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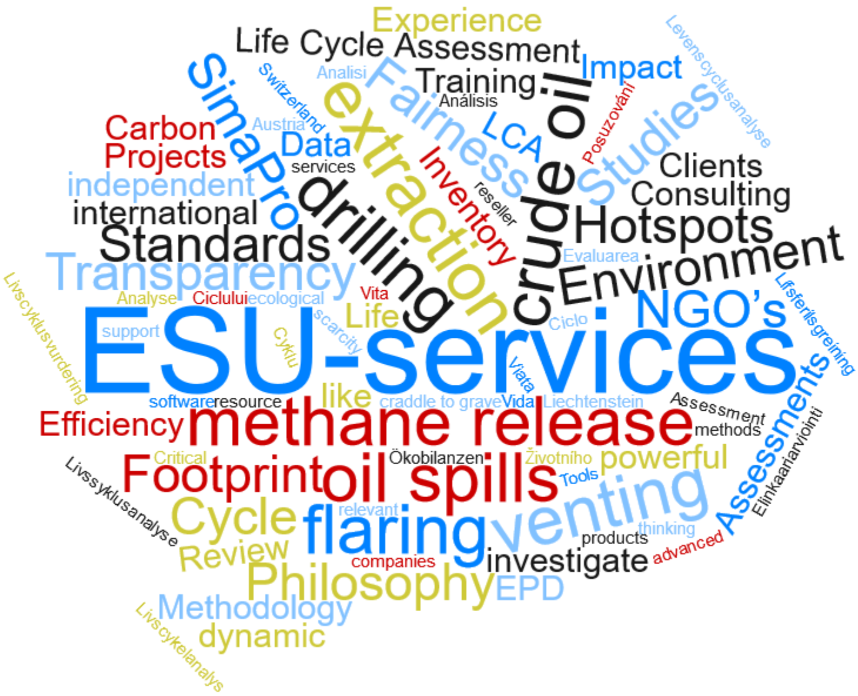
Life cycle inventories of crude oil extraction



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Life cycle inventories of crude oil extraction

Final report

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Abbreviations

a	year (annum)
API	American Petroleum Institute
AZ	Azerbaijan
BAFU	Bundesamt für Umwelt
B(a)P	Benzo(a)Pyren
BAT	Best available Technologies
bbl	Barrel
bcm	billion cubic meters
bld	below limit of detection
bn	Billion
BEW	Bundesamt für Energiewirtschaft (Federal office for the energy industry)
BFE	Bundesamt für Energie
BOD5	Biochemical oxygen demand for 5 days of microbial degardation
BOOS	Burner Out Of Service
BTU	British Thermal Unit (1 BTU = 1055 J)
BTX	Benzene, Toluene, and Xylenes
Bq	Becquerel
BUWAL	Bundesamt für Umwelt, Wald und Landschaft; (Federal offices for environment, forest and landscape
CEL	Central European Pipeline
cf	Cubic Feet
CH4	Methane
CHP	Combined Heat and Power
Ci	Curie
CIS	Commonwealth of Independent States
CMC	Carboxymethyl Cellulose
CO	Carbon monoxide
CO2	Carbon dioxide
COD	Chemical oxygen demand
Concawe	Conservation of Clean Air and Water in Europe (the oil companies' European organization for environmental and health protection, established in 1963)
d	day
DeNOx	Dentirification method (general)
DGMK	Deutsche Wissenschaftliche Gesellschaft für Erdöl, Erdgas und Kohle e.V. (German scientific assosciation for oil, natural gas and coal)
DM	Dry matter
DoE	Department of Energy, US
dwt	Dead weight tons
E5/10/15/85•	Petrol with 5%/10%/15%/85% ethanol
EdF	Electricité de France
EdP	Electricidade de Portugal S.A.
EMPA	Swiss federal material testing institute
ENEA	Italian National Agency for New Technology, Energy and the Environment
EOR	Enhanced Oil Recovery

EOS SA	l'Energie de l'Ouest-Suisse
EPA	Environmental Protection Agency, US
FGD	Flue Gas Desulphurisation system
GGFR	Global Gas Flaring Reduction Partnership
GRT	Gross Registered Tonne
GWP	Global Warming Potential
HC	Hydro carbons
HEC	Hydroxyethyle cellulose
I.f.	insignificant fraction
IEA	International Energy Agency
IMO	International Maritime Organization
IPCC	International Panel on Climate Change
IQ	Iraq
J	Joule
KBOB	Koordinationsgremium der Bauorgane des Bundes
KZ	Kazakhstan
LCI	Life cycle inventory analysis
LCIA	Life cycle impact assessment
LRV	Luftreinhalte-Verordnung (Swiss Clean Air Act)
MEEPD	Ministry of the Environment, Environmental Protection Department
M.	Million
MJ	Megajoule
Mt	Megaton = 1 million tons
MTBE	Methyl tert-butyl ether
MW	Megawatt
MX	Mexico
NCI	Nelson complexity index
NDP	Norvegian Petroleum Directorate
NG	Nigeria
NGL	Natural Gas Liquids
NL	Netherlands
Nm3	Normal-cubic metre (for gases)
NMVOC	Non-Methane-Volatile Organic Compounds
NO	Norway
NOAA	National Oceanic and Atmospheric Administration
NORM	Naturally-Occuring Radioactive Materials
NOX	Nitrogen oxides
NR	Not Reported
Ns	not specified
OBM	Oil Based Mud,
OE	Oil equivalent
OECD	Organisation for Economic Cooperation and Development
OFA	Over Firing Air
PAH	Polycyclic Aromatic Hydrocarbons
PARCOM	Paris Commission
PC	Personal Communication
PM	Particulate Matter

PRTR	Pollutant Release and Transfer Register
RMPE	Royal Ministry of Petroleum and Energy Norway
Rn	Radon
RODP	Relative Ozone Depletion Potential
RSO	Raffinerie du Sud-Ouest SA
RU	Russia
SA	Saudi-Arabia
SEPL	South European Pipeline
SMA	Schweizerische Meteorologische Anstalt (Swiss Meterological Institute)
SN	Smoke number
SNCR	Selective-Non-Catalytic-Reduction
SPCA	State Pollution Control Authority
SPSE	Société du pipeline sud-européen (South European Pipeline)
SRE	Société Romande d'Electricité
SRI	Sustainable Recycling Industries
TDS	Total Dissolved Solids
TEL	Tetraethyl lead
toe	Ton Oil Equivalent
TSP	Total Suspended Particulates
TSS	Total Suspended Solids
UBA	Umweltbundesamt (Federal Office for the Environment)
UCTE	Union for the Co-ordination of Transmission of Electricity
ULCC	Ultra Large Crude Carrier
ULS	Ultra low sulphur
UNEP	United Nations Environment Programme
Unipede	International Union of Producers and Distributors of Electrical Energy
US (A)	United States of America
UVEK	Federal Department for Environment, Transport, Energy and Communications
VDEW	Vereinigung Deutscher Elektrizitätswerke e.V. (Union of German Electricity Works)
VEÖ	Verband der Elektrizitätswerke Österreichs (Association of Austrian Electricity Works)
VFWL	Verein zur Förderung der Wasser- und Lufthygiene (Society to Support Water and Air Hygiene)
VLCC	Very Large Crude Carrier
VOC	Volatile Organic Compounds
VVS	Verordnung über den Verkehr mit Sonderabfällen, (Regulation on handling of hazardous wastes)
WBM	Water Based Mud,
WEC	World Energy Council

Indices

e	electric
End	End energy
In	Input, related to a energy converter (end energy)
Nutz	useful energy
Out	Output, related to an energy converter (useful energy or end energy)
therm	thermal

1 Introduction

This document describes the update of datasets from version v2.0 of the ecoinvent database (Jungbluth 2007). The German report was translated in 2012 by Franziska Peter, PSI for the ecoinvent centre. This English translation forms the starting point for updating the data with the reference year 2016.

The goal of the report is to report the data as they are investigated with this update for the year 2016. Thus, the reader should have a full overview about the data sets as they are now provided for the KBOB database.

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

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

Technical descriptions in the former report often were elaborated for the 1996 version of the data (Frischknecht et al. 1996). They often seemed to be outdated and such descriptions which are not relevant for the estimates have been deleted.

Parts of the text which are not relevant (anymore) for the final estimation of the life cycle inventory have been removed to improve the readability of the new report and shorten the amount of documentation. This concerns e.g. long literature lists of data sources dating back to the 80ies if up-to-date data were available. This concerns also annexes with long documentation of data which finally were not used for a new estimation in this report. If no new information was available only the final estimation is documented to improve the readability. The documentation focuses on aspects which are relevant for the updated life cycle inventories presented in this report.

To keep this report readable outdated and old information has been removed partly. If LCI data are still based on such very old information they are cited as (Jungbluth 2007) which means they often have been published before the year 2000.

Changes made to ecoinvent v2.0 data and implemented in ecoinvent v3 are NOT part of this report. Content of this document therefore does not reflect the LCI data of ecoinvent v3.

A general overview of this project is given in a separate report (Jungbluth et al. 2018b).

The following chapters analyse oil production from the perspective of production regions relevant for Switzerland and Europe.

