); For cooling of compressor stations and fire protection. Based on dutch environmental report.; Gasunie 1998, Gasunie
	Methane, bromochlorodifluoro-, Halon 1211	-	-	kg	2.24E-8	1	1.62	(2,3,1,1,3,5,BU:1.5); For cooling of compressor stations and fire protection. Based on dutch environmental report.; Gasunie 1998, Gasunie

7.2.6 Inventory of the natural gas transport

Description

The Tables („Natural gas, production (country), at long-distance pipeline") describe the energy and material needs as well as the emissions from the transport of natural gas from the country of production to Europe (RER). The transport distances are weighted average distances of the suppy mix. The dataset includes energy use and losses at the seasonal storage.

The transport datasets of North Africa (NAC), Nigeria (NG) and the Region Middle East (RME) include the pipeline transport from the production site to the liquification and from the evaporation plant to the European pipeline system. Tab. 7.16 and Tab. 7.17 give an overview of the datasets (NAC, NG, RU, RME and DE, NL, NO, GB). In Tab. 7.18 an example is shown including the uncertainty data.

The inventory data differ with respect to the natural gas composition. They are calculated with the specific composition of the respective countries. The losses and energy use for seasonal storage is assumed to be the same for all countries.

Data quality

The data for the enery use are qualified estimates from industrial experts. The emissions are calculated from the losses (qualified estimates) and the natural gas composition. For mercury the concentration is estimated, the remaining data stem from published sources.

Tab. 7.16 Unit process raw data of the new datasets “Natural gas, production XX, at long-distance pipeline” (NAC, NG, RU and RME)

	Name	Location	Infrastruct	Unit	natural gas, production NAC, at long-distance pipeline	natural gas, production NG, at long-distance pipeline	natural gas, production RU, at long-distance pipeline	natural gas, production RME, at long-distance pipeline
	Location				RER	RER	RER	RER
	InfrastructureProcess				0	0	0	0
	Unit				Nm3	Nm3	Nm3	Nm3
	natural gas, production NAC, at long-distance pipeline	RER	0	Nm3	1	0	0	0
	natural gas, production NG, at long-distance pipeline	RER	0	Nm3	0	1	0	0
	natural gas, production RU, at long-distance pipeline	RER	0	Nm3	0	0	1	0
	natural gas, production RME, at long-distance pipeline	RER	0	Nm3	0	0	0	1
technosphere	natural gas, burned in gas motor, for storage	DZ	0	MJ	6.02E-2			
	natural gas, burned in gas motor, for storage	GLO	0	MJ		5.97E-2		6.02E-2
	natural gas, burned in gas motor, for storage	RU	0	MJ			5.46E-2	
	natural gas, at production onshore	NAC	0	Nm3	6.89E-1			
	natural gas, production NAC, at evaporation plant	RER	0	Nm3	3.11E-1			
	natural gas, production NG, at evaporation plant	RER	0	Nm3	0	1.00E+0	0	0
	natural gas, at production onshore	RU	0	Nm3			1.00E+0	
	natural gas, production RME, at evaporation plant	RER	0	Nm3	0	0	0	1.00E+0
	transport, natural gas, offshore pipeline, long distance	NAC	0	tkm	8.18E-2			
	transport, natural gas, onshore pipeline, long distance	NAC	0	tkm	3.03E+0			
	transport, natural gas, pipeline, long distance	RU	0	tkm			4.40E+0	
	transport, natural gas, pipeline, long distance	RME	0	tkm				4.90E-1
	transport, natural gas, pipeline, long distance	NG	0	tkm		9.65E-1		
emission air, low population density	Methane, fossil	-	-	kg	6.29E-5	6.57E-5	7.16E-5	6.45E-5
	Ethane	-	-	kg	1.22E-5	6.23E-6	6.00E-7	8.13E-6
	Propane	-	-	kg	4.42E-6	4.82E-6	2.00E-7	4.42E-6
	Butane	-	-	kg	1.63E-6	3.52E-6	1.00E-7	4.06E-6
	NMVOC, non-methane volatile organic compounds, unspecified origin	-	-	kg	0	0	1.00E-7	0
	Carbon dioxide, fossil	-	-	kg	0	0	1.00E-7	0
	Mercury	-	-	kg	1.00E-12	1.00E-12	1.00E-12	1.00E-12

Tab. 7.17 Unit process raw data of the datasets “Natural gas, production XX, at long-distance pipeline” (DE, NL, NO, GB)

Explanations	Name	Location	InfrastructureProcess	Unit	natural gas, at long-distance pipeline	natural gas, at long-distance pipeline	natural gas, production DE, at long-distance pipeline	natural gas, production DZ, at long-distance pipeline	natural gas, production NL, at long-distance pipeline	natural gas, production NO, at long-distance pipeline	natural gas, production RU, at long-distance pipeline	natural gas, production GB, at long-distance pipeline	natural gas, production NO, at long-distance pipeline	natural gas, production RU, at long-distance pipeline
	Location				CH	RER	RER	RER	RER	RER	RER	RER	RER	RER
	InfrastructureProcess				0	0	0	0	0	0	0	0	0	0
	Unit				Nm3	Nm3	Nm3	Nm3	Nm3	Nm3	Nm3	Nm3	Nm3	Nm3
	natural gas, burned in gas motor, for storage	DE	0	MJ			5.25E-02	5.25E-02		5.25E-02				
	natural gas, burned in gas motor, for storage	DZ	0	MJ				5.96E-02	5.96E-02		5.96E-02			
	natural gas, burned in gas motor, for storage	NL	0	MJ				5.24E-02	5.24E-02	5.24E-02		5.24E-02		
	natural gas, burned in gas motor, for storage	NO	0	MJ					6.12E-02	6.12E-02	6.12E-02	6.12E-02	6.12E-02	
	natural gas, burned in gas motor, for storage	RU	0	MJ						5.46E-02	5.46E-02	5.46E-02		5.46E-02
	natural gas, at production onshore	DE	0	Nm3			1.0001	1.0001		1.0001				
	natural gas, at production onshore	DZ	0	Nm3				5.80E-01	5.80E-01		5.80E-01			
	natural gas, at production onshore	NL	0	Nm3				7.16E-01	7.16E-01	7.16E-01		7.16E-01		
	natural gas, at production offshore	NL	0	Nm3				2.84E-01	2.84E-01	2.84E-01		2.84E-01		
	natural gas, at production offshore	NO	0	Nm3					1.0001	1.0001	1.0001		1.0001	
	natural gas, at production onshore	RU	0	Nm3						1.0001	1.0001	1.0001		1.0001
	natural gas, at production offshore	GB	0	Nm3							1.0001	1.0001	1.0001	
	natural gas, production DE, at long-distance pipeline	RER	0	Nm3				1.00E-1	5.00E-2					
	natural gas, production DZ, at long-distance pipeline	RER	0	Nm3				4.00E-2	1.60E-1					
	natural gas, production GB, at long-distance pipeline	RER	0	Nm3				5.00E-2	4.00E-2					
	natural gas, production NL, at long-distance pipeline	RER	0	Nm3				2.80E-1	2.40E-1					
	natural gas, production NO, at long-distance pipeline	RER	0	Nm3				1.70E-1	1.70E-1					
	natural gas, production RU, at long-distance pipeline	RER	0	Nm3				3.60E-1	3.40E-1					
	transport, natural gas, pipeline, long distance	DE	0	tkm			4.80E-1	4.80E-1		4.80E-1				
	natural gas, production DZ, at evaporation plant	RER	0	Nm3				4.20E-1	4.20E-1		4.20E-1			
	transport, natural gas, offshore pipeline, long distance	DZ	0	tkm				4.64E-2	4.64E-2		4.64E-2			
	transport, natural gas, onshore pipeline, long distance	DZ	0	tkm				1.20E+0	1.20E+0		1.20E+0			
	transport, natural gas, pipeline, long distance	NL	0	tkm				5.60E-1	5.60E-1	5.60E-1		5.60E-1		
	transport, natural gas, offshore pipeline, long distance	NO	0	tkm					4.80E-1	4.80E-1	[illegible]	2.00E-1	[illegible]	
	transport, natural gas, onshore pipeline, long distance	NO	0	tkm					6.40E-1	6.40E-1	[illegible]	2.00E-1	[illegible]	
	transport, natural gas, pipeline, long distance	RU	0	tkm						4.80E+0	4.80E+0	4.80E+0		4.80E+0
Emissions, air, low population density	Methane, fossil	-		kg			6.90E-5	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	7.16E-5
	Ethane	-		kg			8.00E-7	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	6.00E-7
	Propane	-		kg			1.00E-7	[illegible]	[illegible]	[illegible]	[illegible]	2.00E-7	1.90E-6	2.00E-7
	Butane	-		kg				[illegible]	[illegible]	[illegible]	[illegible]	1.00E-7	6.00E-7	1.00E-7
	Carbon dioxide, fossil	-		kg			2.00E-7	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1.00E-7
	NMVOC, non-methane volatile organic compounds, unspecified origin	-		kg					2.00E-7	[illegible]	[illegible]	[illegible]	[illegible]	1.00E-7
	Mercury	-		kg			1.00E-12	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	2.00E-12	1.00E-12

Tab. 7.18 Unit process raw data of “Natural gas, production DE, at long-distance pipeline”

Explanations	Name	Location	InfrastructureProcess	Unit	natural gas, production DE, at long-distance pipeline	UncertaintyType	StandardDeviation 95%	GeneralComment
	Location				RER			
	InfrastructureProcess				0			
	Unit				Nm3			
Technosphere	natural gas, burned in gas motor, for storage	DE	0	MJ	5.25E-02	1	1.31	(4,1,1,1,3,3); Data from german industrial expert for 2001, standard technology
	natural gas, at production onshore	DE	0	Nm3	1.0001	1	1.22	(4,1,1,1,1,3); Data for leckages from german industrial expert for 2001
	transport, natural gas, pipeline, long distance	DE	0	tkm	4.80E-1	1	2.01	(2,1,1,1,1,1); Average weighted distance is estimated based on production statistics.
Emissions, air, low population density	Methane, fossil	-		kg	6.90E-5	1	2.01	(2,1,1,1,1,1); calculated based on losses and composition
	Ethane	-		kg	8.00E-7	1	2.01	(2,1,1,1,1,1); calculated based on losses and composition
	Propane	-		kg	1.00E-7	1	2.01	(2,1,1,1,1,1); calculated based on losses and composition
	Carbon dioxide, fossil	-		kg	2.00E-7	1	2.01	(2,1,1,1,1,1); calculated based on losses and composition
	Mercury	-		kg	1.00E-12	1	1.64	(4,1,3,2,3,3); calculated based on losses and estimation of Hg-content
Outputs	natural gas, production DE, at long-distance pipeline	RER	0	Nm3	1.00E+0			

7.3 Transport of Liquefied Natural Gas

Liquefied natural gas (LNG) makes up roughly a third of the global natural gas trade. 16 % of the natural gas imports to Europe are supplied as LNG (BP 2011). Natural gas imports from Northern Africa are supplied partly as LNG (31 %) and partly by pipeline (69 %), while all natural gas imported from the Middle East and Nigeria is delivered as LNG. Minor shares of LNG are also imported from Trinidad and Tobago, Peru and the United States. Due to the small amounts no specific supply chains were created for these proveniences. These imported amounts are attributed to Nigeria.

7.3.1 Natural Gas Liquefaction

Prior to the liquefaction the natural gas is transported by pipeline to the coast. It is then cooled down in a liquefaction plant to -161°C. At this temperature the natural gas is in its liquid state and the volume decreases to 1/600 of the normal state. 15 % of the natural gas is used up in the liquefaction process (Cerbe et al. 1999). Prior to the transport on special ships the LNG is stored in intermediate storage tanks which can hold a volume of up to 200’000 m^3. The interior tank is constructed with pressure-proof aluminium or 9 %-nickel steel, the outer shell with carbon steel or concrete. Thermal insulation materials such as mineral wool and polystyrene are used in between these two layers.

According to <Selzer et al. 1990> the worldwide methane emissions of the natural gas liquefaction are about 0.73 billion m^3. With the corresponding LNG annual production rate of 72 bcm (as gaseous natural gas according to <Cédigaz 1991>) this equals to a leakage rate of about 1.1 % of the output to Europe. In IGU (2000b) the emissions from LNG-plants (liquefaction or evaporation) is stated as 0.05 % of the turnover. This latter value is used in this study.

It is further assumed that the infrastructure needs of the liquefaction and evaporation plants is twice as high as for the drying plant (see Section 6.3.4, infrastructure), since liquefaction plants are likely to be more complex.

The inventory data of the natural gas liquefaction are summed up in Tab. 7.19.

Tab. 7.19 Unit process raw data of “Natural gas, liquefied, at liquefaction plant” (NAC, RME, NG)

	Name	Location	InfrastructureProcess	Unit	natural gas, liquefied, at liquefaction plant	natural gas, liquefied, at liquefaction plant	natural gas, liquefied, at liquefaction plant	UncertaintyType	StandardDeviation95%	GeneralComment
	Location				NAC	RME	NG			
	InfrastructureProcess				0	0	0			
	Unit				Nm3	Nm3	Nm3			
	natural gas, liquefied, at liquefaction plant	NAC	0	Nm3	1	0	0			
	natural gas, liquefied, at liquefaction plant	RME	0	Nm3	0	1	0			
	natural gas, liquefied, at liquefaction plant	NG	0	Nm3	0	0	1			
technosphere	natural gas, burned in gas motor, for storage	DZ	0	MJ	6.02E+0		5.97E+0	1	1.05	(1,1,1,1,1,1,BU:1.05); ; Cerbe 1999
	natural gas, burned in gas motor, for storage	RU	0	MJ		6.02E+0		1	1.05	(1,1,1,1,1,1,BU:1.05); ; Cerbe 1999
	natural gas, at production onshore	DZ	0	Nm3	1.00E+0			1	1.05	(1,1,1,1,1,1,BU:1.05); average data for leakages;
	natural gas, at production	RME	0	Nm3		1.00E+0		1	1.05	(1,1,1,1,1,1,BU:1.05); average data for leakages;
	natural gas, at production	NG	0	Nm3			1.00E+0	1	1.05	(1,1,1,1,1,1,BU:1.05); average data for leakages;
	production plant, natural gas	GLO	1	unit	7.89E-13	7.89E-13	7.89E-13	1	3.00	(1,1,1,1,1,1,BU:3); estimation for infrastructure;
emission air, low population density	Methane, fossil	-	-	kg	3.14E-4	3.23E-4	3.29E-4	1	1.50	(1,1,1,1,1,1,BU:1.5); based on leakage rate (0.05%) and gas composition; IGU 2000
	Ethane	-	-	kg	6.10E-5	4.07E-5	3.12E-5	1	1.50	(1,2,1,1,1,1,BU:1.5); based on leakage rate (0.05%) and gas composition; IGU 2000
	Propane	-	-	kg	2.21E-5	2.21E-5	2.41E-5	1	1.58	(2,4,1,1,1,5,BU:1.5); based on leakage rate (0.05%) and gas composition; IGU 2000
	Butane	-	-	kg	8.13E-6	2.03E-5	1.76E-5	1	1.62	(2,3,1,1,3,5,BU:1.5); based on leakage rate (0.05%) and gas composition; IGU 2000
	Mercury	-	-	kg	5.00E-12	5.00E-12	5.00E-12	1	5.07	(2,4,1,1,1,5,BU:5); based on leakage rate (0.05%) and gas composition; IGU 2000

7.3.2 Storage and ship transportation of LNG

Typically the storage and transport time of LNG are very short. The duration of storage is between 1 and 1.5 days (Cerbe et al. 1999). With a service life time of the tank of 50 years this leads to 9‘000 turnover cycles per tank. Therefore the material use per unit natural gas is very small. In this study the material use for the tanks is therefore not included.