For information on updated data for the most important process steps, see the following chapters. The material and construction costs for onshore and offshore fields are inventoried and the requirements for operating materials and land occupation are determined. The energy required for production and the subsequent cleaning of crude oil is determined based on process-specific data. Process emissions into the atmosphere due to flaring, leakage, venting and low-pressure ventilation are estimated. Data on the quantities of co-produced formation water and the associated emissions into surface waters are discussed. These data are used to prepare life cycle inventories for onshore, offshore and national production in various countries.

2 Goal and scope

2.1 Overview on updates

In this report the most relevant factors for the life cycle inventory (LCI) of crude oil extraction in countries with target market Switzerland and Europe are described. Based on the analysis of existing datasets it is known, which LCI components have the highest influence. A short analysis of these factors is also shown at the end of this report in a short LCIA in chapter 14. Therefore, the focus is on the factors described in the following subchapters when examining new and updating existing data sets. Generic data from previous studies are used to complete the LCIs (Jungbluth 2007).

The market situation for crude oil supplies to Europe and Switzerland was updated and new inventories have been developed for extraction in some countries. Most relevant for the update are methane emissions due to venting, discharge of produced water and the direct energy uses during oil extraction including drilling and flaring. Furthermore, the emissions due to these practices were updated. Air emissions due to ozone depleting substances have been re-evaluated. Other less important aspects are e.g. construction materials and the use of chemicals for enhanced oil recovery.

2.2 Allocation for combined gas and oil production

Crude oil and natural gas production are often very closely linked, and data are often provided for combined production[1]. Therefore, multioutput-processes are generated for several regions under investigation. This study presents data on oil and gas production per kg oil equivalent (kg OE). A net calorific value of 43.2 MJ/kg is used for crude oil and an average value of 36.3 MJ/Nm3 for natural gas (Jungbluth 2007; Schori et al. 2012). These values are also used in the Swiss energy statistics (BFE 2017).

The life cycle impacts from combined crude oil and natural gas production are allocated based on these net calorific values. These values are used for newly created and updated data sets together with the annual production data for 2016 (cf. Tab. 4.1 and Tab. 4.2). Impacts of fresh water use and discharge of produced water are allocated to crude oil only.

3 Methods for oil extraction

This section gives a basic overview on the technologies in use mainly based on the description of the first database version (Frischknecht et al. 1996; Jungbluth 2007). Information on production methods in this report has not been updated for current developments.

3.1 Conventional production

Depending on the variety of crude oils and their properties, the production processes to be used and further treatments are different. While thick, viscous oil must be pumped to the surface, condensate erupts under the high storage site pressure without any additives. The reservoir energy can last for a few days, weeks, months or, as with the oil fields of the Middle East, for years. If the total energy is no longer enough to overcome gravity and friction losses, additional energy must be supplied from outside. Two fundamentally different methods are used:

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1 https://www.britannica.com/science/sedimentary-rock/Oil-and-natural-gas, online 19.10.2017

- The gas lift process and
- Deep pump pumping

In the gas lift process, the energy is supplied in the form of compressed gas (natural gas or exhaust gas). This foams the oil column and makes it correspondingly lighter. Piston pumps with external drive or, more recently, electric centrifugal pumps are used for deep-pump pumping.

The crude oil produced is separated from any gas and water produced. Gas separation plants are usually built in several stages to separate the valuable fractions, such as butane and pentane, from the less economically interesting ones. The pressure in the individual separators is reduced in stages (up to seven stages).

If the oil contains salt water (formation water) after separation of the gas, it must be reduced to a value compatible with the transport system and the refinery (corrosion problems).

3.2 Secondary and tertiary production

If the pressure in the oil field is not enough to transport the oil to the bottom of the borehole, secondary techniques such as water flooding or gas injection must be used. During water flooding, large quantities of water are pressed into the oil field. Water drives oil towards the bottom of the borehole. It compensates for the required but insufficient deposition energy.

For gas injection, in-situ produced oil-associated gases are pressed into the deposits, which requires a compressor with a capacity of several MW - gas turbines (operated with the produced gases) and electric compressors (operated with diesel-electric generators).

Deposits with highly viscous crude oil and in rocks with low permeability are only conditionally suitable for conventional secondary processes. Tertiary recovery methods must be used at an early stage. Three categories can be roughly distinguished (Speight 1991).

- chemical methods,
- thermal methods and
- mixing methods

Within the chemical methods, three methods can be distinguished. Flooding with polymers is a conceptually simple and cost-effective method, but the additional yield is low. Surfactant flooding is complex, expensive and requires extensive preliminary investigations. It has excellent improvement properties for low and medium viscosity oils. Alkaline flooding processes are only used in deposits with strongly acidic crude oils.

Thermal processes are mainly used in America and Indonesia. There heat is used to reduce the viscosity of the oil or to evaporate the oil. In this way, however, the pressure and thus the energy in the deposit is also increased. A distinction is made between cyclic steam injection, steam flooding and in-situ combustion. Steam processes are often carried out in containers with highly viscous or tarred oils instead of (or after) primary or secondary recovery. Only a few projects were realised in the field of in-situ combustion.

4 Production and market data

Information on market data is given in a more comprehensive way in the report "Life cycle inventory for long distance transport of crude oil" (Meili et al. 2018).

4.1 Market situation for supplies to Switzerland and Europe

For this study, LCI datasets for crude oil production in 8 different countries are either updated or newly modelled. To determine, which countries are most meaningful for crude oil supply in Switzerland, besides direct import, also indirect import of crude oil refined in Europe is investigated. Switzerland imports various refined oil products in varying quantities from different countries in Europe. To simplify this analysis, it is assumed that crude oil imports in these refineries reflect European average imports as already done in former reports for ecoinvent v2 (Jungbluth 2007, chapter 5.2.1).

Further details on market data, simplifications made for modelling and their presumed consequences for this study can be found in the relevant reports:

- Meili et al. 2018 - Life cycle inventory for long distance transport of crude oil, chapter 2
- Jungbluth et al. 2018a - Life cycle inventories of oil refinery processing and products, chapter 2
- Jungbluth & Meili 2018 - Life cycle inventories of oil products distribution, chapter 2

According to above mentioned assumption crude oil is imported in 2016 directly or indirectly[2] to Switzerland from different countries as shown in Tab. 4.1 (Erdöl-Vereinigung 2017). Imports of refinery products from non-EU-countries to Switzerland account for less than 1% of total imports and therefore are neglected. The import of refined products to Europe is not analysed in detail for this study (Jungbluth & Meili 2018).

It must be emphasized that the above-mentioned market model does not represent the real supply situation in Switzerland. It is a simplification assuming only one average European refinery. The real supply situation is more complex. In 2016, e.g. more products are imported from refineries in the North Sea region (mainly light crude oil) than from Eastern European refineries (mainly heavy crude oil). It would be necessary to investigate more different refinery regions in Europe to better reflect the real situation for supplies to Switzerland. This was not possible with the resources available for this project.

The countries selected for this study play an important role on the global market. Together, these 8 countries cover about 50% percent of global crude oil and natural gas production in 2016[3]. If the above-mentioned simplification would not have been made this might have had an impact on the decision if Norway, Iraq and Saudi Arabia are investigated in detail or not, as they did export only little or no crude oil directly to Switzerland in 2016. On a global perspective, Saudi Arabia and Iraq are among the largest producers and exporters of crude oil[3]. Therefore, it seems valid to assume that, if not in 2016, in other years, a large amount of crude oil from these origins is refined for end market in Switzerland. As most crude oil products imported to Switzerland are refined in Northern Europe, it also seems valid to investigate crude oil produced in Norway.

2 https://de.statista.com/statistik/daten/studie/172674/umfrage/verteilung-der-oelimporte-der-eu-nach-herkunft/, online 16.10.2017

3 Enerdata 2016, yearbook.enerdata.net/crude-oil/world-production-statitistics.html, online 16.10.17

Tab. 4.1 Information consulted to decide which countries of origin to model for crude oil production, assuming an average European crude oil import mix for refinery products imported to Switzerland in 2016: crude oil directly and indirectly (through refineries in Europe) imported from original country of origin to Switzerland in 2016, availability of LCI data, type of production and selection of datasets for 8 countries to be updated (in green) or newly created (in blue). On the right: Availability of former datasets, type of production (On- or Offshore) and method of data collection (for combined oil and gas extraction or oil only)

Imports of crude oil from	direct to Switzerland	indirect via Europe	cumulated to Switzerland	availability of dataset in	Onshore & Offshore?	combined oil&gas?
Russia	7.8%	**32%**	25.4%	ecoinvent v1.0	Onshore only	No
Nigeria	**35.2%**	6%	13.6%	ecoinvent v1.0	Mainly onshore	Yes
Kazakhstan	**16.2%**	7%	9.6%	KBOB v2.2	Yes	No
Norway		**12%**	8.8%	ecoinvent v1.0	Offshore only	Yes
Iraq	4.7%	**8%**	7.2%	new	Onshore only	Yes
Mexico	**16.8%**	3%	6.4%	new	Yes	Yes
Saudi-Arabia		**8%**	5.8%	new	Yes	Yes
USA	**17.2%**		4.6%	ecoinvent v3	Onshore only	Yes
Azerbaijan		4%	3.2%	KBOB v2.2+	Offshore only	No
Libya	2.1%	2%	2.3%	ecoinvent v1.0	Onshore only	No
Algeria		3%	2.1%	ecoinvent v1.0	Onshore only	No
Egypt		1%	0.9%	no	-	-
Other countries		14%	10.2%			
Total	100%	100%	100%			
Imports to Switzerland in 2016 [tons]	**2'875'500**	**7'777'908**	**10'653'408**			
Type of good	**Crude oil**	**Products**	**Total**			

To model the situation in 2016, inventories for crude oil production in Iraq, Mexico and Saudi Arabia are newly created. Datasets for Russia, Nigeria, Kazakhstan, Norway and the USA are available in ecoinvent v1.0 or v3 and/or the KBOB-database v2.2 (ecoinvent Centre 2003, 2016; KBOB v2.2: 2016). These datasets for Russia, Nigeria, Kazakhstan, Norway and USA are updated and changes are described in this report as explained in chapters 1and 2. For less relevant figures (e.g. for material input in platform construction), which are not updated, previous reports provide explanations on the estimation and links to original sources (c.f. ecoinvent Centre 2016; Jungbluth 2007; Stolz & Frischknecht 2017). If no country specific information is available, a generic global average value is used as estimate.