LNG-tankers with a storage volume up to 135'000 m^3 are constructed in two different ways: self-supporting tanks (spherical tanks) and membrane tanks. Spherical tanks are exclusively built with aluminium. They have a diameter of up to 40.5 m with a storage volume of 33'700 m^3. The wall thickness is about 40-70 mm. The equator ring has a thickness of up to 200 mm.

Membrane tanks are constructed with sheet-invar skin (36 % nickel content). The perlite insulation layer is arranged in plywood boxes (Cerbe et al. 1999). The additional material needed to ship LNG is neglected for the same reasons as mentioned above for the onshore storage.

When the tanks are emptied a small share of the LNG is left in them for the cooling of the tanks on the journey back. An evaporation rate of 0.15 %/d is calculated, relative to the tank volume. For a tanker with 135'000 m^3 storage volume that means 200 m^3 LNG or about 120'000 Nm^3 of evaporated natural gas per day. The evaporated natural gas is used as fuel on the transport ships. Usually LNG-tankers are operated with steam turbines of up to 30'000 kW capacity. The average velocity is 20 nautical miles per hour (Cerbe et al. 1999). For the transport distance with the LNG tanker the average distances are estimated based on the weighted average distance to the receiving ports.

In Snam (1999; 2000) the energy use of the LNG-tankers is reported to be about 8.8-9.7E-03 Nm^3/tkm, which equals about 0.33 MJ/tkm. In Sagisaka & Inaba (1999) the energy use is stated to be 0.23 MJ/tkm. The authors explain the better value with improved technology. For this study the value from Snam (1999; 2000) is used, because it is more representative for the situation in the Mediterranean Sea. The ship reaches a medium lifetime transport service of 2‘000‘000 vehicle kilometers, in accordance with Spielmann et al. (2004). Since the tankers return empty, an average load of 20'600 t (40 % [25]) is calculated with reference to Snam (1999).

It is assumed that the waste water contains about 10 % bilge oil, which has to be disposed of. Values for the average amount of the waste water for the year 98/99 are taken from Snam (1999; 2000) (2.18 E-03 kg/tkm).

The inventory data of the LNG transport is summed up in the Tab. 7.21 and Tab. 7.22.

The transport distances are estimated with the online distance calculator Portworld and weighted according to the shares imported by the various European countries. Tab. 7.20 gives an overview of the transport distances and the values used in this study. LNG from North Africa is transported on average 920 km, from the Middle East 9970 km and from Nigeria 5930 km (one way).

[25] The load of 20'600 t with a utilization of 40 % is valid for an average high sea cargo ship.

Tab. 7.20: Shipping transport distances of LNG imported to Europe (estimated with: www.portworld.com)

Importing country	Northern Africa Distance (km)	Northern Africa % of export	Nigeria Distance (km)	Nigeria % of export	Middle East Distance (km)	Middle East % of export
Belgium	3100	1%	7400	1%	11700	17%
France	800	35%	7200	24%	8500	7%
Greece	2000	5%	-	-	-	-
Italy	1000	12%	-	-	7400	18%
Portugal	-	0%	5500	18%	9700	0%
Spain	500	40%	5500	53%	8900	17%
United Kingdom	2700	7%	5500	3%	11100	41%
Average	918		5935		9974	
This study	**920**		**5930**		**9970**	

Tab. 7.21: Unit process raw data of "Transport, liquefied natural gas, freight ship"

	Name	Location	Infrastru	Unit	transport, liquefied natural gas, freight ship	UncertaintyType	StandardDeviation95%	GeneralComment
	Location				OCE			
	InfrastructureProcess				0			
	Unit				tkm			
technosphere	natural gas, at production onshore	NAC	0	Nm3	9.35E-3	1	1.05	(1,1,1,1,1,1,BU:1.05); environmental report italian company;
	transport, lorry >16t, fleet average	RER	0	tkm	1.09E-5	1	2.00	(1,1,1,1,1,1,BU:2); environmental report italian company;
	disposal, bilge oil, 90% water, to hazardous waste incineration	CH	0	kg	2.18E-4	1	1.05	(1,1,1,1,1,1,BU:1.05); estimates for waste transport;
	transoceanic freight ship	OCE	1	unit	2.43E-11	1	3.00	(1,1,1,1,1,1,BU:3); assumptions on the basis of older data;
	maintenance, transoceanic freight ship	RER	1	unit	2.43E-11	1	3.00	(1,2,1,1,1,1,BU:3); assumptions on the basis of older data;
	operation, maintenance, port	RER	1	unit	2.43E-11	1	3.06	(2,4,1,1,1,5,BU:3); assumptions on the basis of older data;
resource, in water	Water, salt, ocean	-	-	m3	1.12E-2	1	1.31	(2,3,1,1,3,5,BU:1.05); estimates based on environmental report italian company;
emission air, low population density	Methane, fossil	-	-	kg	2.12E-6	1	1.58	(2,4,1,1,1,5,BU:1.5); emissions from standard turbine;
	Carbon dioxide, fossil	-	-	kg	2.12E-2	1	1.24	(2,4,1,1,1,5,BU:1.05); emissions from standard turbine;
	Carbon monoxide, fossil	-	-	kg	1.49E-5	1	5.07	(2,4,1,1,1,5,BU:5); emissions from standard turbine;
	NMVOC, non-methane volatile organic compounds, unspecified origin	-	-	kg	3.72E-7	1	1.62	(2,3,1,1,3,5,BU:1.5); emissions from standard turbine;
	Nitrogen oxides	-	-	kg	7.22E-5	1	1.62	(2,3,1,1,3,5,BU:1.5); emissions from standard turbine;
	Dinitrogen monoxide	-	-	kg	3.72E-7	1	1.62	(2,3,1,1,3,5,BU:1.5); emissions from standard turbine;

Tab. 7.22 Unit process raw data of “Natural gas, liquefied, at freight ship”

	Name	Location	Infrastru	Unit	natural gas, liquefied, at freight ship	natural gas, liquefied, at freight ship	natural gas, liquefied, at freight ship	UncertaintyType	StandardDeviation95%	GeneralComment
	Location				NAC	RME	NG			
	InfrastructureProcess				0	0	0			
	Unit				Nm3	Nm3	Nm3			
	natural gas, liquefied, at freight ship	NAC	0	Nm3	1	0	0			
	natural gas, liquefied, at freight ship	RME	0	Nm3	0	1	0			
	natural gas, liquefied, at freight ship	NG	0	Nm3	0	0	1			
technosphere	natural gas, liquefied, at liquefaction plant	NAC	0	Nm3	1.00E+0	1.00E+0	1.00E+0	1	1.05	(1,1,1,1,1,1,BU:1.05); ;
	transport, liquefied natural gas, freight ship	OCE	0	tkm	7.53E-1	8.14E+0	4.77E+0	1	2.00	(1,1,1,1,1,1,BU:2); Weighted average distances based on export statistics.; BP 2011

7.3.3 Evaporation plant

In the landing terminals the LNG is discharged with pumps and evaporated at pipeline pressure. Mostly sea water is used for the evaporation and cooled down by six degrees in the process <Cerbe 1988> and (SNAM 2002). For peak load steam boilers up to 2 % of the natural gas input are used <Sargent & Lundy 1976>. In SNAM (2002) a consumption of 0.016 Nm^3/Nm^3 is shown, this value is used in this study. The evaporated LNG is transported to the customer via onshore pipelines. Methane emissions from the evaporation are declared as 3.5E-04 kg Methan/m^3 in SNAM (2002).

The inventory data of natural gas at the evaporation plant are summarised in Tab. 7.23.

Tab. 7.23 Unit process raw data of “Natural gas, production (country), at evaporation plant” for NAC, RME and NG

	Name	Location	InfrastructureProcess	Unit	natural gas, production NAC, at evaporation plant	natural gas, production RME, at evaporation plant	natural gas, production NG, at evaporation plant	UncertaintyType	StandardDeviation95%	GeneralComment
	Location				RER	RER	RER			
	InfrastructureProcess				0	0	0			
	Unit				Nm3	Nm3	Nm3			
	natural gas, production NAC, at	RER	0	Nm3	1	0	0			
	natural gas, production RME, at	RER	0	Nm3	0	1	0			
	natural gas, production NG, at	RER	0	Nm3	0	0	1			
technosphere	natural gas, burned in gas turbine, for compressor station	DZ	0	MJ	6.42E-1		6.37E-1	1	1.05	(1,1,1,1,1,1,BU:1.05); Environmental Report for Italian Plant, emissions are already included in this dataset;
	natural gas, burned in gas turbine, for compressor station	RU	0	MJ		6.42E-1		1	1.05	(1,1,1,1,1,1,BU:1.05); Environmental Report for Italian Plant, emissions are already included in this dataset;
	natural gas, liquefied, at freight ship	NAC	0	Nm3	1.00E+0			1	1.05	(1,1,1,1,1,1,BU:1.05); Natural gas
	natural gas, liquefied, at freight ship	RME	0	Nm3		1.00E+0		1	1.05	(1,1,1,1,1,1,BU:1.05); ;
	natural gas, liquefied, at freight ship	NG	0	Nm3			1.00E+0	1	1.05	(1,1,1,1,1,1,BU:1.05); ;

7.4 Data quality long-distance transport

The data representing the long-distance transport of natural gas are of good quality. The data for material and energy use from different sources (literature and operators) show a good correlation.

Reliable information sources are available to model the construction of pipelines. Uncertainties exist with respect to the service lifetime of the pipelines and the average load (influence of short and long term fluctuations). There is very few data available on the disposal of pipelines, which however does hardly affect the overall quality of the data.

No country specific data are available about the leakages in the North African and Nigerian pipelines.

8 Life cycle inventory of regional distribution

8.1 Overview

This chapter describes the regional distribution of natural gas in seventeen European countries. In Switzerland roughly 80 % of the natural gas is distributed from the transit pipelines by Swissgas AG and the regional companies Erdgas Ostschweiz AG, Gasverbund Mittelland AG, Gaznat SA and others (SWISSGAS 2001a). The remaining natural gas is imported directly from abroad in the border regions (Geneva, Ticino, and North-Eastern Switzerland).

The distribution companies run measuring and pressure-reducing stations, in which the pressure is reduced from about 70 bar (high-pressure in the transit pipelines) to about 0.1 bar (at the beginning of the low-pressure network). Larger consumers obtain the natural gas directly from the distribution line (0.1-1 bar overpressure). For the supply of small consumers the natural gas is fed into the local gas supply system (description in Chapter 9).

In this chapter the regional distribution system is described based on a top-down approach. The specific material use per unit of natural gas distributed is calculated based on the Swiss pipeline inventory and a medium term average load. A more precise bottom-up calculation ("how much natural gas is transported by each pipeline section during its lifetime") is not possible due to the complexity of the network and a lack of information. The Swiss data serve as a basis for the other examined countries.

For the regional distribution and the local natural gas supply no precise data about their average load are available. The official natural gas sales statistics (Eurogas 2001) focuses on economic sectors rather than the pressure levels. In line with <Infras 1981> it is assumed that power plants are connected to the high- and medium pressure network while households obtain their natural gas from the low-pressure network. According to SWISSGAS[26] about 63 % of the natural gas supplied in Switzerland to the industry and 95 % of the natural gas supplied to the trade and business sector are obtained from the low-pressure network.

In Europe the proportions are slightly different since major industry plays an important role there. In line with <Infras 1981> and SWISSGAS[26] it is assumed, that 20 % of the natural gas procurement of industry and 50 % of the gas procurements of the trade and business sector stem from the low-pressure network. This leads to the following estimations for the natural gas supplies in the year 2000 (see Tab. 8.1).

[26] Personal information by Mr. Kreber, E-mails from 4.9.2002 and 5.9.2002

Tab. 8.1 Natural gas supply from the different pressure levels in Europe and Switzerland. Total consumption from (Eurogas 2001)>; The shares of low pressure supply in industry and trade/business are based on assumptions

	HP/MP	LP	Total	Share of HP/MP	Share of LP	Share of LP in industry	Share of LP in trade/business
	PJ/a 1)	PJ/a 1)	PJ/a 1)	%	%	%	%
Switzerland	20	93	113	18%	82%	63%	95%
Austria	155	128	283	55%	45%	20%	50%
Belgium	382	240	622	61%	39%	20%	50%
Czech Republic	190	166	356	53%	47%	20%	50%
Denmark	106	73	180	59%	41%	20%	50%
Finland	118	41	159	74%	26%	20%	50%
France	775	880	1655	47%	53%	20%	50%
Germany	1647	1603	3250	51%	49%	20%	50%
Greece	73	4	77	94%	6%	20%	50%
Hungary	236	211	448	53%	47%	20%	50%
Ireland	124	35	160	78%	22%	20%	50%
Italy	1582	1100	2683	59%	41%	20%	50%
Netherlands	924	669	1593	58%	42%	20%	50%
Slovakia	158	128	286	55%	45%	20%	50%
Spain	487	218	705	69%	31%	20%	50%
Sweden	21	16	38	57%	43%	20%	50%
United Kingdom	2037	1752	3789	54%	46%	20%	50%
EU 15 2)	8525	6793	15318	56%	44%	20%	50%

1) Gross calorific value 39 MJ/m^3 according to (Eurogas 2001)

2) EU 15: The members of EU 15 are AT, BE, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, NL, PT, SE.

HP – high pressure, MP – medium pressure LP – low pressure

The process step "Regional distribution" is connected to the natural gas supply chain via the inputs "Pipeline, natural gas, high pressure distribution network/CH and RER, respectively" (manufacture of the pipeline system) and "Natural gas, at long-distance pipeline" for DE, NAC, NL, NO, RU (natural gas supply from producing regions and countries). The outputs are „Natural gas, high pressure, at consumer" in the countries AT, BE, CH, CZ, DE, DK, ES, FI, FR, GB, GR, HU, IE, IT, NL, SE, SK and Europe (RER), as well as JP and RNA. The natural gas production and distribution for Japan (no domestic production) and North America are described separately in the Chapter 10 and 11.

8.2 Infrastructure

8.2.1 Material use

The Swiss distribution network was constructed in the early 1970ies and has been further developed in the last two decades. Thus the age of the pipelines varies considerably. Since most of the pipelines are no older than 40 years few practical experiences exist to their achievable service life. Analogue to the long-distance transport the steel pipelines used in the regional distribution system have a service life of more than 40 years. For modern plastic pipes similar life times are expected <Fasler 1992>. Older plastic pipelines will show first damages after 15 years <Wiget 1992>. A common time span for distribution companies to write off the pipelines is 20-25 years <Zeder 1992>.

In this study a service life of 40 years is assumed. No differentiation is made for the different pipeline types, since there are no qualified data available. The material use is summed up in Tab. 8.4.

The following section presents the inventory of the natural gas distribution network in the year 2000. It is assumed that this network can provide the average natural gas sales of the year 2000 during 40 years. This leads to an average load of about 30 TJ/km*a (Tab. 8.2). It is questionable whether this simplified assumption is justified. Tab. 8.2 shows the development of natural gas sales in Switzerland from 1996 to 2000. In this time period the values range from 29 to 32 TJ/km*a, which is in the range of the average load.

Tab. 8.2 Pipeline length, natural gas sales and average load of the Swiss natural gas distribution system

Year	Total pipeline length (high- and medium pressure) [1]	Gas sales	Average load
	km	PJ/a [2]	TJ/km
1996	3479	110	31.6
1997	3601	107	29.6
1998	3677	110	29.9
1999	3743	114	30.4
2000	3777	113	30.0
Source	(VSG 2001)	(BFE 2001)	

[1] The share of the high- and medium-pressure pipelines on the total pipeline length is set as 29 % (1996 data, without long-distance pipelines above 5 bar, in (Seifert 1998)

[2] Gross calorific value 39 MJ/m^3 according to (Eurogas 2001)

Due to the increasing demand for natural gas and supporting technical measures (e.g. the construction of daily and weekly storage) the average load is likely to rise. It is assumed that the load of the Swiss natural gas network in 2000 represents an average of the 1990ies. This value is also used for the network in countries other than Switzerland (Tab. 8.3).

Tab. 8.3 Pipeline length by the end of 1999, natural gas sales in 2000 and average load of the European natural gas distribution network (Eurogas 2001)

	Transmission	Distribution	Total sales 2000	Load
	km	km	PJ	TJ/km
Switzerland	2147	13050	113	30
Austria	5213	24099	283	29
Belgium	3731	47000	622	33
Czech Republic	3350	50958	356	17
Denmark	1415	16889	180	27
Finland	955	1245	159	319
France	34232	159020	1655	12
Germany	57000	299000	3250	19
Greece	961	1870	77	103
Hungary	5214	58754	448	19
Ireland	1199	6944	160	58
Italy	30500	180000	2683	37
Netherlands	11600	117500	1593	34
Slovakia	5725	18195	286	39
Spain	11989	25033	705	70
Sweden	530	1900	38	49
United Kingdom	18600	260700	3789	36
EU 15	177004	1138128	15318	34

An inventory of the pipelines with their composition can be found in SVGW/SSIGE (2002) for the year 2001 (Tab. 8.4). Four pressure levels are distinguished in the network:

- High pressure > 5 bar overpressure
- High pressure 1 - 5 bar overpressure
- Medium pressure 0.1 - 1 bar overpressure
- Low pressure <0.1 bar overpressure

The low-pressure network is described in Chapter 9. For the European countries only the high and medium pressure network is described. The values shown below are used to describe the Swiss distribution network.

Tab. 8.4 Pipeline length and used materials for Switzerland in 2001 (SVGW/SSIGE 2002)

	High pressure > 5 bar	High pressure 1-5 bar	Medium pressure 0.1-1 bar
	km	km	km
Steel	2147	1408	355
Grey cast			2
Ductile cast		88	98
Plastic (PE)		1251	680
Total	2147	2747	1135

Reichert (2000) shows the pipeline length of the German network with the materials used (s. Tab. 8.5). These values are used to describe the average European distribution network. The long-distance network is described in Chapter 7.

Tab. 8.5 Pipeline lengths and material used in Germany (Reichert & Schön 2000). Due to different categories and older data the data for long-distance pipelines don't coincide perfectly with the value for "transmission" shown in Tab. 8.3.

	Long-distance pipelines	HP network	MP network
	km	km	km
Steel	44555	44562	32067
Grey cast	-	0	81
Ductile cast	-	489	1443
Plastic	-	3679	83738
Total	44555	48730	117329

Tab. 8.6 shows the material use per km for the different pipeline types.

Tab. 8.6 Material use per km for the pipelines in the regional natural gas distribution network. The material use refers to the companies Swissgas, GVM, GVO, Gaznat, Unigaz, Gansa, EGZ und a few larger local gas suppliers.

		Average diameter	Average wall thickness 1)	Specific material needs 2)
		<Swissgas 1990>		
		mm	mm	kg/km
> 5 bar	Steel 3)	275	6	42’000
1 - 5 bar	Steel 3)	225	5.5	31’500
	Ductile cast	240	6.5	36’200
	HDPE	200	7.5	4’600
0.1 - 1 bar	Steel	150	5	19’200
	Ductile cast	180	6	25’200
	HDPE	150	7	3’300

1) Sources: <Fasler 1992>, <Seifert 1992>, <Keller 1992>, <Zeier et al. 1990>.

2) Density: steel 7'900 kg/m^3; ductile cast 7'200 kg/m^3; HDPE 950 kg/m^3.

3) Since no differentiation is made for the two high pressure levels in (Reichert & Schön 2000) the European high pressure pipelines are calculated with an average of 36'000 kg steel per km.

The metallic pipelines are coated with a polyethylene film or bitumen to protect them from corrosion (Tab. 8.7, see also Section 7.2.1). It is assumed that 75 % of the pipelines are coated with low-density-PE and 25 % with bitumen. Plastic pipelines need no further coating.

Tab. 8.7 Coating of the regional distribution pipelines

Material	Specif. material use 1)
	t/km
LD-PE	1.6
Bitumen	2.4

1) 2.2 mm thick LDPE film (density 0.92 t/m^3) or 3.0 mm thick bitumen layer (density 1.01 t/m^3).

Typical trench profiles and material requirements for the bedding of the pipelines (mostly sand) are displayed in Tab. 8.8.

Tab. 8.8 Trench profiles and pipeline bedding materials for pipelines in the natural gas regional distribution network <Keller 1992>, <SKS 1992>, <Öhrli 1991>

	Trench profile	Specific sand use 1)	Specific cement use 1)
	m x m	kg/m	kg/m
> 1 bar	0.8 x 1.5	1'000	26
0.1 - 1.0 bar	0.6 x 1.2	600	26

1) About 85 % of the pipelines are bedded on sand. The sand fills roughly one third of the trench profile. The other 15 % of the pipelines are coated with fibre cement mortar (about 12 mm thick layer) and directly covered with soil <Fasler 1992>. Density sand: 2.6 t/m^3; density fibre cement mortar: 2.8 t/m^3.

The material use for the valves (gate valves, pressure reducing unit, pig traps etc.) is included in the data for the pipelines. Additionally smaller buildings and switch cabinets are needed which accommodate the valves. For the buildings no statistical data are available. For this study the data from <Balzari et al. 1992> for a 100 km long pipeline are used (pipeline Ruswil-Mülchi-Altavilla) which are extrapolated to the total length of the pipeline system of the various regional distribution networks. This rough estimation results in the following values for 1000 km regional distribution pipeline system:

- about 140 slide valve control cabinets (about 10 m^3 per metal construction <Fasler 1992>)
- about 10 gas transfer stations (about 1'000 m^3 per massive construction)
- about 10 gas transfer stations (about 300 m^3 per massive construction)
- about 10 pressure reducing measuring stations (about 300 m^3 per massive construction).

These premises are modelled with the dataset “building, multi-storey” (massive construction) and “building, hall, steel construction” (metal construction). For the calculation of the surface due to lack of more precise data a building height of 7 meters is assumed.

In densely populated areas special constructional measures are used to overcome obstacles. For instance, the following objects needed to be crossed underneath during the construction of the natural gas pipeline Malters-Hünenberg (25 km length) which connects the existing pipeline system of the canton of Lucerne with the region Zug <Zeier et al. 1990>:

- 1 cantonal road
- 1 line of the Swiss Federal Railways (SBB)
- 1 highway
- 2 highway exits
- 1 local road
- 2 times the river Reuss
- Various creeks

For the crossing below streets and train lines the natural gas pipelines are embedded in concrete mantle pipes (diameter about 1 m). The mantle pipes are introduced to the ground with the use of special contractors. In special cases concrete channels may be necessary. A simple concrete mantle is usually sufficient when crossing smaller and larger watercourses. These are lowered into the water by using special cranes called side booms. For the undercrossing of rivers siphon pipes are used <Zeier et al. 1990>, <Keller 1992>.

The additional material use needed to overcome special obstacles is roughly estimated. The data are shown in Tab. 8.9 as an average of the whole distribution system. Compared to the other installation the material use is modest thus justifying this rough estimation.

Tab. 8.9 Additional material use in the construction of gas distribution pipelines due to special obstacles

	Concrete filling	Concrete mantle pipe	Reinforced concrete structures
	t/km	t/km	t/km
Undercrossing of streets		3	1
Undercrossing of rivers	1		1

Whether or not pipelines will be excavated when they reached the end of their service life remains unclear. The excavation is uneconomical. In the case of replacement however, often old trenches are used, in which case the old pipes can be recycled. It is assumed in this study that about 50 % of the pipelines are excavated, the metallic components of which are recycled, and 50 % remain in the ground. Further it is assumed that the bitumen mantle and plastic pipelines are disposed of in a landfill and are incinerated in a MWI plant, respectively. The pipelines which remain in the ground are also modelled as if disposed of in the landfill.

8.2.2 Construction and transport expenses

The construction of a high pressure natural gas pipeline has already been described in Chapter 7. This section focuses on the energy and material use for the construction of the regional distribution system in Switzerland. Building machines are used in the construction, which is modelled with the datasets “excavation, skid-steer loader” and “excavation, hydraulic digger”. Tab. 8.10 gives an overview of the necessary work for the construction of the regional distribution network.

Tab. 8.10 Work for the construction of natural gas distribution pipelines

Construction machine/ constr. work	Profile 1)	Excavation volume
		m^3/km
Skid-steer loader / Humus erosion	18 m x 0.5 m	9'000
Hydraulic digger/ Trench excavation	0.8 m x 1.5 m	1'200
Skid-steer loader / Filling up of the trench		10'000

1) <Keller 1992>, <SKS 1992>, <Oehrli 1991>

The transport of the materials to and from the construction site is calculated using standard distances. The superfluous soil is used elsewhere and is therefore considered to be a by-product of the pipeline construction.

8.2.3 Surveillance

The pipelines need to be controlled frequently for breakages. The potential damage from construction works in the proximity of the pipelines is particularly feared. According to <SKS 1992> and <Fasler 1992> the Swiss distribution pipelines are controlled at least once a month by car and foot. For this study we calculate with 960 passenger car km per km pipeline over 40 years. In addition to this the pipelines are controlled via helicopters once a month <Fasler 1992>. Projected to 40 years this means 480 km helicopter flight per km of pipeline.

For Europe a helicopter flight every two weeks is assumed for the whole pipeline length. This results in 26 km per year and km pipeline or a total of 1040 km[27].It is assumed that per flight 250 km are flown in 2.5 hours. Per flight kilometre 0.01 h of flight and 0.004 LTO (Landing and Take-Off)-cycles are needed. The helicopter controls are only used for the main (high pressure) pipelines.

8.2.4 Land use

The land use is relevant in the construction and the operation phases. Most of the surface areas that are affected are agricultural areas. During the planning of the pipeline layout it is ensured that the use of forest and nature preservation areas is minimised. According to more recent pipeline projects (<SKS 1992>, <Balzari et al. 1992> and <Fasler 1992>) this share is lower than 15 % of the area needed.

During the operation phase a security zone is installed 10 m to the left and the right of the pipeline. This zone needs to be accessible for control and maintenance works <Défago 1992>. Therefore the utilisation for agriculture and recreational activities is possible but the forest cannot be reafforested. A land transformation from “forest” to “agriculture” is assumed for the cleared land.

The construction phase is estimated to last 2 months and the operation phase 40 years analogue to Chapter 7. In the original state 10 % of the land used are forest land and 90 % agricultural land. The agricultural use of the land is not considered in the inventory of the pipeline infrastructure since it belongs to the agricultural system. The land use change from forest to agricultural land however is included in this inventory.

27 Personal information by Mr..Fasold, Ruhrgas, 18.12.2001.

8.2.5 Inventory data

The following tables ("Pipeline, natural gas, high pressure distribution network", Tab. 8.11 and Tab. 8.12) describe the infrastructure needed for the high pressure network in Switzerland and Europe. Material, construction and land use are included. The inventory data of pipelines in Europe differ with respect to the pipeline materials used, the corresponding transport and the frequency of surveillance. An average service lifetime of 40 years is assumed for all pipelines.

Data quality

Good statistical data is available regarding the material used and the length of the pipeline system in Switzerland. No such statistics are known for Europe, only the study by Reichert (2000) presents similar data for German pipelines. These data are used to model European pipelines. The values used for the material and construction needs are largely based on qualified estimates.

The Swiss regional distribution system is depicted quite accurately. The data about the material composition are however rather outdated. In most cases they stem from the distributing companies. Newer data exist (e.g. SVGW 2010) they have however not been included in the inventory yet. For European pipelines a standard network is defined as the basis for modelling. The data used are specific for Germany and of good quality.

The "regional distribution" system is fairly easy to oversee, since it consists almost exclusively of pipelines. The aggregation level is therefore very low and the data completeness high.

The reference value, the natural gas sold during the service life, is subject to uncertainties. It is assumed that the year 2000 data represent a typical load. For the average service lifetime little practical experience exists, thus the chosen value is subject to uncertainty as well.