4.2 Proportion of offshore oil and natural gas production

In 2015, global offshore crude oil production (including lease condensate and hydrocarbon gas liquids) accounted for nearly 30% of total global crude oil production. [4]

More than 27 million barrels of oil were produced offshore in 2015 in more than 50 different countries. Global offshore oil production is expected to remain high in 2016, as many oil-producing nations continue to increase production. A significant amount of global offshore

[4] U.S. EIA 2016, https://www.eia.gov/todayinenergy/detail.php?id=28492, online: 10.10.17

production is concentrated in a few countries. In 2015, five countries provided 43% of total offshore oil production: Saudi Arabia[5], Brazil, Mexico, Norway, and the United States.[4]

On the other side countries like Russia and Iraq[6] only produce onshore (EIA 2016).

This means, the proportion of maritime production, varies largely between different producing regions.

Independent of the share of onshore and offshore production, also the amount of natural gas extracted in the joint production varies largely between different producing regions.

Tab. 4.2 shows the total crude oil and natural gas production[7] and modelled shares for onshore and offshore production.

Tab. 4.2 Total crude oil and natural gas production (in mega tons and billion cubic meters per year) and share of offshore and onshore-production in 2016

Origin	crude oil production	natural gas production	energy production	Oil equivalent	share offshore	share onshore	source for share on vs offshore
Unit	Mt/a	bcm/a	MJ/a	kg OE/a	%	%	
Russia	547	628	4.57E+13	1.09E+12	0%	100%	Jungbluth 2007
Nigeria	103	40	5.76E+12	1.38E+11	25%	75%	Jungbluth 2007
Kazakhstan	79	36	4.61E+12	1.10E+11	24%	76%	EIA 2016
Norway	90	120	8.12E+12	1.94E+11	100%	0%	EIA 2016
Iraq	193	10	8.44E+12	2.02E+11	0%	100%	EIA 2016
Mexico	120	40	6.48E+12	1.55E+11	75%	25%	EIA 2016
Saudi-Arabia	598	90	2.83E+13	6.76E+11	22%	78%	Saudi Aramco, Arab Oil and Gas Journal 2012
USA	556	750	5.05E+13	1.21E+12	18%	82%	estimate, based on graph from EIA 2016
Default GLO	**4358**	**3629**	**1.82E+14**	**4.36E+12**	**30%**	**70%**	**EIA 2016**

4.3 Proportion of enhanced oil recovery (EOR)

Enhanced oil recovery is used to enhance the recovery factor of oil fields. The tendency to EOR methods is increasing because aging oil sources are running dry and new discoveries are often only of smaller sizes.

The maturity of production is an important driver of emissions through time. Simply said, this means, an aged oil field is harder to exploit than a young one and therefore, resource and energy needs are higher and lead to higher emissions. Emissions from the same field 20 years after first production can increase by as much as a factor of 10 to 20 over emissions at the start of production (Energy-Redefined 2010). This increase is driven by several factors, including but not limited to:

- Gas and water injection for secondary and tertiary recovery
- Oil flow rates
- Water cut/water production

5 Saudi Aramco, Arab Oil and Gas Journal 2012, cited in secondary source http://large.stanford.edu/courses/2014/ph241/aljamaan1/docs/saudi_arabia.pdf
6 http://www.opec.org/opec_web/en/about_us/164.htm, online, 09.10.2017
7 Enerdata 2016, yearbook.enerdata.net/crude-oil/world-production-statitistics.html, online 16.10.17

Using EOR, 30 to 60 percent, or more, of the reservoir's original oil can be extracted, compared with 20 to 40 percent using primary and secondary recovery (Abubaker 2015).[8] This means, by using EOR up to 30% more crude oil can be yielded from a certain oil field. Depending on the market price of crude oil and the availability of easily accessible oil fields, EOR is used intensively.

As current data is not available publicly on a country or global level, it is assumed for the new and updated regional datasets, that 15% of crude oil production is done with EOR. In the latest assessment, EOR made 3.2% of total production, assuming to be done mainly with chemical methods (Jungbluth 2007). The estimated increase leads to a factor of 4.7 for chemical use per kg of crude oil which is applied for generic values in this model.

5 Characteristics and properties of crude oil

This section describes the main properties of crude oil. No major changes or updates have been made compared to previous versions of ecoinvent data (Jungbluth 2007).

5.1 Classification and API

Within natural resources, oil belongs to the subgroup of naturally occurring hydrocarbons. In contrast to coal, whose elemental composition is very well investigated and documented, the classification of oil is much more difficult because of the lower number of extensive analyses. The ratios of the elements C and H in oil fluctuate only slightly within rather tight limits – despite the big variation in physical characteristics between light mobile hydro carbons and oils and bitumen (Speight 1991).

Classifying crude oil can be done from different perspectives (Speight 1991):

- Based on proportion of paraffin, naphthenic, aromatic, wax and asphalt components.
- By a correlation index. It describes the correlation of density and boiling temperature on the one hand, and the chemical composition on the other hand.
- By carbon distribution. The distribution of fractions as a function of their volatility is an important parameter. Furthermore, the fractions of aromatic, naphthenic and paraffinic hydrocarbons are determined, whereby paraffinic is subdivided into normal and iso-paraffin.

The new refinery model for ecoinvent v3 will depend on API values for the crude oil. So far, this parameter is not investigated or specified for single countries investigated in this report.

5.2 Calorific value and density

The calorific value, as well as the density of crude oil and natural gas products varies, depending on its composition and external conditions. For crude oil, values from several publications are presented in Tab. 5.1. In this study, a net calorific value of 43.2 MJ for crude oil and an average value of 36.3 MJ/Nm3 for all the natural gas products (including flaring) are used for modelling. These values are used in the Swiss energy statistics and were already used in former studies (BFE 2017). In these former studies, the derivation is further described (Jungbluth 2007; Schori et al. 2012).

8 https://energy.gov/fe/science-innovation/oil-gas-research/enhanced-oil-recovery, online 12.10.17

Tab. 5.1 Applied calorific values and densities for crude oil in this and various other studies

	Net calorific value	Gross calorific value	Density
	MJ/kg	MJ/kg	kg/l
Birnbaumetal. 1992	42.6	ns	ns
Raffoil 1991	43.3	45.8	0.836
Schmidt et al. 1981	42.3	45.4	0.86
BP 1993	41.8	45.5	0.855
Speight 1991	ns	41.8-48.5	ns
Jungbluth 2007	43.3	45.8	0.86
IEA 2017	41.6	43.8	
BP world energy report 2017	42	ns	
Erdöl-Vereinigung 2017	ns	ns	ns
This study	**43.2**	**45.8**	**0.86**

5.3 Hydrocarbons

Hydrocarbons (HC), which are the main component of crude oil and which only consist of carbon and hydrogen, can be divided into three groups according to their chemical characteristics:

- **Saturated HC (paraffines and alkanes):**
  They form the main components of crude oil;
  Chemical formula : C_nH_{2n+2}
  Examples :
  CH_4 – C_5H_{12}, methane, ethane, propane etc. (gaseous),
  C_6H_{14}- $C_{21}H_{44}$, hexane, heptane, octane etc. (liquid)
  >= $C_{22}H_{46}$, pentacosane, triacontane etc. (solid).
  Cyclic saturated (alicyclic) HC (naphtenes, cyclo-paraffines, and cyclo-alkanes).

- **Unsaturated HC (alkenes or olefins or alkines).**
  Chemical formula: C_nH_{2n}, or C_nH_n
  Examples:
  C_2H_4 (IUPAC: ethene, ecoinvent: ethylene),
  C_3H_6 (IUPAC: propene, ecoinvent: propylene),
  C_2H_2 (ethyne, etc.)

  Unsaturated HC are of subordinate importance for natural crude oils. They form in the refineries during cracking processes as valuable by-products, which improve fuel characteristics and partially attained high importance as starting material for many syntheses. Because of their reactivity they have a high significance for the formation of tropospheric ozone.

- **Aromatic HC as aromatics are called unsaturated, ring-shaped HC.**
  Examples:
  C_6H_6 (benzene),
  C_7H_9 (toluene),
  C_8H_{12} (ortho-, meta- and para-xylene)

The share of different components of HCs varies among different crude oils. Generally, it can be said that heavier crude oils (Latin America, Middle East) show higher proportions of poly-cyclic naphthenic and poly-nuclear aromatics, but lower shares of paraffins and monocyclic naphthenes (Speight 1991). Among other things, this also leads to higher metal contents (Ni, V).