Tab. 8.11 Unit process raw data of "pipeline, natural gas, high pressure distribution network" (CH)

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

Tab. 8.12: Unit process raw data of “pipeline, natural gas, high pressure distribution network” (RER)

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

8.3 Operation of the Network

8.3.1 Energy use

In general the high pressure from the transition pipelines is sufficient to maintain the needed pressure in the distribution network without the need for further compressor stations. The pressure reducing stations however need energy to preheat the natural gas. This service is not included in the inventories described in Chapter 7 and is assigned to the process of “regional distribution”. In (Italgas 2001) this energy use is declared as 0.17 % of the distributed natural gas and 2.6 Wh/Nm^3 electricity. These values are used for all European datasets. The specifications from the communication with the UN Climate Change Convention are used for the specific gas consumption in the operation of the Swiss distribution network. This share is declared as 0.7 % (UNFCCC 2011b). It is assumed that 80 % of this natural gas demand is used in the compressor station in Ruswil and 20 % occur in the local natural gas distribution. The energy use for the regional distribution is modelled with the dataset “natural gas, burned in industrial furnace”. The country specific supply mixes are used to represent the electricity consumption.

8.3.2 Emissions

The long-distance transport is calculated in a manner to reflect the natural gas losses for the respective country. The transport distances for one MJ of natural gas of different origins are calculated for Germany, since data are available here. According to (Reichert & Schön 2000) 22.4 million Nm^3 natural gas are emitted from long-distance pipelines. This equals 0.02 % of the transported volumes. Considering an emission factor of 3.22 E-04 Nm^3/tkm and 93.7 billion Nm^3 of transported natural gas the natural gas must be transported over a distance of 900 km to result in losses as presented by Reichert & Schön (2000). The share of the natural gas that crosses Germany is included in the dataset representing long-distance transport. Therefore only 75 % of the 900 km are attributed to the inventory of regional distribution (for all countries). The ratio of the transport distance and the total length of the pipeline network is used for the other countries as well (Tab. 8.13).

Tab. 8.13 Required amounts of long-distance transport for the high pressure network in Europe

	Transmissions lines	Long-distance transport requirements	
	km	tkm/pro t natural gas	tkm/MJ [2)]
Switzerland	2536 [1)]	982	0.0216
Austria	5213	990	0.0228
Belgium	3731	355	0.0077
Czech Republic	3350	442	0.0096
Denmark	1415	353	0.0069
EU 15	177004	443	0.0096
Finland	955	250	0.0055
France	34232	883	0.0186
Germany	57000	684	0.0156
Greece	961	675	0.0148
Hungary	5214	492	0.0114
Ireland	1199	518	0.0099
Italy	30500	461	0.0097
Netherlands	11600	188	0.0043
Slovakia	5725	814	0.0179
Spain	11989	1591	0.0325
Sweden	530	541	0.0106
EU 15	177004	443	0.0096

[1)] Total length 2009: 17950 km (SVGW 2010)

[2)] Calculated based on the net calorific value of natural gas (36.3 MJ/m^3)

Natural gas leakages of the pipelines and valves are relevant process related emissions. For this study leakage data from (Reichert & Schön 2000) are used that were assessed in the framework of a study for Germany (Tab. 8.14). The emission factors are calculated taking into account the origin of the gas transported (Tab. 4.3) and the respective natural gas composition and quality (Tab. 3.6).

Tab. 8.14 Natural gas losses in the German distribution system (**Reichert & Schön 2000, Tab. 4.1**). The values for methane are converted to natural gas with a methane content of 89 vol. %. The leakage of the different pressure levels (e.g. losses for high and medium pressure) are calculated as the weighted average of all nets of this pressure level.

		Leakage rate		**Sum for Germany**	
Local natural gas network		607	Nm^3/km/a	178	million Nm^3
	HP-network	369	Nm^3/km/a	18	million Nm^3
	MP-network	144	Nm^3/km/a	17	million Nm^3
	LP-network	1128	Nm^3/km/a	143	million Nm^3
Measuring and regulation stations		245	Nm^3/station/a	19	million Nm^3
	HP	930	Nm^3/station/a	2	million Nm^3
	LP	227	Nm^3/station/a	17	million Nm^3
Above-ground storage			Share of Volume	2	million Nm^3
Household connections		1021	Nm^3/km/a	108	million Nm^3
	MP	481	Nm^3/km/a	25	million Nm^3
	LP	1864	Nm^3/km/a	82	million Nm^3
Total inland				307	million Nm^3
Losses high and medium pressure [1)]		**418**	**m^3/km/a**	**62**	**million Nm^3**
Losses low pressure and household connections [2)]		**2166**	**m^3/km/a**	**244**	**million Nm^3**

[1)] Losses in the local natural gas network and the measuring and regulation stations of the respective pressure level.

[2)] Losses in the local natural gas network and the measuring and regulation stations of the respective pressure level plus household connections and above-ground storage.

The losses in the European distribution network are calculated with data from Reichert & Schön (2000, Tab. 4.1) based on the length of the pipeline networks. Where no specific data are available an average distribution of the pipeline lengths of 40 % high and medium pressure and 60 % low pressure is assumed.

Tab. 8.15 Shares of the pipeline lengths in the high and medium pressure and the low pressure natural gas network (sources indicated in the table).

	High pressure	Low pressure	Source
Switzerland	34%	66%	(SVGW 2010)
Austria	40%	60%	assumption
Belgium	40%	60%	(Reichert & Schön 2000)
Czech Republic	40%	60%	(GDF 2001)
Denmark	40%	60%	assumption
Finland	40%	60%	assumption
France	87%	13%	assumption
Germany	57%	43%	assumption
Greece	40%	60%	assumption
Hungary	40%	60%	assumption
Ireland	40%	60%	assumption
Italy	40%	60%	assumption
Netherlands	40%	60%	assumption
Slavakia	40%	60%	assumption
Spain	40%	60%	assumption
Sweden	40%	60%	assumption
United Kingdom	40%	60%	assumption
EU 15	40%	60%	assumption

The specific pipeline lengths (see Tab. 8.15) are multiplied with the emission factor of the respective pressure level from Tab. 8.14 (418 m^3/km/a for the HP/MP-network, 2'166 m^3/km/a for the LP-network). This results in the ratio of the losses at the different pressure levels. This value depends on the division of the total network length to the pressure levels and is therefore equal for all countries for which the same assumptions are used (see Tab. 8.16).

Tab. 8.16 Calculated losses with the ratio for high/medium pressure and low pressure networks

	Losses HP/MP	Losses LP
	% of total losses	% of total losses
Switzerland	9%	91%
Germany	20%	80%
France	55%	45%
Other European countries	11%	89%

Only the losses in the high pressure network are of interest for the further calculations described in this section. The losses in the local natural gas distribution are presented in Chapter 9. The annual leakage of the Swiss distribution network of about 1.3 million Nm^3 corresponds to a leakage of about 0.04 % of the transported natural gas which is also the European average (Tab. 8.17).

The natural gas distributed in Switzerland is dry. Almost no condensates occur in the entire distribution system which would need to be disposed of <Fasler 1992>.

Tab. 8.17 Losses in the European distribution network

	Total losses in the distribution network		Losses HP	Total sales in 2000	Losses HP/MP
		Source	m^3/a	PJ [1)]	
Switzerland	0.39 %	(UNFCCC 2011b) [2)]	1.02E+06	126[3)]	0.04%
Germany [2)]	0.38 %	(Reichert & Schön 2000)	6.40E+07	3250	0.08%
France	0.21 %	(GDF 2001)	4.97E+07	1655	0.12%
Italy	0.75 %	(SNAM 2002)	5.88E+07	2683	0.09%
Netherlands	0.44 %	(IGU 1997)	2.05E+07	1593	0.05%
Austria	0.23 %	(IGU 1997)	1.90E+06	283	0.03%
United Kingdom	0.88 %	(IGU 1997)	9.75E+07	3789	0.10%
Other European countries	0.50 %	Assumption			0.06%

1) Gross calorific value 39 MJ/m^3 according to (Eurogas 2001)

2) 2009 data. Natural gas sales statistics from (Erdgas 2010).

3) The losses in the HP network as well as the total losses are calculated with the sales data for the year 2000 from Eurogas (2001).

8.3.3 Life cycle inventory of the regional distribution

Tab. 8.19 “Natural gas, high pressure, at consumer” describes the energy use and the emissions during the operation of the regional distribution of natural gas in various European countries.

The inventory data differ with respects to the emissions since they are calculated with the specific natural gas supply mixes (different origins) and the respective gas compositions. If information on the composition is not available, the European average composition is used (see Tab. 3.6).

For Switzerland, Germany, France, Italy, the Netherlands, Austria and the United Kingdom specific leakage factors are available, for the remaining countries the leakage rate is estimated. The specific factor for the high pressure network was determined from German data. Data from an Italian company is available to quantify the energy use. The need for infrastructure is estimated based on the average calculated load of the network in the different countries.

Tab. 8.18 shows the inventory data of Austria with specifications of the uncertainties. For the other datasets this information is available in the database.

Data quality

No specific data about the construction and material use of high pressure networks are available except for Germany. For some countries data on the total losses in the distribution network are available. The German data permits to allocate the losses to the high and low pressure networks. For several European countries the leakages are estimated.

Tab. 8.18 Unit process raw data of „Natural gas, high pressure, at consumer“ (AT)

	Name	Location	InfrastructureProcess	Unit	natural gas, high pressure, at consumer	UncertaintyType	StandardDeviation95%	GeneralComment	Remarks	Literature
	Location				AT					
	InfrastructureProcess				0					
	Unit				MJ					
	natural gas, high pressure, at consumer	AT	0	MJ	1					
technosphere	natural gas, burned in gas turbine	CH	0	MJ	1.67E-3	1	1.05	(1,1,1,1,1,1,BU:1.	environmental report of Italian compa	Italgas 2001
	electricity, medium voltage, at grid	AT	0	kWh	7.13E-5	1	1.05	(1,1,1,1,1,1,BU:1.	environmental report of Italian compa	Italgas 2001
	natural gas, production DE, at long-distance pipeline	RER	0	Nm3	1.79E-4	1	1.24	(2,4,1,1,1,5,BU:1.	leakage from literature	
	natural gas, production GB, at long-distance pipeline	RER	0	Nm3	4.82E-5	1	1.24	(2,4,1,1,1,5,BU:1.	leakage from literature	
	natural gas, production NL, at long-distance pipeline	RER	0	Nm3	4.10E-4	1	1.24	(2,4,1,1,1,5,BU:1.	leakage from literature	
	natural gas, production NO, at long-distance pipeline	RER	0	Nm3	4.83E-3	1	1.24	(2,4,1,1,1,5,BU:1.	leakage from literature	
	natural gas, production RU, at long-distance pipeline	RER	0	Nm3	2.15E-2	1	1.24	(2,4,1,1,1,5,BU:1.	leakage from literature	
	pipeline, natural gas, high pressure distribution network	RER	1	km	9.55E-10	1	3.06	(2,4,1,1,1,5,BU:3)	statistics of distribution	
	transport, natural gas, pipeline, long distance	RER	0	tkm	2.28E-2	1	1.31	(2,3,1,1,3,5,BU:1.	calculated on the basis of German data	
emission air, low population density	Methane, fossil	-	-	kg	5.05E-6	1	1.58	(2,4,1,1,1,5,BU:1.	calculated based on gas mix and leakage	
	Ethane	-	-	kg	1.31E-7	1	1.58	(2,4,1,1,1,5,BU:1.	calculated based on gas mix and leakage	
	Propane	-	-	kg	3.57E-8	1	1.58	(2,4,1,1,1,5,BU:1.	calculated based on gas mix and leakage	
	Butane	-	-	kg	1.33E-8	1	1.62	(2,3,1,1,3,5,BU:1.	calculated based on gas mix and leakage	
	NMVOC, non-methane volatile organic compounds, unspecified origin	-	-	kg	8.60E-9	1	1.62	(2,3,1,1,3,5,BU:1.	calculated based on gas mix and leakage	
	Carbon dioxide, fossil	-	-	kg	2.31E-8	1	1.31	(2,3,1,1,3,5,BU:1.	calculated based on gas mix and leakage	
	Mercury	-	-	kg	7.05E-14	1	5.11	(2,3,1,1,3,5,BU:5)	calculated based on gas mix and leakage	
	Heat, waste	-	-	MJ	2.57E-4	1	1.31	(2,3,1,1,3,5,BU:1.	environmental report of Italian company	

Tab. 8.19 Unit process raw data of “Natural gas, high pressure, at consumer (country)” (AT, BE, CH, CZ, DE, DK, ES, FI, FR)