5.4 Components other than hydrocarbons

Next to the high number of pure hydrocarbons, crude oil contains a variety of organic components other than hydrocarbons. Mainly they are sulphur-, nitrogen-, or oxygen compounds. In smaller amounts, also dissolved organo-metallic components and inorganic salts in different colloidal suspension are present. These components occur within the entire boiling range of crude oil, but mainly they are concentrated in the heavier fraction and the non-volatile residues (Speight 1991).

These components can have a major impact in technical processes, despite the relatively low quantity. This entails thermal decomposition of inorganic chlorides to free hydrochloric acid and thus to corrosion problems in distillation. Also, the presence of organic acidic components such as mercaptans and acids can cause metal corrosion. In catalytic processes, e.g. by nickel and vanadium deposits or by chemisorption of compounds containing nitrogen, a passivation or poisoning of the catalyst can occur, which leads to frequent regeneration or premature replacement of the catalyst.

5.5 Sulphur components

Sulphur content correlates, as first approximation, with the density of crude oil. It fluctuates between 0.04% for light paraffin oil and 5% and more for heavy crude oil. Sulphur in oil products can lead to corrosion in many applications. For instance, mercaptan in hydrocarbon solutions leads to corrosion of copper and brass if oxygen is present. The sulphur compounds vary from simple thiols (mercaptans) via sulphides, poly-cyclic sulphates and thiophenes to derivates of benzo-thiophenes (Speight 1991). For the main production areas, the following sulphur contents can be reported (Fig. 5.1). Sulphur contents of final products depends on processing in the refinery (Jungbluth et al. 2018a).

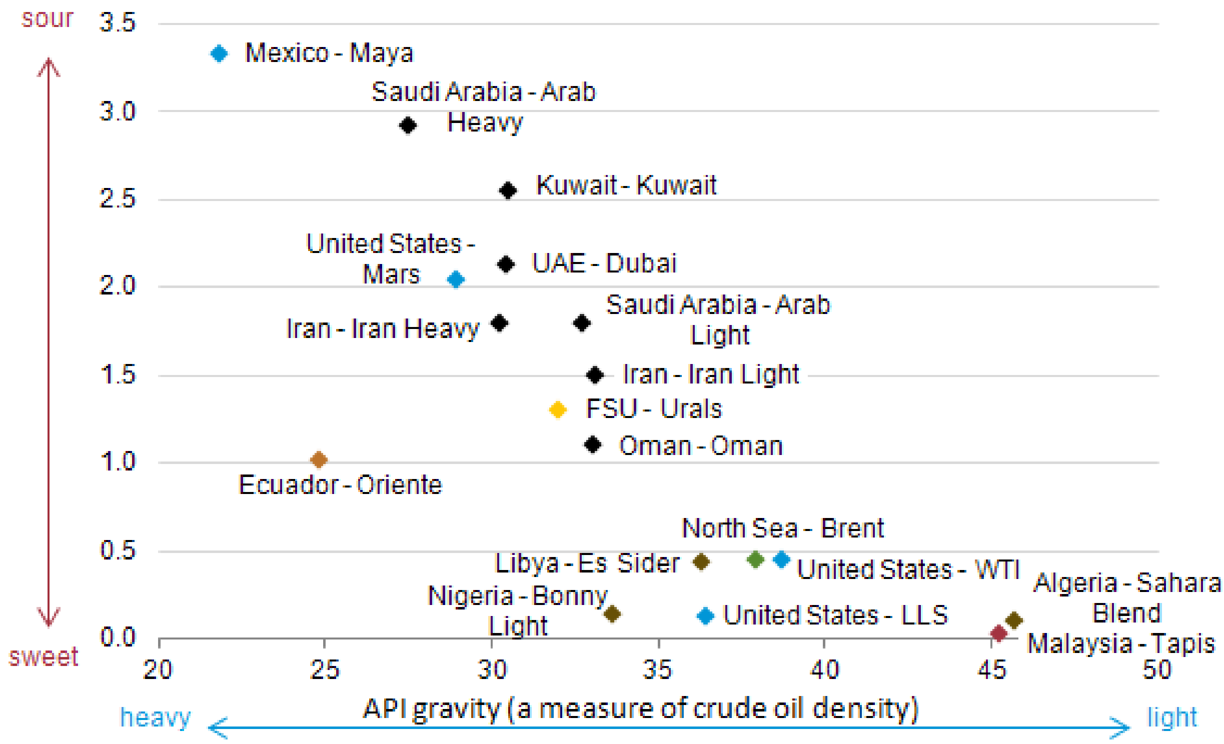

Fig. 5.1 Density and sulphur content of selected crude oils, sulphur content in % by weight according to EIA[9]. Points on the graph are labelled by country and benchmark name and are colour coded to correspond with regions. The graph does not indicate price or volume output values. United States-Mars is an offshore drilling site in the Gulf of Mexico. WTI = West Texas Intermediate; LLS = Louisiana Light Sweet; FSU = Former Soviet Union; UAE = United Arab Emirates.

5.6 Oxygen compounds

The oxygen compounds are: alcohols (phenols), ethers, carboxylic acids, ketones and furans. Thereby, ketones, esters, ethers and anhydrides can rather be found in heavy, non-volatile residues. They can originate from residues and do not need to be original components of crude oil (cf. Jungbluth 2007, chapter 9).

5.7 Nitrogen compounds

Nitrogen compounds can be divided into alkaline or non-alkaline. Nitrogen content tends to increase with asphalt content of crude oil. Therefore, nitrogen is more likely to be found in those fractions and remains which are higher boiling. Increasing refinement of residues to lighter fractions ("whitening of the Barrel") can lead to harmful effects of nitrogen on crack-catalysts in refineries (Speight 1991).

5.8 Porphyrins

Porphyrins are cyclic, conjugated components, which occur usually in the non-alkaline part of the nitrogen-containing concentrate. Nearly all crude oils contain vanadyl and nickel porphyrins (metal chelates). Other metals were hardly found in such compounds, probably for geochemical reasons. However, by far not all vanadium and nickel is incorporated in porphyrins. They can

9 https://www.eia.gov/todayinenergy/detail.php?id=7110, online 18.04.2018

also occur as non-porphyrin, metallic chelates (Speight 1990). Porphyrins are concentrated in the asphalt fraction. Therefore, deasphalted crude oils do have smaller concentrations of porphyrins and usually also very small concentrations of non-porphyrin metals.

5.9 Further trace elements

For processing but also for emission inventories of oil-energy systems, next to calorific value and sulphur content, also information on concentrations of other trace elements of crude oil and its products are of interest.

From the point of view of the oil processor and oil customer, trace elements in the oil are not desired. On the one hand, because they impair the effect of the catalyst in the refinery; on the other hand, for example they can lead to ash formation and corrosion in turbines. The trace elements which occur in significant concentrations in oil can be divided into two groups. Zinc, titanium, calcium and magnesium and others are present as organometallic soaps; while e.g. vanadium, copper, nickel and iron occur as components soluble by oil.

By distillation processes, trace elements are generally concentrated in the residues. Thus, the content of trace elements tends to increase from light to heavy products and is higher in heavy fuel oils and bitumen than in processed crude oil.

Various publications contain results and analyses on trace elements or their emission factors in crude oils and products. The extent to which element contents in crude oil can fluctuate is shown in a former study (Jungbluth 2007, Table A.1). The high concentration of zinc and iron in the composition of oil indicate an enrichment during oil processing (separation of water and gases) and transport (Pacyna 1982, Jungbluth 2007, appendix Tab A.1).

5.10 Mercury

Amount of mercury in this study is assessed as 0.030 mg/kg of crude oil (Jungbluth 2007).

5.11 Summary of properties used in this study

The LCI data for extraction processes modelled in this study is calculated for crude oil with the physical and chemical properties as defined in Tab. 5.2.

Tab. 5.2 Physical and chemical properties of crude oil as defined in this study

	unit	This study
Lower heating value (Hu)	MJ	43.2
Higher heating value (HHV)	MJ	45.8
Density at 20°C	kg/l	0.86
	% by weight	This study
C-content	83 - 87	85%
H-content	10 - 14	12%
O-content	0.05 - 1.5	0.80%
N-content	0.1 - 2.0	1.0%
S-content	0.05 - 6	1.2%

6 Material use and land occupation for infrastructure

The LCI modules "Production plant crude oil, onshore" and "Platform, crude oil, offshore" are used for infrastructure expenses. Details about data collection are provided in a former study (Jungbluth 2007). The infrastructure is allocated to natural gas and crude oil production based on the quantity produced (in calorific value).

It is assumed that these inventories are still accurate for this model and no updates were commissioned for the infrastructure. However, as described in chapters 3.2 and 4.3 oil fields get more depleted globally, which means, that wells need to get deeper, the number of wells increases, and new/ enhanced oil recovery methods must be used. Data for these factors are investigated and updated in this study.

6.1 Number of wells

The number of wells needed to maintain a steady flow of crude oil highly depends on regional aspects. In the Rumaila oil field in Iraq, 350 wells are sufficient to extract 1.5 million barrels per day (bbl. /d), leading to a productivity of 4'300 bbl. /d and well (2b1stconsulting[10]) On the other hand, in the US, where oil fields are highly deployed, production from about 21,500 wells in shale accounted for 2.7 million bbl. /d of U.S. production, with each well averaging 125 bbl. /d. Another 558,000 wells averaging less than 10 bbl. /d produced the other 5.3 million barrels (AOGR[11]).

The national average length of the wells has a smaller variability with 1524m for US (EIA[12]) and 2400 m in Iraq (FAS[13]).

For the newly modelled and updated processes the values shown in Tab. 6.1 are used.

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10 2b1stconsulting: https://www.2b1stconsulting.com/bp-and-cnpc-tender-iraq-rumaila-produced-water-re-injection-prwi/, online 19.10.17

11 AOGR: http://www.aogr.com/web-exclusives/exclusive-story/iraqs-future-key-to-u.s.-oil-prices; online 19.10.17

12 EIA: https://www.eia.gov/dnav/pet/pet_crd_welldep_s1_a.htm, online 19.10.17

13 FAS: https://fas.org/sgp/crs/mideast/RS21626.pdf, online 19.10.17

Tab. 6.1 Information considered to estimate amount and length of wells assessed for modelled extraction processes, onshore and offshore: white background: Data used in model, grey background: values considered for estimation, blue background: Average as global estimate.

Origin / Reference Year	amount of wells	reference	wells per kg OE, onshore	source for amount of wells	well length	well length (m) per kg OE, onshore	source for length of wells	well length (m) per kg OE, offshore	
Unit	No		No/kg OE		m/well	m/kg OE		m/kg OE	
Russia						2.55E-5	Data from Rosneft and Lukoil	3.70E-06	Average of literature
2000						2.55E-5	Data from Rosneft and Lukoil		
Nigeria						4.10E-6	Jungbluth 2007	3.70E-06	Average of literature
2011						4.10E-6	Jungbluth 2007		
2000						4.08E-6	Jungbluth 2007		
Kazakhstan						2.55E-5	Data from Rosneft and Lukoil		
Kazakhstan, onshore						2.55E-5	Data from Rosneft and Lukoil		
Kazakhstan, offshore								4.81E-6	Stolz & Frischknecht 2017
2016, onshore						2.55E-05	Data from Rosneft and Lukoil		
Norway								2.60E-06	Schori 2012
2010								2.60E-06	Schori 2012
Iraq	1'600	1.5mio bbl/day on	1.39E-09	2b1stconsulting	2'400	3.34E-6	FAS	-	
2016	1'600	1.5mio bbl/day on oilfield Rumaila	1.3925E-09	2b1stconsulting	2'400	3.34E-06	FAS		
Mexico			2.37E-08	average country data	-	3.71E-5	Default GLO	3.70E-06	Average of literature
Saudi-Arabia	3'200	national production	3.17E-10	AOGR 2014	2'400	7.60E-7	data for IQ	3.70E-06	Average of literature
2016	3'200	national production	3.17E-10	AOGR 2014	2'400	7.60E-07	data for IQ		
USA	579'500	national production	6.95E-08	AOGR 2014	1'524	1.06E-4	EIA 2016	3.70E-06	Average of literature
2016	579'500	national production	6.95E-08	AOGR 2014	1'524	1.06E-04	EIA 2016		
2016						4.07E-06	Wernet 2016, Ecoinvent v3.4, approximated with data for Nigeria, Jungbluth 2007		
Default GLO			**2.37E-08**	**average country data**		**3.71E-5**	**Average of literature**	**3.70E-06**	**Average of literature**

Tab. 6.2 shows a life cycle inventory for the drilling of one meter of well for exploration and production of crude oil and natural gas. Data is kept similar to the former study (Jungbluth 2007). For onshore production land must be transformed to drill the well and access it. A relatively high value was estimated for production in Russia, which is however rather uncertain (Jungbluth 2007). For this model it is estimated that a smaller area of 50m times 50m is needed for a well with depth 2000m[14]. This estimation is applied in all the datasets in this study.

Tab. 6.2 Life cycle inventory data for the drilling of wells for exploration and production of crude oil, onshore

	Name	Location	InfrastructureProcess	Unit	well for exploration and production, onshore	UncertaintyType	StandardDeviation95%	GeneralComment
	Location				GLO			
	InfrastructureProcess				1			
	Unit				m			
resource, land	Occupation, mineral extraction site	-	-	m2a	1.88E+1	1	1.80	(3,4,5,3,1,na); Lifetime of well 15a
	Transformation, from forest, unspecified	-	-	m2	1.25E+0	1	2.03	(3,4,1,3,1,na); Estimation 50*50 metre area for a 2000 m well
	Transformation, to mineral extraction site	-	-	m2	1.25E+0	1	2.03	(3,4,1,3,1,na); Calculation
resource, in water	Water, well, in ground	-	-	m3	3.34E+0	1	2.24	(2,3,5,3,1,na); Literature, basic uncertainty estimated with 2
technosphere	lignite, at mine	RER	0	kg	2.00E-1	1	1.51	(2,3,5,1,1,na); Literature
	barite, at plant	RER	0	kg	2.70E+2	1	1.51	(2,3,5,1,1,na); Literature
	bentonite, at processing	DE	0	kg	2.00E+1	1	1.51	(2,3,5,1,1,na); Literature
	chemicals inorganic, at plant	GLO	0	kg	4.22E+1	1	1.51	(2,3,5,1,1,na); Literature
	chemicals organic, at plant	GLO	0	kg	9.05E+0	1	1.51	(2,3,5,1,1,na); Literature
	lubricating oil, at plant	RER	0	kg	6.00E+1	1	1.51	(2,3,5,1,1,na); Literature
	reinforcing steel, at plant	RER	0	kg	2.10E+2	1	1.54	(3,4,5,3,1,na); Literature
	portland cement, strength class Z 52.5, at plant	CH	0	kg	2.00E+2	1	1.54	(3,4,5,3,1,na); Literature
	transport, lorry >16t, fleet average	RER	0	tkm	8.11E+1	1	2.99	(4,5,5,5,5,na); Standard distance 100km
	transport, freight, rail	RER	0	tkm	4.87E+2	1	2.99	(4,5,5,5,5,na); Standard distance 600km
	crude oil, used in drilling tests	GLO	0	kg	3.16E+1	1	2.30	(3,4,5,3,3,na); Estimation with data for offshore, basic uncertainty estimated with 2
	diesel, burned in diesel-electric generating set	GLO	0	MJ	8.99E+3	1	3.33	(3,5,5,3,3,na); Environmental reports and literature
	natural gas, vented	GLO	0	Nm3	4.10E+0	1	3.28	(4,4,5,3,1,na); Literature, basic uncertainty estimated with 3
	disposal, drilling waste, 71.5% water, to landfarming	CH	0	kg	2.37E+2	1	1.51	(2,3,5,3,1,na); Environmental reports and literature
	disposal, drilling waste, 71.5% water, to residual material landfill	CH	0	kg	1.58E+2	1	1.51	(2,3,5,3,1,na); Environmental reports and literature
	disposal, hazardous waste, 25% water, to hazardous waste incineration	CH	0	kg	5.00E+0	1	1.53	(2,4,5,3,1,na); Environmental reports and literature
emission air, low population density	Particulates, > 10 um	-	-	kg	1.49E-2	1	2.29	(3,5,5,3,1,na); Literature, use of barite
emission water, river	Aluminium	-	-	kg	6.00E-2	1	5.35	(3,4,5,5,3,na); Literature, effluent sludge pond
	AOX, Adsorbable Organic Halogen as Cl	-	-	kg	4.78E-7	1	1.79	(3,3,5,1,1,na); Environmental report
	Arsenic	-	-	kg	4.20E-4	1	1.87	(3,4,5,5,3,na); Literature, effluent sludge pond
	Barium	-	-	kg	6.00E-3	1	1.87	(3,4,5,5,3,na); Literature, effluent sludge pond
	BOD5, Biological Oxygen Demand	-	-	kg	3.00E-1	1	5.35	(3,4,5,5,3,na); Literature, effluent sludge pond
	Boron	-	-	kg	9.00E-3	1	5.35	(3,4,5,5,3,na); Literature, effluent sludge pond
	Calcium	-	-	kg	6.00E-1	1	1.87	(3,4,5,5,3,na); Literature, effluent sludge pond
	Chloride	-	-	kg	6.00E+0	1	3.31	(3,4,5,5,3,na); Literature, effluent sludge pond, basic uncertainty estimated with 3
	Chromium	-	-	kg	6.00E-4	1	5.35	(3,4,5,5,3,na); Literature, effluent sludge pond
	COD, Chemical Oxygen Demand	-	-	kg	3.00E+0	1	5.35	(3,4,5,5,3,na); Literature, effluent sludge pond
	Fluoride	-	-	kg	3.00E-3	1	5.35	(3,4,5,5,3,na); Literature, effluent sludge pond
	Hydrocarbons, aromatic	-	-	kg	3.00E-3	1	3.31	(3,4,5,5,3,na); Literature, effluent sludge pond
	Iron	-	-	kg	1.80E-1	1	5.35	(3,4,5,5,3,na); Literature, effluent sludge pond
	Magnesium	-	-	kg	1.20E-1	1	5.35	(3,4,5,5,3,na); Literature, effluent sludge pond
	Manganese	-	-	kg	3.00E-3	1	5.35	(3,4,5,5,3,na); Literature, effluent sludge pond
	Methane, dichloro-, HCC-30	-	-	kg	6.00E-2	1	5.35	(3,4,5,5,3,na); Literature, effluent sludge pond
	Phosphorus	-	-	kg	1.20E-3	1	5.35	(3,4,5,5,3,na); Literature, effluent sludge pond
	Potassium	-	-	kg	9.00E-1	1	3.31	(3,4,5,5,3,na); Literature, effluent sludge pond, basic uncertainty estimated with 3
	Silicon	-	-	kg	3.00E-2	1	5.35	(3,4,5,5,3,na); Literature, effluent sludge pond
	Sodium	-	-	kg	6.00E+0	1	3.31	(3,4,5,5,3,na); Literature, effluent sludge pond, basic uncertainty estimated with 3
	Strontium	-	-	kg	1.80E-2	1	5.35	(3,4,5,5,3,na); Literature, effluent sludge pond
	Sulfur	-	-	kg	1.20E-1	1	1.87	(3,4,5,5,3,na); Literature, effluent sludge pond
	DOC, Dissolved Organic Carbon	-	-	kg	3.00E-1	1	1.87	(3,4,5,5,3,na); Literature, effluent sludge pond
	TOC, Total Organic Carbon	-	-	kg	3.00E-1	1	1.87	(3,4,5,5,3,na); Literature, effluent sludge pond
	Zinc	-	-	kg	1.20E-3	1	5.35	(3,4,5,5,3,na); Literature, effluent sludge pond