	Name	Location	InfrastructureProcess	Unit	natural gas, high pressure, at consumer	natural gas, high pressure, at consumer	natural gas, high pressure, at consumer	natural gas, high pressure, at consumer	natural gas, high pressure, at consumer	natural gas, high pressure, at consumer	natural gas, high pressure, at consumer	natural gas, high pressure, at consumer	natural gas, high pressure, at consumer
	Location				AT	BE	CH	CZ	DE	DK	ES	FI	FR
	InfrastructureProcess				0	0	0	0	0	0	0	0	0
	Unit				MJ	MJ	MJ	MJ	MJ	MJ	MJ	MJ	MJ
technosphere	natural gas, burned in gas turbine	CH	0	MJ	1.67E-3	1.67E-3	5.59E-3	1.67E-3	1.67E-3	1.67E-3	1.67E-3	1.67E-3	1.67E-3
	electricity, medium voltage, at grid	AT	0	kWh	7.13E-5	0	0	0	0	0	0	0	0
	electricity, medium voltage, at grid	BE	0	kWh	0	6.82E-5	0	0	0	0	0	0	0
	electricity, medium voltage, at grid	CH	0	kWh	0	0	7.12E-5	0	0	0	0	0	0
	electricity, medium voltage, at grid	CZ	0	kWh	0	0	0	7.04E-5	0	0	0	0	0
	electricity, medium voltage, at grid	DE	0	kWh	0	0	0	0	7.02E-5	0	0	0	0
	electricity, medium voltage, at grid	DK	0	kWh	0	0	0	0	0	7.21E-5	0	0	0
	electricity, medium voltage, at grid	ES	0	kWh	0	0	0	0	0	0	6.77E-5	0	0
	electricity, medium voltage, at grid	FI	0	kWh	0	0	0	0	0	0	0	7.28E-5	0
	electricity, medium voltage, at grid	FR	0	kWh	0	0	0	0	0	0	0	0	6.87E-5
	electricity, medium voltage, at grid	GB	0	kWh	0	0	0	0	0	0	0	0	0
	electricity, medium voltage, at grid	GR	0	kWh	0	0	0	0	0	0	0	0	0
	electricity, medium voltage, at grid	HU	0	kWh	0	0	0	0	0	0	0	0	0
	electricity, medium voltage, at grid	IE	0	kWh	0	0	0	0	0	0	0	0	0
	electricity, medium voltage, at grid	IT	0	kWh	0	0	0	0	0	0	0	0	0
	electricity, medium voltage, at grid	NL	0	kWh	0	0	0	0	0	0	0	0	0
	electricity, medium voltage, production UCTE, at grid	UCTE	0	kWh	0	0	0	0	0	0	0	0	0
	electricity, medium voltage, at grid	SE	0	kWh	0	0	0	0	0	0	0	0	0
	electricity, medium voltage, at grid	SK	0	kWh	0	0	0	0	0	0	0	0	0
	natural gas, at long-distance pipeline	CH	0	Nm3	0	0	2.69E-2	0	0	0	0	0	0
	natural gas, at long-distance pipeline	RER	0	Nm3	0	0	0	0	0	0	0	0	0
	natural gas, production DE, at long-distance	RER	0	Nm3	1.79E-4	3.39E-4	0	0	3.02E-3	8.21E-5	1.50E-5	0	4.09E-4
	natural gas, production GB, at long-distance	RER	0	Nm3	4.82E-5	2.85E-3	0	0	5.30E-4	2.21E-5	1.33E-5	0	4.41E-4
	natural gas, production NL, at long-distance	RER	0	Nm3	4.10E-4	4.78E-3	0	0	4.55E-3	1.87E-4	3.54E-5	0	3.30E-3
	natural gas, production NO, at long-distance	RER	0	Nm3	4.83E-3	9.63E-3	0	7.15E-3	9.18E-3	2.67E-2	2.38E-3	0	9.03E-3
	natural gas, production RU, at long-distance	RER	0	Nm3	2.15E-2	6.72E-4	0	1.95E-2	9.31E-3	2.67E-4	2.66E-5	2.75E-2	5.40E-3
	natural gas, production NAC, at long-distance	RER	0	Nm3	0	2.43E-4	0	0	9.11E-6	0	1.06E-2	0	3.76E-3
	natural gas, production RME, at long-distance	RER	0	Nm3	0	6.76E-3	0	0	9.41E-5	0	4.17E-3	0	1.53E-3
	natural gas, production NG, at long-distance	RER	0	Nm3	0	4.93E-4	0	0	1.47E-5	0	8.38E-3	0	2.13E-3
	pipeline, natural gas, high pressure distribution network	CH	1	km	0	0	8.96E-10	0	0	0	0	0	0
	pipeline, natural gas, high pressure distribution network	RER	1	km	9.55E-10	7.95E-10	0	1.51E-9	1.45E-9	8.98E-10	3.54E-10	8.41E-11	2.13E-9
	transport, natural gas, pipeline, long distance	RER	0	tkm	2.28E-2	7.67E-3	1.83E-2	9.58E-3	1.56E-2	6.92E-3	3.25E-2	5.49E-3	1.86E-2
emission air, low population density	Methane, fossil	-	-	kg	5.05E-6	1.00E-5	6.42E-6	1.09E-5	1.44E-5	1.11E-5	9.47E-6	1.12E-5	2.09E-5
	Ethane	-	-	kg	1.31E-7	8.86E-7	3.11E-7	3.68E-7	6.86E-7	1.13E-6	1.33E-6	9.40E-8	1.77E-6
	Propane	-	-	kg	3.57E-8	3.03E-7	1.19E-7	9.96E-8	1.65E-7	2.89E-7	6.28E-7	3.13E-8	6.20E-7
	Butane	-	-	kg	1.33E-8	2.05E-7	5.38E-8	3.55E-8	5.63E-8	9.14E-8	3.71E-7	1.57E-8	3.06E-7
	NMVOC, non-methane volatile organic compounds, unspecified origin	-	-	kg	8.60E-9	6.82E-8	2.97E-8	1.92E-8	3.55E-8	3.10E-8	3.00E-9	1.57E-8	4.55E-8
	Carbon dioxide, fossil	-	-	kg	2.31E-8	1.03E-7	1.02E-7	6.41E-8	1.34E-7	1.99E-7	1.79E-8	1.57E-8	1.79E-7
	Mercury	-	-	kg	7.05E-14	1.34E-13	0	1.52E-13	2.02E-13	1.55E-13	1.46E-13	1.57E-13	3.00E-13
	Heat, waste	-	-	MJ	2.57E-4	2.45E-4	2.56E-4	2.54E-4	2.53E-4	2.59E-4	2.44E-4	2.62E-4	2.47E-4

Tab. 8.19 Unit process raw data of “Natural gas, high pressure, at consumer (country)” (GB, GR, HU, IE, IT, NL, RER, SE, SK)

	Name	Location	InfrastructureProcess	Unit	natural gas, high pressure, at consumer	natural gas, high pressure, at consumer	natural gas, high pressure, at consumer	natural gas, high pressure, at consumer	natural gas, high pressure, at consumer	natural gas, high pressure, at consumer	natural gas, high pressure, at consumer	natural gas, high pressure, at consumer	natural gas, high pressure, at consumer
	Location				GB	GR	HU	IE	IT	NL	RER	SE	SK
	InfrastructureProcess				0	0	0	0	0	0	0	0	0
	Unit				MJ	MJ	MJ	MJ	MJ	MJ	MJ	MJ	MJ
technosphere	natural gas, burned in gas turbine	CH	0	MJ	1.67E-3	1.67E-3	1.67E-3	1.67E-3	1.67E-3	1.67E-3	1.67E-3	1.67E-3	1.67E-3
	electricity, medium voltage, at grid	AT	0	kWh	0	0	0	0	0	0	0	0	0
	electricity, medium voltage, at grid	BE	0	kWh	0	0	0	0	0	0	0	0	0
	electricity, medium voltage, at grid	CH	0	kWh	0	0	0	0	0	0	0	0	0
	electricity, medium voltage, at grid	CZ	0	kWh	0	0	0	0	0	0	0	0	0
	electricity, medium voltage, at grid	DE	0	kWh	0	0	0	0	0	0	0	0	0
	electricity, medium voltage, at grid	DK	0	kWh	0	0	0	0	0	0	0	0	0
	electricity, medium voltage, at grid	ES	0	kWh	0	0	0	0	0	0	0	0	0
	electricity, medium voltage, at grid	FI	0	kWh	0	0	0	0	0	0	0	0	0
	electricity, medium voltage, at grid	FR	0	kWh	0	0	0	0	0	0	0	0	0
	electricity, medium voltage, at grid	GB	0	kWh	6.80E-5	0	0	0	0	0	0	0	0
	electricity, medium voltage, at grid	GR	0	kWh	0	7.06E-5	0	0	0	0	0	0	0
	electricity, medium voltage, at grid	HU	0	kWh	0	0	7.24E-5	0	0	0	0	0	0
	electricity, medium voltage, at grid	IE	0	kWh	0	0	0	6.93E-5	0	0	0	0	0
	electricity, medium voltage, at grid	IT	0	kWh	0	0	0	0	6.84E-5	0	0	0	0
	electricity, medium voltage, at grid	NL	0	kWh	0	0	0	0	0	7.21E-5	0	0	0
	electricity, medium voltage, production UCTE, at grid	UCTE	0	kWh	0	0	0	0	0	0	6.95E-5	0	0
	electricity, medium voltage, at grid	SE	0	kWh	0	0	0	0	0	0	0	7.21E-5	0
	electricity, medium voltage, at grid	SK	0	kWh	0	0	0	0	0	0	0	0	7.28E-5
	natural gas, at long-distance pipeline	CH	0	Nm3	0	0	0	0	0	0	0	0	0
	natural gas, at long-distance pipeline	RER	0	Nm3	0	0	0	0	0	0	2.63E-2	0	0
	natural gas, production DE, at long-distance	RER	0	Nm3	9.19E-5	0	3.22E-4	0	2.08E-4	1.33E-4	0	8.02E-4	0
	natural gas, production GB, at long-distance	RER	0	Nm3	1.36E-2	0	6.20E-5	1.37E-2	1.79E-4	3.78E-4	0	0	0
	natural gas, production NL, at long-distance	RER	0	Nm3	1.44E-3	0	6.18E-4	1.93E-3	2.22E-3	2.03E-2	0	0	0
	natural gas, production NO, at long-distance	RER	0	Nm3	6.64E-3	0	1.08E-3	6.36E-3	2.68E-3	4.58E-3	0	2.65E-2	0
	natural gas, production RU, at long-distance	RER	0	Nm3	1.27E-4	1.41E-2	2.46E-2	0	5.35E-3	2.25E-3	0	0	2.75E-2
	natural gas, production NAC, at long-distance	RER	0	Nm3	3.26E-4	7.29E-3	3.68E-4	3.28E-4	1.29E-2	8.29E-6	0	0	0
	natural gas, production RME, at long-distance	RER	0	Nm3	3.41E-3	0	1.32E-4	3.39E-3	2.14E-3	8.56E-5	0	0	0
	natural gas, production NG, at long-distance	RER	0	Nm3	5.26E-4	5.30E-3	2.06E-4	5.29E-4	1.44E-4	1.34E-5	0	0	0
	pipeline, natural gas, high pressure distribution network	CH	1	km	0	0	0	0	0	0	0	0	0
	pipeline, natural gas, high pressure distribution network	RER	1	km	6.57E-10	2.59E-10	1.48E-9	4.15E-10	6.87E-10	8.23E-10	7.88E-10	4.83E-10	6.81E-10
	transport, natural gas, pipeline, long distance	RER	0	tkm	4.22E-3	1.48E-2	1.14E-2	1.02E-2	9.68E-3	4.31E-3	9.63E-3	1.06E-2	1.79E-2
emission air, low population density	Methane, fossil	-	-	kg	1.77E-5	1.04E-5	1.11E-5	1.01E-5	1.46E-5	9.51E-6	1.05E-5	1.12E-5	1.12E-5
	Ethane	-	-	kg	1.43E-6	7.43E-7	1.79E-7	8.08E-7	1.75E-6	4.24E-7	3.89E-7	1.12E-6	9.40E-8
	Propane	-	-	kg	3.22E-7	3.45E-7	5.92E-8	1.80E-7	6.34E-7	7.90E-8	8.98E-8	2.87E-7	3.13E-8
	Butane	-	-	kg	2.04E-7	1.82E-7	2.86E-8	1.15E-7	2.79E-7	2.72E-8	2.99E-8	9.04E-8	1.57E-8
	NMVOC, non-methane volatile organic compounds, unspecified origin	-	-	kg	4.91E-7	8.04E-9	1.65E-8	2.80E-7	1.45E-8	1.24E-8	1.50E-8	3.01E-8	1.57E-8
	Carbon dioxide, fossil	-	-	kg	1.79E-7	8.04E-9	2.54E-8	1.02E-7	5.08E-8	1.14E-7	8.98E-8	1.97E-7	1.57E-8
	Mercury	-	-	kg	1.53E-13	1.52E-13	1.56E-13	8.70E-14	2.20E-13	1.38E-13	1.50E-14	1.55E-13	1.57E-13
	Heat, waste	-	-	MJ	2.45E-4	2.54E-4	2.61E-4	2.49E-4	2.46E-4	2.60E-4	2.50E-4	2.60E-4	2.62E-4

9 Life cycle inventory of the local natural gas supply

9.1 Overview

This chapter describes the local natural gas supply in Switzerland. The local natural gas supply is the step between the regional natural gas distribution and the natural gas provided to the consumer at low pressure with less than 0.1 bar overpressure.

In Switzerland a total of 97 local gas distribution companies were in operation in 2000 (SWISSGAS 2001a). Most of them were constructed in the 1970ies after the construction of the TENP pipeline (Trans Europa Naturgas Pipeline) and the regional distribution network. In the beginning almost exclusively steel and ductile cast pipelines were built, from the mid-70ies plastic pipelines became increasingly popular. In exceptional cases old steel and cast pipelines from old city gas networks were taken over.

In line with the regional distribution networks the local gas supply is described with a top-down approach. The specific material needs per unit of natural gas supplied are calculated based on the Swiss pipeline inventory and an average load.

To balance short-time peaks in the demand gas tanks are used. They are described with the rest of the infrastructure in Subchapter 9.2.

The process step “local natural gas supply” has the input “natural gas, high pressure, at consumer” (in MJ) and the output “natural gas, low pressure, at consumer” (in MJ).

9.2 Infrastructure

9.2.1 Material use

An average load of the Swiss low pressure natural gas network of about 93 PJ/a is used for the calculations. In line with Subchapter 8.2 it is assumed that the average load of the year 2000 represents a mean value. An average service lifetime of 40 years is assumed for all types of pipeline materials (as for the regional distribution network) even though operational experience is still missing for plastic pipelines.

The pipelines are most relevant with respect to the material use. (SVGW/SSIGE 2002) provides a pipeline inventory with indications of the material but excluding the pipelines connecting to the buildings. Data from (Seifert 1998) allow calculating the ratio of household connecting pipelines to the total network length.

Tab. 9.1 Lengths of the low pressure and the building connection pipelines and their material compositions (**SVGW/SSIGE 2002**). The length of the building connections is calculated based on the ratio with the total pipeline length in 1996 (**Seifert 1998**). The building connection lengths are not included in statistics (Tab. 8.3: The value for "Distribution" contains the length oh the High-, medium- and low pressure).

	Low pressure pipelines [1)]	Pipelines connecting to buildings	Ratio of the building connections to the total network length (1996)
	km	km	
Steel	2162	896	23%
Grey cast	526	45	8%
Ductile cast	2127	44	2%
PE	4655	1372	21%
Total	9470	2356	

[1)] Excluding building connections

PE pipes are also used in the restoration of older pipelines (especially grey cast pipes). In the so-called relining method new PE pipes are drawn into the old pipeline. According to <Wiget 1992> roughly 10 % of the existing PE pipes are dedicated to relining.

We are using the information from Tab. 9.1 and assumptions on typical wall-thicknesses and pipe diameters to estimate the total material expenditures for the existing local natural gas supply network (Tab. 9.2). Most of the pipelines are additionally covered with a PE film (about 1 kg/m pipeline) to protect them from corrosion.

Tab. 9.2 Material expenditures for the local natural gas distribution network existing in 2000 (low pressure and building connection network)

Material	Pipeline length	Average diameter <Cerbe 1988>	Average wall thickness <Cerbe 1988>	Specific material expenditures [1)]	Total material expenditures
	km	mm	mm	kg/km	t
Low pressure level					
Steel	-	180	4	18 300	39570
Ductile cast	526	180	6	34 700	18250
Grey cast	2127	250	6	25 200	53600
HDPE	4655	200	15	9 600	44690
LDPE foil	4815 [2)]	-	-	1 000	4820
Households connection pipelines					
Steel	896	60	2.9	4 500	4060
Ductile cast	45	180	6	34 700	1550
Grey cast	44	250	6	25 200	1100
HDPE	1372	63	5.8	1 200	1630
LDPE foil	984	-	-	1 000	980

[1)] Density steel 7'900 kg/m3; HDPE 950 kg/m3; cast 7'200 kg/m3.