14 http://www.ecoinvent.org/support/ecoinvent-forum/topic.html?&tid=410, online 11.01.2018

6.2 Offshore infrastructure

Material costs for production drillings are inventoried in the process step “exploration” and must be requested under the respective life cycle inventory. For offshore production, at this place, material requirements for the platforms and further production installations are assessed and described in more detail in former studies (Faist Emmenegger et al. 2007; Jungbluth 2007). The inventory is created for an average platform with a total weight of 2500 t.

Tab. 6.3 shows the life cycle inventory for the construction and disposal of production platforms. Construction occurs onshore. Thereafter the platform is transferred to its destination. Transports of the mentioned materials are estimated using standard distances. Transport of platforms to the destination could not be taken into account here (Jungbluth 2007).

Tab. 6.3 Material input and construction costs for drilling platforms in this study. The inventory is valid for a platform with a weight of 2500t and the assumption of 80% steel and 20% concrete platforms.

	Name	Location	InfrastructureProcess	Unit	*platform, crude oil, offshore*	UncertaintyType	StandardDeviation95%	GeneralComment
	Location				*OCE*			
	InfrastructureProcess				*1*			
	Unit				*unit*			
resource, land	Occupation, industrial area, benthos	-	-	m2a	4.50E+4	1	2.03	(5,4,5,3,1,na); Life time 15a
	Transformation, from seabed, unspecified	-	-	m2	3.00E+3	1	2.47	(5,4,5,3,1,na); Literature
	Transformation, to industrial area, benthos	-	-	m2	3.00E+3	1	2.47	(5,4,5,3,1,na); Literature
	Occupation, industrial area	-	-	m2a	1.50E+4	1	2.47	(5,4,5,3,1,na); Life time 15a
	Transformation, from unknown	-	-	m2	1.00E+3	1	2.47	(5,4,5,3,1,na); Literature
	Transformation, to industrial area	-	-	m2	1.00E+3	1	2.47	(5,4,5,3,1,na); Literature
resource, in water	Water, unspecified natural origin, GLO	-	-	m3	1.11E+2	1	1.51	(1,3,5,3,1,na); Environmental report
technosphere	electricity, medium voltage, production ENTSO, at grid	ENTSO	0	kWh	9.18E+6	1	1.83	(5,5,5,3,1,na); Estimation, plus 25% for disposal
	diesel, burned in building machine	GLO	0	MJ	1.65E+7	1	1.51	(1,3,5,3,1,na); Environmental report, plus 25% for disposal
	concrete, exacting, with de-icing salt contact, at plant	CH	0	m3	6.14E+2	1	1.53	(3,3,5,3,1,na); Literature
	chromium steel 18/8, at plant	RER	0	kg	7.51E+3	1	1.53	(3,3,5,3,1,na); Literature
	steel, low-alloyed, at plant	RER	0	kg	1.14E+6	1	1.53	(3,3,5,3,1,na); Literature
	aluminium, production mix, cast alloy, at plant	RER	0	kg	1.36E+5	1	10.80	(5,5,5,1,1,na); Estimation for aluminium anode, basic uncertainity estimated = 10
	cast iron, at plant	RER	0	kg	1.73E+2	1	10.80	(5,5,5,1,1,na); Estimation for aluminium anode, basic uncertainity estimated = 10
	MG-silicon, at plant	NO	0	kg	2.16E+2	1	10.80	(5,5,5,1,1,na); Estimation for aluminium anode, basic uncertainity estimated = 10
	copper, at regional storage	RER	0	kg	8.64E+0	1	10.80	(5,5,5,1,1,na); Estimation for aluminium anode, basic uncertainity estimated = 10
	zinc, primary, at regional storage	RER	0	kg	7.20E+3	1	10.80	(5,5,5,1,1,na); Estimation for aluminium anode, basic uncertainity estimated = 10
	transport, lorry >16t, fleet average	RER	0	tkm	2.64E+5	1	2.09	(4,5,na,na,na,na); Standard distance 100km
	transport, freight, rail	RER	0	tkm	7.76E+5	1	2.09	(4,5,na,na,na,na); Standard distance 600km
	disposal, concrete, 5% water, to inert material landfill	CH	0	kg	1.35E+6	1	1.53	(3,3,5,3,1,na); Estimation
	disposal, hazardous waste, 25% water, to hazardous waste incineration	CH	0	kg	4.75E+4	1	1.51	(1,3,5,3,1,na); Environmental report
	disposal, municipal solid waste, 22.9% water, to municipal incineration	CH	0	kg	5.25E+4	1	1.51	(1,3,5,3,1,na); Environmental report
emission air, low population density	Heat, waste	-	-	MJ	3.30E+7	1	1.83	(5,5,5,3,1,na); Calculation
emission water, ocean	Aluminium	-	-	kg	1.16E+5	1	10.80	(5,5,5,1,1,na); Estimation 85% utilisation of anode
	Iron	-	-	kg	1.47E+2	1	10.80	(5,5,5,1,1,na); Estimation 85% utilisation of anode
	Silicon	-	-	kg	1.84E+2	1	10.80	(5,5,5,1,1,na); Estimation 85% utilisation of anode
	Copper	-	-	kg	7.34E+0	1	10.80	(5,5,5,1,1,na); Estimation 85% utilisation of anode
	Zinc	-	-	kg	6.12E+3	1	10.80	(5,5,5,1,1,na); Estimation 85% utilisation of anode
	Titanium	-	-	kg	3.06E+1	1	10.80	(5,5,5,1,1,na); Estimation 85% utilisation of anode

6.3 Onshore infrastructure

For onshore production several hundred production sites are summarized to one production field. The inventory is estimated for a field with 100 drilling sites and described in more detail in former studies (Faist Emmenegger et al. 2007; Jungbluth 2007). Oil refining is done centrally, which requires pipes and pumps.

Onshore production requires space for pumps, separators, tanks, pipes, energy generation (for internal electricity production) as well as cleaning processes (particularly wastewater cleaning).

In this study a value of 1000 m²/drilling is used. Like this, the production sites which are mostly situated in a remote area, are transforming a virtually unaffected area into a developed area. Therefore, for all production sites, transformation of forest to industrial area is assumed. There is no information on recultivation after production ceased, for the regions investigated here.

Tab. 6.4 shows a life cycle inventory based on the former study (Jungbluth 2007). It is assumed that the life-time of the land use change is only 20 instead of the formerly estimated 30 years. This assumption is based on analysis done for horizontal wells in Oklahoma US. In the US, more than half of the production of oil and gas, which is projected for the total lifetime occurs during its first three years.[15] As an estimate, 20 years of lifetime might be too low for exceptionally large oil fields as Rumaila in Iraq. Therefore, by using this estimate, the impact of land use might be slightly underestimated for the dataset for Iraq. However, for most of the globally accessible, smaller oil fields, this estimate seems appropriate.

Tab. 6.4 Material input and construction costs for onshore production in this study.