[2)] Coating steel- and grey cast-/ductile cast pipes

The material expenditures for the valves (gate valve, pressure reduction units etc.) are included in the inventory of the pipelines. The pressure regulating/measuring units and the gas transmission stations of the local natural gas supply network are located in small control cabinets or buildings. In this study it is estimated that about 0.5 larger feed-in/control facilities and 0.5 smaller control facilities are used per kilometre low pressure pipeline (this can be derived e.g. from <GVZ 1993>). For larger facilities we assume buildings with a volume of 100 m^3, for the smaller metallic control cabinets (6 m^3). The extrapolation to the total network length results in the following need for buildings:

- Roughly 427'000 m^3 buildings
- Roughly 26'000 m^3 metallic control cabinets. (Assumption: 50 kg steel per m^3 internal volume, 1'300 t steel for the low pressure level)

Local gas suppliers use gas storage facilities to balance short-term fluctuations in demand. Older floating bell gasholders and spherical gas tankers are slowly replaced by high pressure pipe storage. All bell gasholders and pipe storages in Switzerland have a total useful gas volume of about 1.6 million Nm^3 natural gas (GW Rüti 2002; SVGW/SSIGE 2002). Steel pipes with thick walls are usually used due to the high storage pressure. (Europipe 2002) specifies the wall thickness of the natural gas pipe storage Eymatt of the Gasverbund Mittelland AG Arlesheim with 19.4 mm. The specific weight of this storage facility is 720 kg/m, the specific capacity 110 Nm^3/m pipe. These values are used to calculate the material use of the gas storage. The pipe storages are furthermore protected with a 100 mm thick layer of fibre cement plaster and covered with soil. In total natural gas storage facilities lead to an additional material use of roughly:

- 9'740 t steel (1.524 m in diameter, 19.4 mm wall thickness)
- 19'300 t fibre cement mortar

9.2.2 Construction and transport expenditures

Analogue to Chapter 9 the construction expenditures are modelled with the datasets "excavation, skid-steer loader". Tab. 9.4 shows the necessary construction works.

The Ordinance of the Federal Council on safety in trench works ("Verordnung über die Unfallverhütung bei Graben- und Schachtbau sowie bei ähnlichen Arbeiten") of Sept. 13th 1963 regulates the minimal trench width. Typical trench geometries and pipeline bedding materials are estimated based on <Sager 1992> (see Tab. 9.3).

The transport of materials to and from the construction site is considered by using standard transport distances for the respective materials. The redundant and partially polluted soil and removed road paving need to be transported back to a landfill. This is modelled with a 28 t lorry over a transport distance of 30 km. A density of 740 kg/m^3 is assumed for roughly 670 m^3/km excavated material which leads to a total of 494 t/km pipeline.

Tab. 9.3 Trench profiles and pipeline bedding materials used for local natural gas supply networks in Switzerland

		Low pressure pipelines	Pipelines connecting to buildings	Total local natural gas network
Trench profile	m x m	0.6 X 1.2	0.5 X 1.0	
Pipeline length	km	9470	2356	11826
Specific sand use [1)]	kg/m	500	350	376
Specific gravel concrete [1)]	kg/m	150	100	28
Total sand use	Mio. t	3.79	0.66	4.45
Total gravel concrete use	Mio. t	0.28	0.05	0.33

[1)] About 80 % of the pipelines are bedded on sand. The sand fills up about a third of the trench profile. The remaining 20 % of the pipelines is bedded on gravel concrete.

Tab. 9.4 Construction works to be done with the skid-steer loader (excavation volume) for the local natural gas supply networks in Switzerland

	Pipeline length	Profile	Excavation volume	Excavation volume
	km	m x m	m^3/km	Mio. m^3
Low pressure pipelines Pipelines connecting to the buildings	9'470 2'356	0.6 x 1.2 0.5 x 1.0	720 500	6.82 1.18
Total low pressure			676	8.00

There is no information available concerning the share of the pipelines that are digged out and recycled at the end of life. However, since there is an acute shortage of space in the urban areas it is assumed that the old trenches are used for replacement investments and that all old pipelines are excavated. The expenditures are allocated entirely to the new pipelines. It is assumed that 100 % of the steel and cast iron can be recycled.

9.2.3 Monitoring during operation

Monitoring and reparation of the pipelines requires trips with cars and small vans. The energy use for heating and lighting of the administration buildings are considered too. Based on <Sager 1992> from the natural gas supply Zurich, 100 km are driven by car per TJ natural gas supplied.

9.2.4 Land use

The land use is relevant in the construction phase. In most cases the area is already populated and situated in an urban environment. In accordance with the other energy systems this area is not taken into account to avoid double counting (with road transportation). The land use during construction is accounted for with 3'333 m^2a per km, the same as for the high pressure natural gas pipeline system. A room height of 7 metres is assumed to calculate the land use of buildings.

9.2.5 Life cycle inventory of the local gas supply infrastructure

Tab. 9.5 describes the infrastructure of the low pressure distribution network in Switzerland, including the pipelines connecting to the buildings (access pipes).

The material needs are calculated based on statistics and assumptions concerning the wall thickness. No statistical data about the access pipes but data provided by the operators are available. The construction expenditures are roughly estimated.

Tab. 9.5: unit process raw data of „Pipeline, natural gas, low pressure distribution network“

Explanations	Name	Location	InfrastructureProcess	Unit	pipeline, natural gas, low pressure distribution network	UncertaintyType	StandardDeviation95%	GeneralComment
	Location				CH			
	InfrastructureProcess				1			
	Unit				km			
Technosphere	Transformation, from unknown	-	0	m2	7.14E+0	1	2.11	(4,3,3,1,1,5); qualified estimate
	Transformation, to industrial area, built up	-	0	m2	7.14E+0	1	2.11	(4,3,3,1,1,5); qualified estimate
	Occupation, industrial area, built up	-	0	m2a	1.43E+2	1	1.64	(4,3,3,1,1,5); qualified estimate
	Occupation, construction site	-	0	m2a	3.33E+3	1	2.01	(4,3,3,3,1,5); qualified estimate for CH
	reinforcing steel, at plant	RER	0	kg	5.24E+3	1	1.64	(4,3,3,1,1,5); qualified estimate
	cast iron, at plant	RER	0	kg	6.30E+3	1	1.64	(4,3,3,1,1,5); qualified estimate
	polyethylene, HDPE, granulate, at plant	RER	0	kg	4.63E+3	1	1.64	(4,3,3,1,1,5); qualified estimate
	polyethylene, LDPE, granulate, at plant	RER	0	kg	4.90E+2	1	1.64	(4,3,3,1,1,5); qualified estimate
	concrete, normal, at plant	CH	0	m3	2.73E+0	1	1.64	(4,3,3,1,1,5); qualified estimate
	gravel, round, at mine	CH	0	kg	2.80E+4	1	1.64	(4,3,3,1,1,5); qualified estimate
	cement, unspecified, at plant	CH	0	kg	2.84E+3	1	1.64	(4,3,3,1,1,5); qualified estimate
	sand, at mine	CH	0	kg	3.76E+5	1	1.64	(4,3,3,1,1,5); qualified estimate
	bitumen, at refinery	RER	0	kg	1.22E+3	1	1.64	(4,3,3,1,1,5); qualified estimate
	drawing of pipes, steel	RER	0	kg	1.15E+4	1	1.64	(4,3,3,1,1,5); qualified estimate
	transport, passenger car	CH	0	pkm	3.77E+4	1	2.34	(4,3,3,1,1,5); qualified estimate
	transport, lorry 28t	CH	0	tkm	9.05E+3	1	2.09	(4,5,na,na,na,na); standard distance
	transport, lorry 32t	RER	0	tkm	3.17E+2	1	2.32	(5,1,1,3,3,5); estimates for waste transport
	transport, freight, rail	CH	0	tkm	8.97E+3	1	2.09	(4,5,na,na,na,na); standard distance
	excavation, skid-steer loader	RER	0	m3	6.76E+2	1	2.34	(4,3,3,1,1,5); qualified estimate
	building, multi-storey	RER	1	m3	5.00E+1	1	3.11	(4,3,3,1,1,5); qualified estimate
	disposal, plastics, mixture, 15.3% water, to municipal incineration	CH	0	kg	5.12E+3	1	1.64	(4,3,3,1,1,5); qualified estimate
	disposal, bitumen, 1.4% water, to sanitary landfill	CH	0	kg	1.22E+3	1	1.64	(4,3,3,1,1,5); qualified estimate
Outputs	pipeline, natural gas, low pressure distribution network	CH	1	km	1.00E+0			

9.3 Operation of the network

9.3.1 Emissions from the operation

The pressure for the local natural gas supply is provided by the regional distribution network. The energy used to maintain this pressure is included in the regional distribution inventory described in Chapter 8.

In the Communication of Switzerland to the UN Climate Change Convention the internal consumption is reported as 788 TJ, which equals 0.7 % of the Swiss natural gas consumption (UNFCCC 2011b). Most of this natural gas is used in the compressor station in Ruswil and for the heating of (own) rooms. For this study it is assumed that 80 % of the gas is used in the compressor station and the rest in the local natural gas network.

Further operational energy use, e.g. for control technology, the anodic protection of pipelines, the operation of gate valves etc. is negligible according to <Sager 1992>.

9.3.2 Natural gas leakages

The main sources of natural gas leakages in the local supply are the following:

- Pipelines including the pipelines connecting to the buildings and pressure reducers
- Control units including safety valves in transfer- and regional stations
- Block valves (often operated with natural gas)
- Other valves (meters, various measurement devices)

The leakage rate in Switzerland is 0.39 % of the natural gas consumed (UNFCCC 2011b). The relative share of the leakages from the low- and high pressure nework in Switzerland are calculated using the leakage factors per km and year from Reichert et al. (2000) and the details on pipeline length in the low- resp.- high pressure network from SVGW (2010). In Switzerland 64 % of the pipeline network length belong to the high pressure network and 66 % to the low pressure network (SVGW 2010). 9 % of the leakage thus occurs in the high pressure network, 91 % in the low pressure network. This corresponds to 0.04 % (HP/MP) resp. 0.43 % (LP) of the natural gas consumed in Switzerland.

9.3.3 Accidents

The statistics on natural gas-related accidents in Switzerland is not complete. <Bützer 1988> based himself on information provided by the association of the cantonal fire insurances (Vereinigung kantonaler Feuerversicherungen) which included nine cantons at that time. According to the statistics, the long-time average mean value of deadly accidents related to natural gas in Switzerland is only one to two per year of over two thousand accidents in total. In 15 % of the cases the causes were defect gas stoves, in 85 % faulty pipelines. In most occasions the incident was an explosion. The causes of the accidents in the natural gas supply are mostly cracked pipelines, which occur spontaneously or due to external influences. For the years 2009 and 2010 about 15 accidents occurred per year with a long-term average of 1.1 fatalities per year (including suicides, SVGW 2010).

As to how much natural gas is burned or emitted when an accident occurs no data are available. Following a worst-case assumption it is assumed that 20 accidents occur annually with a leakage of 1'000 m^3 each. This accidental leakage volume is still very small compared to the regularly occurring leakages in the network (see Section 9.3.2) and is therefore neglected.

9.3.4 Inventory data for the local natural gas supply

Tab. 9.6 describes the operation of the low-pressure network in Switzerland (incl. building connection pipelines).

Data quality

No statistical data are available for the natural gas supplied by the low-pressure network. Therefore the reference value is uncertain. Up to date emission factors were used from from the Swiss communication to the UNFCCC (2011b).

Tab. 9.6 Unit process raw data of “natural gas, low pressure, at consumer” (CH)

	Name	Location	Infrastru	Unit	natural gas, low pressure, at consumer	UncertaintyType	StandardDeviation95%	GeneralComment	Remarks	Literature
	Location				CH					
	InfrastructureProcess				0					
	Unit				MJ					
	natural gas, low pressure, at consumer	CH	0	MJ	1					
technosphere	natural gas, burned in boiler atm. low-NOx condensing non-modulating <100kW	RER	0	MJ	1.40E-3	1	1.05	(1,1,1,1,1,1,BU:1.05); Literature and estimates.; UNFCC 2011	Literature and estimates.	UNFCC 2011
	natural gas, high pressure, at consumer	CH	0	MJ	1.00E+0	1	1.05	(1,1,1,1,1,1,BU:1.05); incl. leakage;	incl. leakage	
	pipeline, natural gas, low pressure distribution network	CH	1	km	2.87E-9	1	3.00	(1,1,1,1,1,1,BU:3); based on statistics;	based on statistics	
emission air, low population density	Methane, fossil	-	-	kg	7.85E-5	1	1.50	(1,1,1,1,1,1,BU:1.5); calculated based on gas composition and leakage;	calculated based on gas composition and leakage	
	Ethane	-	-	kg	3.80E-6	1	1.50	(1,2,1,1,1,1,BU:1.5); calculated based on gas composition and leakage;	calculated based on gas composition and leakage	
	Propane	-	-	kg	1.45E-6	1	1.58	(2,4,1,1,1,5,BU:1.5); calculated based on gas composition and leakage;	calculated based on gas composition and leakage	
	Butane	-	-	kg	6.58E-7	1	1.62	(2,3,1,1,3,5,BU:1.5); calculated based on gas composition and leakage;	calculated based on gas composition and leakage	
	NMVOC, non-methane volatile organic compounds, unspecified origin	-	-	kg	3.63E-7	1	1.58	(2,4,1,1,1,5,BU:1.5); calculated based on gas composition and leakage;	calculated based on gas composition and leakage	
	Carbon dioxide, fossil	-	-	kg	1.25E-6	1	1.24	(2,4,1,1,1,5,BU:1.05); calculated based on gas composition and leakage;	calculated based on gas composition and leakage	

9.4 Critics, points for improvement

The local natural gas supply system consists of a multitude of interlinked networks that are expanded constantly. This makes it difficult to obtain static inventories as is the approach in this study.

The material use and construction needs could be assessed quite precisely for the existing network, although there may be more recent data available today. The data used are considered to be very reliable and are supplied mostly by the operators. A satisfying completeness is also reached with respect to other material flows such as emissions and operation resources.

The amount of natural gas supplied during the whole lifetime of the network (reference value) is rather uncertain. It is assumed that the natural gas supply in the year 2000 represents a typical load value. Projects planned after 2000 aiming at improving the load and increasing pressure have not been considered in this study. The service lifetime of the pipelines is also subject to uncertainties, since at the time of the research no operational experience values existed (especially for the newer plastic pipelines). For the leakage current data (from 2009) published in the communication to the UNFCCC (2011b) was used.

10 Life cycle inventory of natural gas in Japan

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Last changes: 2007
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96.5 % of the natural gas imported in Japan is liquefied natural gas (LNG), two quarters of which from from the pacific region (Australia, Indonesia, Malaysia) roughly a quarter from the Middle East and a small share (3 %) from the USA and Nigeria (BP Amoco 2005). Tab. 10.1 shows the imported LNG volumes and the distance from the countries of origin to Japan, as well as the weighted average distance for the supply mix.

Tab. 10.1: Imported LNG volumes in 2004 and estimated distance from the country of origin to Japan28 (BP Amoco 2005).

Country/Region of origin	Total Nm^3 (2004)	Share	Distance
USA	1.68E+9	2 %	17'000 km
Middle East	1.78E+10	23 %	12'000 km
Nigeria	1.60E+8	0 %	20'000 km
Australia	1.12E+10	15 %	9'000 km
Brunei	8.29E+9	11 %	4'500 km
Indonesia	2.12E+10	28 %	6'000 km
Malaysia	1.66E+10	22 %	4'500 km
Total	7.70E+10	100 %	
Weighted average distance			7'600 km

Due to lack of specific data for the countries of origin for Japan, the data set “natural gas, liquefied, at freight ship/JP” is approximated with the one for Algeria, resp. North Africa. The weighted average distance used is displayed in Tab. 10.1. The transport requirements in tonne-kilometres are calculated with a density of 0.78kg/Nm^3.

See: Tab. 7.22 Unit process raw data of “Natural gas, liquefied, at freight ship”

See: Tab. 7.23 Unit process raw data of “Natural gas, production (country), at evaporation plant” for NAC, RME and NG

The sales volume of natural gas in Japan amounts to 30 million Nm^3 natural gas per year, bought by 28 million end customers. In the reference year 2005 32'459 million Nm^3 natural gas were sold (Japan Gas Association (2006)). The two big natural gas companies Osaka and Tokyo- Gas Corporation hold more than 40 % market share. Since the LNG is distributed to 28 evaporation plants in Japan, no long-distance transport of the natural gas is necessary (METI 2005). According to the Japan Gas Association (2006), the regional distribution network consists of roughly 230'000 km natural gas pipeline, of which almost 14 % belong to the high- and medium pressure network.

[28] The distances are calculated from the country of origin to Tokyo, since a large share oft he LNG terminals is located there.

Tab. 10.2 Japanese pipeline network: shares of high/medium and low pressure pipelines

	High- / Medium pressure	Low pressure	Source
Japan share in %	13.7 %	86.3 %	Japan Gas Association (2006)
Length of the pipelines	31’200 km	196'800 km	Japan Gas Association (2006)

The losses of the Japanese distribution network are approximated with German data on the basis of the total pipeline length of the networks. It is assumed that per year and kilometre 418 Nm^3 natural gas are emitted in the high pressure network (see Tab. 8.14). For the composition of Japanese natural gas the mix known from the company Osaka-Gas is used. It consists of 78 % methane, 11 % ethane, 7 % propane and 4 % butane (Osaka Gas 2006). For the gross and net calorific values of Japanese natural gas Algerian data were used (gross calorific value: 42.4 MJ / Nm^3, net calorific value: 38.5 MJ / Nm^3).

Tab. 10.3 shows the unit process raw data of the natural gas at the high pressure pipeline.

Tab. 10.3 Unit process raw data of “natural gas, high pressure, at consumer / JP“

	Name	Location	InfrastructureProcess	Unit	natural gas, high pressure, at consumer	UncertaintyType	StandardDeviation95%	GeneralComment
	Location				JP			
	InfrastructureProcess				0			
	Unit				MJ			
product	natural gas, high pressure, at consumer	JP	0	MJ	1			
technosphere	natural gas, burned in industrial furnace >100kW	RER	0	MJ	1.67E-3	1	1.14	(1,3,2,5,1,3); environmental report of Italian company
	electricity, medium voltage, at grid	JP	0	kWh	6.94E-5	1	1.14	(1,3,2,5,1,3); environmental report of Italian company
	natural gas, at evaporation plant	JP	0	Nm3	2.60E-2	1	1.27	(4,4,2,5,1,3); calculated with heating value of Algerian natural gas
	pipeline, natural gas, high pressure distribution network	RER	1	km	2.50E-8	1	3.12	(4,4,1,5,1,5); calculated on the basis of German data
emission air, high population density	Methane, fossil	-	-	kg	6.36E-6	1	1.54	(3,1,2,5,1,3); calculated based on gas mix and leakage
	Ethane	-	-	kg	8.96E-7	1	1.54	(3,1,2,5,1,3); calculated based on gas mix and leakage
	Propane	-	-	kg	5.70E-7	1	1.54	(3,1,2,5,1,3); calculated based on gas mix and leakage
	Butane	-	-	kg	3.26E-7	1	1.54	(3,1,2,5,1,3); calculated based on gas mix and leakage
	Carbon dioxide, fossil	-	-	kg	6.27E-8	1	1.27	(3,1,2,5,3,3); calculated based on gas mix and leakage
	NMVOC, non-methane volatile organic compounds, unspecified origin	-	-	kg	1.04E-8	1	1.60	(3,1,2,5,3,3); calculated based on gas mix and leakage
	Mercury	-	-	kg	1.04E-14	1	5.09	(3,1,2,5,3,3); calculated based on gas mix and leakage
	Heat, waste	-	-	MJ	2.50E-4	1	1.17	(3,1,2,5,1,3); environmental report of Italian company

11 Life cycle inventory of natural gas in the USA

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Last changes: 2007

11.1 Introduction

Natural gas is an important fuel for electricity production in the United States. In 2005, the electricity generation from natural gas in US amounted to about 776 TWh. This corresponds to about 18 % of the total US electricity production (OECD/IEA 2006). 166 billion cubic meters of natural gas were consumed for electric power production in US (EIA 2006). The total natural gas production in US was about 665 billion cubic meters in 2005; the total natural gas consumption was about 630 billion cubic meters (EIA 2006). Natural gas accounted for nearly 25% of the total primary energy consumption in US in 2005 (BP 2007).

The information in this report is only related to the natural gas production and supply. Further information on the electricity production with US natural gas can be found in Faist Emmenegger et al. (2003).

11.2 Natural gas model for US data

The major data sources for the present ecoinvent modelling of natural gas in US are the LCI database provided by the US National Renewable Energy Laboratory (NREL 2007) and the Emissions & Generation Resource Integrated Database (eGRID) provided by the US Environmental Protection Agency (EPA 2006).

The upstream part of the natural gas chain model is based on the NREL LCI database (NREL 2007) with some modifications as described below. Compared to the European natural gas chain model, the present upstream model for US is rather simplified.

The NREL database provides only limited data concerning the operating natural gas power plants. More detailed information about the operation of the natural gas power plants in US was available in the eGRID database (EPA 2006). The eGRID data for the power plants refers to the year 2004.

The structure of the simplified natural gas chain model is shown in Fig. 11.1.

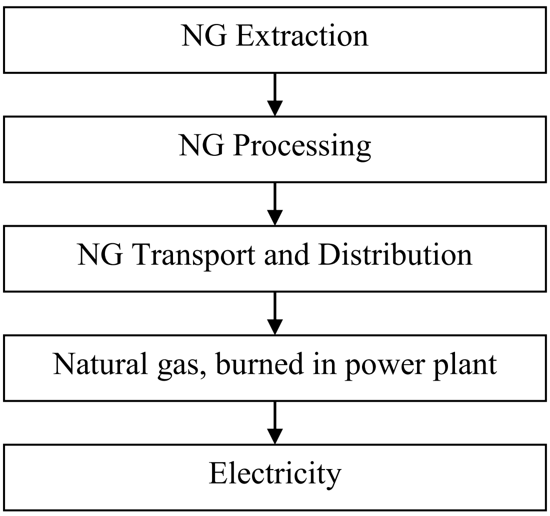

Fig. 11.1 Model of the natural gas chain for US.

An overview on basic data for natural gas in US between the years 2001 and 2005 is shown in Tab. 11.1 (EIA 2006).

Tab. 11.1 Natural gas data for US (Source: EIA 2006)

	2001	2002	2003	2004	2005
Number of Gas and Gas Condensate Wells					
Producing at End of Year	373,304	387,772	393,327	^{R}406,147	425,303
Production (million cubic meters)					
Gross Withdrawals					
From Gas Wells	513,368	503,894	506,356	^{R}506,454	495,553
From Oil Wells	180,417	174,047	176,617	^{R}172,292	169,560
Total	**693,785**	**677,942**	**682,973**	**^{R}678,746**	**665,113**
Repressuring	95,451	97,839	100,462	104,819	104,980
Vented and Flared	2,744	2,808	2,778	^{R}2,730	3,372
Wet After Lease Separation	595,589	577,294	579,733	^{R}571,196	556,761
Nonhydrocarbon Gases Removed	13,103	14,220	14,122	^{R}18,523	20,136
Marketed Production	582,486	563,074	565,611	^{R}552,674	536,625
Extraction Loss	27,014	27,099	24,800	26,238	24,820
Total Dry Production	**555,472**	**535,975**	**540,811**	**^{R}526,435**	**511,805**
Supply (million cubic meters)					
Dry Production	555,472	535,975	540,811	^{R}526,435	511,805
Receipts at U.S. Borders					
Imports	112,614	113,705	111,675	120,589	122,924
Intransit Receipts	15,267	16,670	20,682	16,693	16,075
Withdrawals from Storage					
Underground Storage	65,375	88,849	87,746	85,986	86,553
LNG Storage	1,004	1,212	1,754	1,448	1,366
Supplemental Gas Supplies	2,444	1,925	1,917	^{R}1,709	1,804
Balancing Item	3,804	-378	-1,090	^{R}10,108	9,380
Total Supply	**755,981**	**757,959**	**763,495**	**^{R}762,968**	**749,907**
Disposition (million cubic meters)					
Consumption	629,728	651,486	630,800	^{R}633,985	629,801
Deliveries at U.S. Borders					
Exports	10,570	14,618	19,253	24,186	20,632
Intransit Deliveries	16,279	15,021	18,357	14,127	13,002
Additions to Storage					
Underground Storage	98,125	75,602	93,211	89,198	84,995
LNG Storage	1,280	1,232	1,874	^{R}1,471	1,478
Total Disposition	**755,981**	**757,959**	**763,495**	**^{R}762,968**	**749,907**
Consumption (million cubic meters)					
Lease Fuel	21,164	20,688	21,475	20,716	21,417
Pipeline and Distribution Use	17,697	18,885	16,749	^{R}16,033	16,559
Plant Fuel	10,510	10,831	10,305	10,374	10,058
Delivered to Consumers					
Residential	135,109	138,436	143,831	^{R}137,869	136,095
Commercial	85,594	89,033	90,033	^{R}88,603	87,825
Industrial	207,965	212,580	202,477	^{R}205,094	191,021
Vehicle Fuel	412	423	517	581	630
Electric Power	151,277	160,610	145,413	^{R}154,717	166,196
Total Delivered to Consumers	**580,357**	**601,082**	**582,272**	**^{R}586,863**	**581,767**
Total Consumption	**629,728**	**651,486**	**630,800**	**^{R}633,985**	**629,801**

11.3 Natural gas extraction

The NREL LCI database provides data for the natural gas extraction in North America. The dataset includes data for natural gas extracted from onshore and offshore wells. Furthermore, the dataset includes data for natural gas co-extracted with crude oil as well as for wells that produce only natural gas (NREL 2007). The NREL data is based on data provided by government and industry sources (NREL 2007).

For ecoinvent, the emission species provided by the NREL dataset "Natural Gas Extraction" were converted as far as possible to ecoinvent format by adjusting the corresponding names and units of elementary flows and processes. Most elementary flows refer to emissions of substances into water.

The NREL natural gas extraction data includes also emissions to water for three radioactive species (Lead-210, Radium-226, Radium-228) per mass unit. The radioactive emissions have been converted into activity units (kBq) used in the ecoinvent database. The conversion factors are assumed as follows: Lead-210: 2.8E+12 kBq/kg, Radium-226: 3.7E+10 kBq/kg, Radium-228: 1.0E+13 kBq/kg.

The module "electricity mix; US" was used for the electricity supply of the gas extraction processes. Small input amounts of residual fuel oil, distillate fuel oil and gasoline have been neglected because corresponding modules were not available for the region North America (RNA) and it seems misleading to use modules as substitutes which match only roughly and refer to other regions.

The input data for the extraction module for ecoinvent is shown in Tab. 11.2. Uncertainty factors are not provided in the NREL database and have been only roughly estimated based on estimates for the European natural gas production (Chapter 6). A more thorough uncertainty analysis could not be performed.

Tab. 11.2 Unit process raw data of "natural gas, unprocessed, at extraction".