	Name	Location	Unit	production plant crude oil, onshore	UncertaintyType	StandardDeviation95%	GeneralComment
	Location			GLO			
	InfrastructureProcess			1			
	Unit			unit			
resource, land	Occupation, industrial area	-	m2a	2.00E+6	1	1.53	(3,4,1,3,1,na); Life time 20a
	Transformation, from forest, unspecified	-	m2	1.00E+5	1	2.26	(3,4,5,3,1,na); Literature
	Transformation, to mineral extraction site	-	m2	1.00E+5	1	2.26	(3,4,5,3,1,na); Literature
resource, in water	Water, unspecified natural origin, GLO	-	m3	8.28E+1	1	1.13	(1,3,3,3,1,na); Environmental report
technosphere	electricity, medium voltage, production ENTSO, at grid	ENTSO	kWh	3.67E+6	1	1.84	(5,4,5,3,3,na); Literature
	diesel, burned in building machine	GLO	MJ	6.75E+5	1	1.14	(2,3,3,3,1,na); Environmental report
	reinforcing steel, at plant	RER	kg	7.20E+5	1	1.54	(3,4,5,3,1,na); Literature
	transport, lorry >16t, fleet average	RER	tkm	3.60E+5	1	2.38	(4,5,5,5,3,na); Estimation 500km
	transport, freight, rail	RER	tkm	1.44E+5	1	2.38	(4,5,5,5,3,na); Standard distance 600km
	disposal, municipal solid waste, 22.9% water, to municipal incineration	CH	kg	7.20E+2	1	1.51	(1,3,5,3,1,na); Environmental report
emission air, low population density	Heat, waste	-	MJ	1.32E+7	1	1.83	(5,5,5,3,1,na); Literature

7 Operating materials

7.1 Chemicals

As operating materials, those production chemicals are considered which fulfil different functions. Generally, in oil production, three process steps are distinguished that require chemicals:

- Production and separation
- Water flooding
- Stimulation and workover

[15] Oklahoma Watch: https://nondoc.com/2017/07/12/horizontal-wells-first-three-years/, online 03.01.2018

For gas production, to treat the gas chemicals are used too. The production can be disturbed by depositions and corrosion. An overview over troubles and chemicals used to fight them, can be found in the appendix of the former report (Jungbluth 2007).

As chemicals for stimulation and workover, acids and corrosion inhibitors are used. Investigations for the former report lead to 90g of organic chemicals and 118g of inorganic chemicals per ton of crude oil extracted (Jungbluth 2007). As described in chapter 4.3, a factor of 4.7 is applied on these values to model the increased demand due to more depleted oil fields.

Transport of these chemicals is assumed with 100 km by lorry and 600 km by rail.

7.2 Fresh water

Water consumption in oil production varies substantially by geography, geology, and recovery-technique and reservoir depletion. Water in oil extraction is mainly used for enhanced oil recovery (EOR), where a reservoir is flooded with water or steam to displace or increase the flow of oil to the surface. Oil extraction also generates large volumes of produced water (cf. chapter 10.1). After treatment, the produced water can be used for reinjection as part of EOR activities. Consumed water is thus total water injected less produced water used for injection (Mielke et al. 2010; Wu et al. 2009). As EOR activities are increasing globally, this parameter was considered relevant for the update and therefore new data was collected.

7.2.1 Amount

For this study the values and sources listed in Tab. 7.1 are used. The major datasource applied is the environmental report for different oil producing regions (IOGP 2017). Several other country and company data show a large variation (BP 2013, 2016; Chevron 2015; ExxonMobil 2015; Mielke et al. 2010; Schori et al. 2012; Tiedeman et al. 2012).

Tab. 7.1 Fresh water use intensity in cubic meter per kg of extracted crude oil; white background: Data used in model, grey background: values considered for estimation.

Origin / Reference Year	fresh water use intensity	source & comments
Unit	m3/kg OE	
Russia	1.66E-05	IOGP 2016
2016	1.66E-05	IOGP 2016
2008	1.20E-03	Lukoil (2008),cited in BP-2013-ESC-water-handbook, value from the line in figure 2.8
Nigeria	5.03E-05	IOGP 2016
2016	5.03E-05	IOGP 2016
Kazakhstan	1.66E-05	IOGP 2016
Kazakhstan, onshore	1.66E-05	IOGP 2016
2016, onshore	1.66E-05	IOGP 2016
2016	1.66E-05	IOGP 2016
2008	1.20E-03	Lukoil (2008),cited in BP-2013-ESC-water-handbook, value from the line in figure 2.8
Norway	4.20E-05	IOGP 2016
2016	4.20E-05	IOGP 2016
2010	1.63E-03	Schori, 2012, water, salt, ocean and sole
2005	6.05E-05	Khatib, Z. (2007),cited in BP-2013-ESC-water-handbook, Half of the value from the lowest line in figure 2.8
Iraq	3.14E-06	IOGP 2016
2016	3.14E-06	IOGP 2016
2005	4.32E-05	BP-2013-ESC-water-handbook, value for middle east in table 2.1
Mexico	3.60E-04	IOGP 2016
2016	3.60E-04	IOGP 2016
2005	6.59E-04	BP-2013-ESC-water-handbook, value for north america in table 2.1
Saudi-Arabia	3.14E-06	IOGP 2016
2016	3.14E-06	IOGP 2016
2008	2.35E-03	Mielke 2010, desalinated seawater and brackish water
2005	6.05E-05	Khatib, Z. (2007),cited in BP-2013-ESC-water-handbook, Half of the value from the lowest line in figure 2.8
USA	3.60E-04	IOGP 2016
2016	3.60E-04	IOGP 2016
2008	7.02E-03	Mielke 2010
Default GLO	**7.90E-04**	**average company and country data**
BP-2013, Global average	6.48E-04	BP-2013-ESC-water-handbook, table 2.1

While the water consumption estimates vary, it is possible to summarize the data, e.g. for the U.S., into two data sets: (i) primary/secondary recovery and (ii) tertiary using common EOR techniques (Mielke et al. 2010). To give an example of this variety, these results are shown in Tab. 7.2.

Tab. 7.2 Water consumption for different oil production techniques in the US (conversion factor for this table: 58MMBtu per barrel according to EIA). Own calculation of average based on literature (Mielke et al. 2010)

	gal/MMBtu	% of US output	m3 water / kg crude oil
Primary	1.4	0.2%	1.53E-04
Secondary	62	79.7%	6.79E-03
Tertiary			
Steam injection	39	5.5%	4.27E-03
CO2 injection	94	11.0%	1.03E-02
Caustic injection	28	0.0%	3.07E-03
Forward combustion/air injection	14	0.1%	1.53E-03
Other	63	3.5%	6.90E-03
Micellar polymer injection	2485	0.0%	2.72E-01
Weighted Average	**64**	**100.0%**	**7.02E-03**

7.2.2 Allocation

Impacts of fresh water use are allocated to crude oil only, as for natural gas extraction alone, no water injection would be necessary, and the water is used for and released due to EOR.

7.2.3 Origin of water

Depending on the availability, diverse types of water are used for crude oil production.

For offshore, typically salt water from the ocean is used. Surface water from lakes or rivers is used onshore, if the availability is high.

In arid regions like Saudi Arabia mostly desalinated seawater and brackish water is used for oil recovery (Wu et al. 2009).

7.2.4 Return

A full water balance is not demanded by ecoinvent v2 guidelines. In view of ecoinvent v3 data the return of water to rivers (amount taken from the surface water plus discharged produced water) is inventorized as an emission to water in the same country. Further research seems to be necessary how to fully balance the water flows in case of crude oil extraction considering the environmental relevance. Such a research goes beyond the scope of this update study.

8 Energy demand

The update of the data for the energy demand in single countries turned out to be more difficult than expected.

The energy use in different oil fields can be quite variable as shown in an example in Fig. 8.1. Most of the information found was related to modelling of energy uses in oil fields and not related to measured data e.g. on a country wide average. In this example a net energy return (NER) ratio of 33 was calculated for the different oil fields.[16]