InputGroup	OutputGroup	Name	Location	Category	SubCategory	InfrastructureProcess	Unit	natural gas, unprocessed, at extraction	UncertaintyType	StandardDeviation95%	GeneralComment
		Location						RNA			
		InfrastructureProcess						0			
		Unit						m3			
5		electricity, medium voltage, at grid	US			0	kWh	2.88E-2	1	1.5	NREL 2007
5		natural gas, at production	RNA			0	m3	2.41E-2	1	1.2	NREL 2007
4		Gas, natural, in ground		resource	in ground	0	Nm3	1.00E+0	1	1	NREL 2007
	4	Methane, fossil		air	unspecified	0	kg	8.82E-3	1	3	NREL 2007
	4	4-Methyl-2-pentanone		water	unspecified	0	kg	1.33E-8	1	5	NREL 2007
	4	Acetone		water	unspecified	0	kg	3.17E-8	1	5	NREL 2007
	4	Aluminum		water	unspecified	0	kg	5.84E-5	1	5	NREL 2007
	4	Ammonium, ion		water	unspecified	0	kg	3.91E-5	1	5	NREL 2007
	4	Antimony		water	unspecified	0	kg	3.57E-8	1	5	NREL 2007
	4	Arsenic, ion		water	unspecified	0	kg	7.01E-7	1	5	NREL 2007
	4	Barium		water	unspecified	0	kg	9.03E-4	1	5	NREL 2007
	4	Benzene		water	unspecified	0	kg	5.32E-6	1	5	NREL 2007
	4	Beryllium		water	unspecified	0	kg	3.18E-8	1	5	NREL 2007
	4	BOD5, Biological Oxygen Demand		water	unspecified	0	kg	5.52E-4	1	5	NREL 2007
	4	Boron		water	unspecified	0	kg	9.96E-6	1	5	NREL 2007
	4	Bromine		water	unspecified	0	kg	6.80E-4	1	5	NREL 2007
	4	Cadmium, ion		water	unspecified	0	kg	1.02E-7	1	5	NREL 2007
	4	Calcium, ion		water	unspecified	0	kg	1.02E-2	1	5	NREL 2007
	4	Chloride		water	unspecified	0	kg	1.15E-1	1	5	NREL 2007
	4	Chromium, ion		water	unspecified	0	kg	1.61E-6	1	5	NREL 2007
	4	Cobalt		water	unspecified	0	kg	7.03E-8	1	5	NREL 2007
	4	COD, Chemical Oxygen Demand		water	unspecified	0	kg	9.13E-4	1	5	NREL 2007
	4	Copper, ion		water	unspecified	0	kg	4.48E-7	1	5	NREL 2007
	4	Cyanide		water	unspecified	0	kg	2.29E-10	1	5	NREL 2007
	4	Benzene, ethyl-		water	unspecified	0	kg	2.99E-7	1	5	NREL 2007
	4	Fluoride		water	unspecified	0	kg	1.11E-9	1	5	NREL 2007
	4	Acidity, unspecified		water	unspecified	0	kg	6.67E-7	1	5	NREL 2007
	4	Iron, ion		water	unspecified	0	kg	1.84E-4	1	5	NREL 2007
	4	Lead		water	unspecified	0	kg	1.01E-6	1	5	NREL 2007
	4	Lithium, ion		water	unspecified	0	kg	3.41E-3	1	5	NREL 2007
	4	Magnesium		water	unspecified	0	kg	1.99E-3	1	5	NREL 2007
	4	Manganese		water	unspecified	0	kg	3.22E-6	1	5	NREL 2007
	4	Mercury		water	unspecified	0	kg	6.23E-10	1	5	NREL 2007
	4	Molybdenum		water	unspecified	0	kg	7.29E-8	1	5	NREL 2007
	4	m-Xylene		water	unspecified	0	kg	9.61E-8	1	5	NREL 2007
	4	Nickel, ion		water	unspecified	0	kg	5.55E-7	1	5	NREL 2007
	4	o-Xylene		water	unspecified	0	kg	7.00E-8	1	5	NREL 2007
	4	Oils, unspecified		water	unspecified	0	kg	6.09E-5	1	5	NREL 2007
	4	Phenol		water	unspecified	0	kg	1.42E-6	1	5	NREL 2007
	4	Selenium		water	unspecified	0	kg	7.05E-9	1	5	NREL 2007
	4	Silver, ion		water	unspecified	0	kg	6.65E-6	1	5	NREL 2007
	4	Sodium, ion		water	unspecified	0	kg	3.23E-2	1	5	NREL 2007
	4	Strontium		water	unspecified	0	kg	1.73E-4	1	5	NREL 2007
	4	Sulfate		water	unspecified	0	kg	2.34E-4	1	5	NREL 2007
	4	Sulfur		water	unspecified	0	kg	8.41E-6	1	5	NREL 2007
	4	Thallium		water	unspecified	0	kg	7.54E-9	1	5	NREL 2007
	4	Tin, ion		water	unspecified	0	kg	3.49E-7	1	5	NREL 2007
	4	Titanium, ion		water	unspecified	0	kg	5.48E-7	1	5	NREL 2007
	4	Toluene		water	unspecified	0	kg	5.03E-6	1	5	NREL 2007
	4	Solved solids		water	unspecified	0	kg	1.41E-1	1	5	NREL 2007
	4	Vanadium, ion		water	unspecified	0	kg	8.62E-8	1	5	NREL 2007
	4	Xylene		water	unspecified	0	kg	2.54E-6	1	5	NREL 2007
	4	Zinc, ion		water	unspecified	0	kg	1.57E-6	1	5	NREL 2007
	4	Lead-210		water	unspecified	0	kBq	9.18E-4	1	5	NREL 2007
	4	Radium-226		water	unspecified	0	kBq	4.20E-3	1	5	NREL 2007
	4	Radium-228		water	unspecified	0	kBq	5.91E-3	1	5	NREL 2007
	0	natural gas, unprocessed, at extraction	RNA			0	m3	1			

11.4 Natural gas processing

According to NREL (2007), natural gas processing plants in North America are located close to extraction sites. Therefore it was assumed that transportation between extraction and processing is negligible. The natural gas processing dataset describes the sweetening of natural gas i.e. the removal of sulphur and other by-products (NREL 2007).

The ecoinvent module "natural gas, at production", region RNA, includes the data of the NREL natural gas processing dataset. The data has been converted into ecoinvent standard in the same way as described above for the extraction process. The mixture "BTEX (Benzene, Toluene, Ethylbenzene, and Xylene)" used in the NREL dataset was included as "Hydrocarbons, aromatic". A self-consumption of processed gas of about 2.6% was considered in the dataset.

The input data for the natural gas production are shown in Tab. 11.3.

Tab. 11.3 Unit process raw data of "natural gas, at production" for the Region North America (RNA)

InputGroup	OutputGroup	Name	Location	Category	SubCategory	InfrastructureProce	Unit	natural gas, at production	UncertaintyType	StandardDeviation 95%	GeneralComment
		Location						RNA			
		InfrastructureProcess						0			
		Unit						m3			
5		electricity, medium voltage, at grid	US			0	kWh	1.61E-2	1	1.5	NREL 2007
5		natural gas, unprocessed, at extraction	RNA			0	m3	1.05E+0	1	1.2	NREL 2007
	4	Methane, fossil		air	unspecified	0	kg	1.42E-3	1	3	NREL 2007
	4	Sulfur dioxide		air	unspecified	0	kg	1.84E-2	1	3	NREL 2007
	4	NMVOC, non-methane volatile organic compounds, unspecified origin		air	unspecified	0	kg	5.81E-4	1	3	NREL 2007
	4	Hydrocarbons, aromatic		air	unspecified	0	kg	2.60E-4	1	3	NREL 2007
	0	natural gas, at production	RNA			0	m3	1			

11.5 Natural gas transport and distribution

The NREL database does not provide detailed information on the transport and distribution of natural gas in US. The NREL database includes a natural gas "precombustion" table which describes the combination of natural gas production and transportation in one dataset.

For consistency reasons, it was necessary to construct a separate module which describes the transportation and distribution processes from the production sites to the power plants i.e. a module which does not include the production processes (extraction and processing) already modelled. The emissions, natural gas and infrastructure requirements for the transportation and distribution per MJ gas delivered are summarized in the module "natural gas, at consumer" (Tab. 11.4). The average energy density of natural gas in US was assumed to be about 38.4 MJ/m^3 (EIA 2006).

The starting point for the module "natural gas, at consumer" was the NREL precombustion module "Natural gas" (NREL 2007). The emissions of "natural gas, unprocessed, at extraction" and of "natural gas, at production" have been subtracted from the NREL pre-combustion data.

The pipeline requirement for the natural gas transport (23 ton-miles/ft^3) assumed in the NREL database module "Natural gas utility combustion" (NREL 2007) corresponds to an average pipeline length of about 1600 km i.e. about 1.3 tkm per m^3 gas. For the infrastructure, data from the European ecoinvent data for natural gas pipelines are used (Chapter 7). The life time of a pipeline is assumed to be about 50 years. The modelled pipeline has a capacity of 1.1 Mio m^3/h i.e. about 2.6E-9 km pipeline has to be built for the transport of 1 tkm gas.

The consumption of natural gas for the transportation and distribution has been estimated from the Natural Gas Annual data for the year 2005 (EIA 2006). The natural gas consumption for pipeline and distribution use in US is about 2.8% of the total amount of natural gas delivered to consumers (Tab. 11.1). This loss has been considered in the transportation and distribution process described in the module “natural gas, at consumer” by a factor 1.028 for the input requirement of “natural gas, at production”.

The NREL precombustion data are based on iterative calculations which are not further specified (NREL 2007). Therefore the ecoinvent module constructed from the NREL precombustion dataset can be viewed only as a rough approximation of the transport and distribution processes.

The NREL database does not provide uncertainty factors for natural gas data. The uncertainties have been roughly estimated based on estimates of uncertainties of the European natural gas systems.

Tab. 11.4 Input data for module „natural gas, at consumer".

InputGroup	OutputGroup	Name	Location	Category	SubCategory	InfrastructureProcess	Unit	*natural gas, at consumer*	UncertaintyType	StandardDeviation95%	GeneralComment
		Location InfrastructureProcess Unit						*RNA* *0* *MJ*			
5	-	natural gas, at production	RNA			0	m3	2.68E-2	1	1.05	based on Natural Gas Annual, EIA 2005
5		pipeline, natural gas, long distance, high capacity, onshore	GLO			1	km	8.66E-11	1	1.5	NREL 2007, Faist Emmenegger et al. 2003
	4	Methane, fossil		air	unspecified	0	kg	2.82E-5	1	3	based on NREL 2007 data
	4	Particulates, > 10 um		air	unspecified	0	kg	2.52E-7	1	3	based on NREL 2007 data
	4	Particulates, > 2.5 um, and < 10um		air	unspecified	0	kg	1.14E-7	1	3	based on NREL 2007 data
	4	Particulates, < 2.5 um		air	unspecified	0	kg	2.28E-7	1	3	based on NREL 2007 data
	4	Nitrogen oxides		air	unspecified	0	kg	6.84E-6	1	2	based on NREL 2007 data
	4	NMVOC, non-methane volatile organic compounds, unspecified origin		air	unspecified	0	kg	1.33E-6	1	3	based on NREL 2007 data
	4	Sulfur dioxide		air	unspecified	0	kg	3.98E-5	1	3	based on NREL 2007 data
	4	Carbon monoxide, fossil		air	unspecified	0	kg	5.70E-6	1	3	based on NREL 2007 data
	4	Carbon dioxide, fossil		air	unspecified	0	kg	4.83E-3	1	2	based on NREL 2007 data
	4	Carbon dioxide, biogenic		air	unspecified	0	kg	1.91E-5	1	2	based on NREL 2007 data
	4	Acenaphthene		air	unspecified	0	kg	8.80E-14	1	5	based on NREL 2007 data
	4	Acetaldehyde		air	unspecified	0	kg	5.58E-10	1	5	based on NREL 2007 data
	4	Acetic acid		air	unspecified	0	kg	0	1	5	based on NREL 2007 data
	4	Acrolein		air	unspecified	0	kg	5.10E-10	1	5	based on NREL 2007 data
	4	Aldehydes, unspecified		air	unspecified	0	kg	3.75E-9	1	5	based on NREL 2007 data
	4	Ammonia		air	unspecified	0	kg	1.83E-9	1	5	based on NREL 2007 data
	4	Antimony		air	unspecified	0	kg	3.88E-12	1	5	based on NREL 2007 data
	4	Arsenic		air	unspecified	0	kg	8.50E-11	1	5	based on NREL 2007 data
	4	Benzene		air	unspecified	0	kg	1.99E-6	1	5	based on NREL 2007 data
	4	Benzo(a)pyrene		air	unspecified	0	kg	6.56E-15	1	5	based on NREL 2007 data
	4	Benzal chloride		air	unspecified	0	kg	6.47E-14	1	5	based on NREL 2007 data
	4	Beryllium		air	unspecified	0	kg	5.72E-12	1	5	based on NREL 2007 data
	4	Bromine		air	unspecified	0	kg	3.61E-15	1	5	based on NREL 2007 data
	4	Cadmium		air	unspecified	0	kg	3.86E-11	1	5	based on NREL 2007 data
	4	Carbon disulfide		air	unspecified	0	kg	1.20E-14	1	5	based on NREL 2007 data
	4	Methane, tetrachloro-, R-10		air	unspecified	0	kg	4.40E-12	1	5	based on NREL 2007 data
	4	Methane, dichlorodifluoro-, CFC-12		air	unspecified	0	kg	9.84E-15	1	5	based on NREL 2007 data
	4	Benzene, hexachloro-		air	unspecified	0	kg	2.03E-15	1	5	based on NREL 2007 data
	4	Chloroform		air	unspecified	0	kg	5.46E-15	1	5	based on NREL 2007 data
	4	Chlorine		air	unspecified	0	kg	7.73E-11	1	5	based on NREL 2007 data
	4	Chromium		air	unspecified	0	kg	8.53E-11	1	5	based on NREL 2007 data
	4	Chromium VI		air	unspecified	0	kg	1.36E-11	1	5	based on NREL 2007 data
	4	Cobalt		air	unspecified	0	kg	4.34E-11	1	5	based on NREL 2007 data
	4	Copper		air	unspecified	0	kg	3.19E-12	1	5	based on NREL 2007 data
	4	Cumene		air	unspecified	0	kg	4.90E-16	1	5	based on NREL 2007 data
	4	Cyanide		air	unspecified	0	kg	2.31E-13	1	5	based on NREL 2007 data
	4	Dinitrogen monoxide		air	unspecified	0	kg	9.84E-8	1	5	based on NREL 2007 data
	4	Dioxins, measured as 2,3,7,8-tetrachlorodibenzo-p-dioxin		air	unspecified	0	kg	1.64E-13	1	5	based on NREL 2007 data
	4	Ethene, chloro-		air	unspecified	0	kg	3.70E-15	1	5	based on NREL 2007 data
	4	Fluorine		air	unspecified	0	kg	1.57E-13	1	5	based on NREL 2007 data
	4	Formaldehyde		air	unspecified	0	kg	7.87E-9	1	5	based on NREL 2007 data
	4	Furan		air	unspecified	0	kg	7.86E-16	1	5	based on NREL 2007 data
	4	Hydrogen chloride		air	unspecified	0	kg	2.14E-7	1	5	based on NREL 2007 data
	4	Hexane		air	unspecified	0	kg	6.20E-15	1	5	based on NREL 2007 data
	4	Hydrogen fluoride		air	unspecified	0	kg	2.59E-8	1	5	based on NREL 2007 data
	4	Isoprene		air	unspecified	0	kg	1.05E-14	1	5	based on NREL 2007 data
	4	Lead		air	unspecified	0	kg	1.01E-10	1	5	based on NREL 2007 data
	4	Magnesium		air	unspecified	0	kg	1.90E-9	1	5	based on NREL 2007 data
	4	Manganese		air	unspecified	0	kg	2.65E-10	1	5	based on NREL 2007 data
	4	Mercury		air	unspecified	0	kg	2.30E-11	1	5	based on NREL 2007 data
	4	Methane, bromo-, Halon 1001		air	unspecified	0	kg	1.48E-14	1	5	based on NREL 2007 data
	4	Nickel		air	unspecified	0	kg	4.33E-10	1	5	based on NREL 2007 data
	4	Ethene, tetrachloro-		air	unspecified	0	kg	8.00E-12	1	5	based on NREL 2007 data
	4	Phenol		air	unspecified	0	kg	3.48E-11	1	5	based on NREL 2007 data
	4	PAH, polycyclic aromatic hydrocarbons		air	unspecified	0	kg	6.00E-11	1	5	based on NREL 2007 data
	4	Propanal		air	unspecified	0	kg	3.51E-14	1	5	based on NREL 2007 data
	4	Propene		air	unspecified	0	kg	8.31E-10	1	5	based on NREL 2007 data
	4	Propylene oxide		air	unspecified	0	kg	0	1	5	based on NREL 2007 data

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