16 https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4687841/

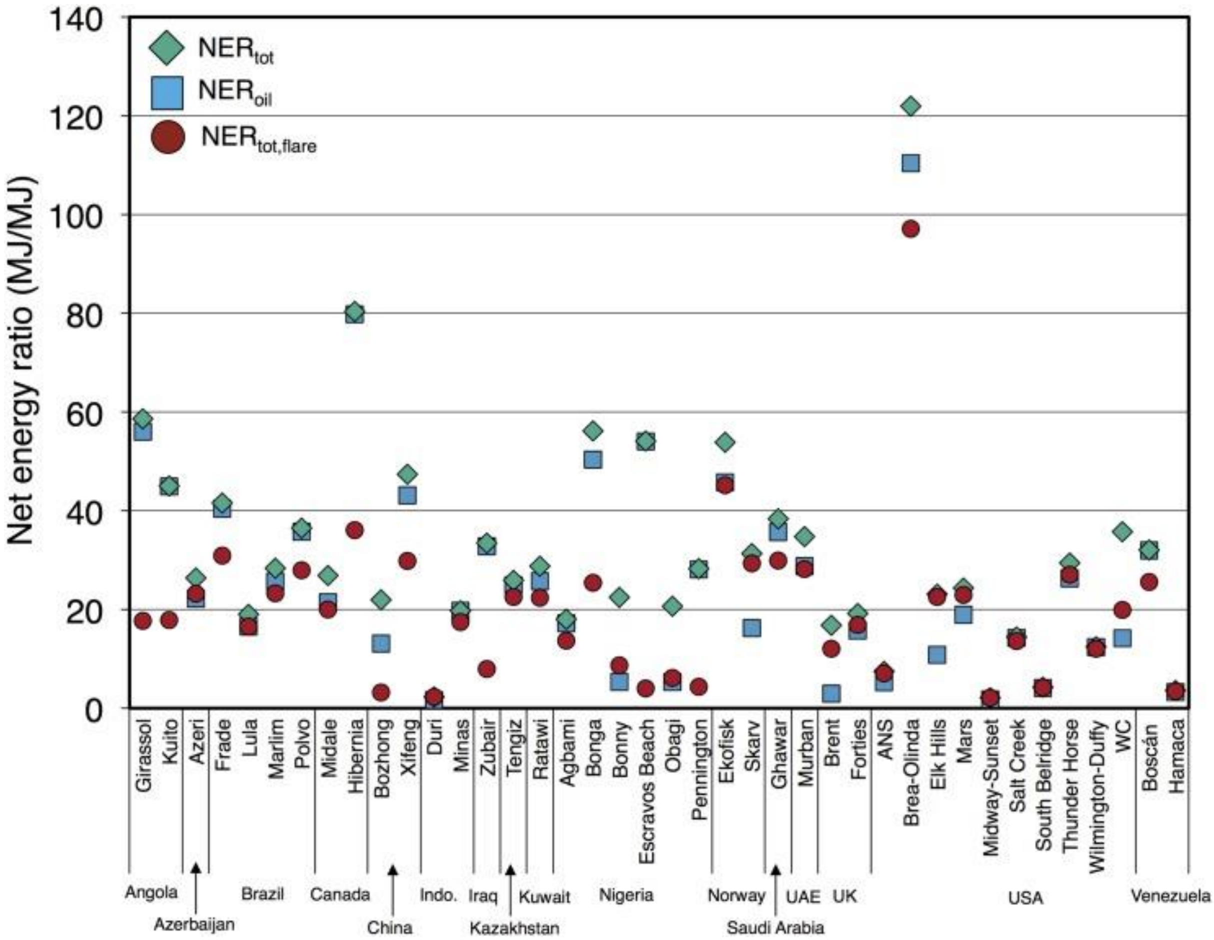

Fig. 8.1 Total net energy ratio NERtot and oil-specific net energy ratio NERoil for studied global oil fields[17]

An extensive documentation of differing energy uses in oil fields was found in a calculation of greenhouse gas emissions.[18] Some major findings and statements from this research are repeated below:[19]

Conventional oil resources are dwindling as tight oil, oil sands, heavy oils, and others emerge. Technological advances mean that these unconventional hydrocarbon deposits in once-unreachable areas are now viable resources.

The Carnegie Endowment's Energy and Climate Program, Stanford University, and the University of Calgary have developed a first-of-its-kind Oil-Climate Index (OCI) to compare these resources.

Greenhouse gas (GHG) emissions were analysed throughout the entire oil supply chain—oil extraction, crude transport, refining, marketing, and product combustion and end use. There is an over 80 percent difference in total GHG emissions per barrel of the lowest GHG-emitting Phase 1 oil and the highest.

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17 https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4687841/figure/pone.0144141.g002/, online 15.01.2018

18 http://carnegieendowment.org/2015/03/11/know-your-oil-creating-global-oil-climate-index-pub-59285, online 15.01.2018

19 http://carnegieendowment.org/files/Brief-OCI.pdf, online 15.01.2018

Climate impacts vary whether crudes are measured based on their volumes, their products' monetary values, or their products' energy delivered.

The GHG emission spread between oils is expected to grow as new, unconventional oils are identified.

The variations in oils' climate impacts are not sufficiently factored into policymaking or priced into the market value of crudes or their petroleum products. As competition among new oils for market share amounts, it will be increasingly important to consider climate risks in prioritizing their development.

Another source of information is the reporting for regional average based on environmental reports of several single oil producing companies (IOGP 2017).The figures include the extraction, processing and transport of oil and gas. In 2016, IOGP reporting companies consumed on average 1.4 gigajoules of energy for every tonne of hydrocarbon produced. The report indicate that onshore production is more energy intensive than offshore production. No clear trend for increased energy consumption can be seen. Thus, average figures for 2011-2016 are taken for the further calculations.

The energy used to produce oil and gas reported by IOGP covers a range of activities. These include the following but seems to exclude drilling, venting, and flaring:

- powering compressors to re-inject produced gas or to export it through pipelines,
- driving turbines to generate electricity needed for operational activities, including logistics, and for living quarters (e.g. at offshore platforms),
- driving pumps that produce the hydrocarbons (and any associated produced water),
- heating produced oil for separation,
- producing steam for enhanced oil recovery,
- driving the pumps to re-inject produced water, inject water for waterflooding,
- and transport the produced oil through pipelines.

For the calculation of NER (net energy return), EROI (energy return on investment) or EROEI (energy return on energy investment) some further publications have been found (NREL 2012; Safronov & Sokolov 2014; Stolz & Frischknecht 2016). These values give at least an idea for the total energy use in different regions and different years. The calculations include also the well drilling, flaring, venting, and other energy uses during the oil production. But, different authors might use slightly different definitions e.g. for the accounting on electricity or materials. Such differences could not be fully harmonized here.

These estimations for the total energy demand have been combined with the available data for partial aspects e.g. well drilling, venting, and flaring. The data have been estimated in a way that the best guess for the EROI in each country is met.

Other sources of information were environmental reports of companies active in the oil sector. However, these companies are often multinational and thus data cannot be related to a single country. Furthermore, today such environmental reports often provide less detail and are less transparent than during the work on the previous update (Jungbluth 2007). Thus, they were not useful for this study.

The assumptions used in the former study are not directly updated here. Thus, also the extensive documentation for these assumptions is not repeated here and instead these older data are cited as (Jungbluth 2007) even if the actual background of these assumptions is often even longer ago.

For some production regions, detailed data on energy demand was available (NREL 2012; Safronov & Sokolov 2014; Stolz & Frischknecht 2016).

Tab. 8.1 gives an overview of the values for energy demand per kg crude oil extracted which are estimated for this study. The estimation considers information available for the specific country for single energy uses as well as information about EROI results. It must be noted that the value for the total energy demand includes also energy uses for well drilling, flaring and venting. This was considered when estimates for the energy use were made to prevent double counting.

In the data sources listed in Tab. 8.1, it is not stated, if energy losses due to oil spills are considered. For this study it is assumed that they are not included in these figures published for the total energy demand. Modelling assumptions for oil spills are described in chapter 10.3. It must be noted that in this study, the oil loss is also accounted for in the calculation of the cumulative energy demand (see chapter 14.1).

For the estimation of the energy demand the following principle has been followed. First an estimate has been made with the most recent or most reliable data available for the use of single fuels, flaring, venting and well drilling.

For the direct energy uses of fuel oil, gas and electricity region specific data according to the average 2015-2016 are applied (IOGP 2017). The 36 companies providing these data were responsible for oil and gas wellhead production of 2,032 million tonnes (approximately 15.2 billion BOE), about 27% of 2016 global production sales.

The assumptions for the energy use have been cross-checked with the figures reported in literature for the EROEI.

Results for the cumulative energy demand in chapter 14.1 are also cross checked with available literature results. If necessary, further refinements to assumptions made above have been made. As many studies show only partial information, our final estimation is generally higher than the single parts of information available for a country.

Compared to the previous version, where each country was modelled on its own, also further cross comparisons between countries have been made to correct unusual high or low figures. Nevertheless, the estimation for the total energy demand of crude oil extraction must be considered as rather uncertain. This is also confirmed by evaluating available literature results in chapter 14.3 which show a high variation. The variation between different fields, between different years and between different regions can be high and no statistical data sources could be identified reporting the necessary information in a consistent, detailed, and up-to-date way.

To account for the high uncertainty a basic uncertainty of 2 is applied to all energy uses recorded for the unit process raw data.

Tab. 8.1 Total fossil energy use and diesel in MJ and electricity in kWh per kg crude oil extracted (Included in “total fossil energy use” but not listed here: drilling and energy losses due to flaring and venting), white background: Data used in model, grey background: values considered for estimation

Origin / Reference Year	Total fossil energy use	EROEI (or EROI)	source	Diesel burned in electric generator	source	Electricity at grid	source
Unit	MJ/kg OE	MJout/MJin		MJ/kg OE		kWh/kg OE	
Russia	2.78	16	Safronov 2014	0.014	Mean IOGP & Safronov	0.060	Mean IOGP & Safronov
2016	1.27		IOGP 2016	0		0.017	IOGP 2016
2015	1.72	25	http://oci.carnegieendowment.org/		http://oci.carnegieendowment.org/		
2012	0.90	48	Safronov 2014	0.029	Safronov 2014	0.104	Safronov 2014
2000	3.18	14	Jungbluth 2007	0.422	Jungbluth 2007	0.005	Jungbluth 2007
Nigeria	4.13	10	http://oci.carnegieendowment.org/			0.012	IOGP 2016
2016	2.09	21	World Bank 2017				
2016	1.48		IOGP 2016			0.012	IOGP 2016
2015	2.60	**17**	http://oci.carnegieendowment.org/		http://oci.carnegieendowment.org/		
2011	3.44	**13**	Cai et al 2014				
2000	6.79	6	Jungbluth 2007				
Kazakhstan	2.96	15	IOGP 2016	0.03	IOGP 2016	0.017	IOGP 2016
Kazakhstan, onshore	2.96	15	IOGP 2016	0.000	IOGP 2016	0.017	IOGP 2016
Kazakhstan, offshore	2.71	16	calculated from Stolz 2016	0.118	calculated from Stolz 2016, diesel at regional storage		
2016, onshore	3.16	14	Jungbluth 2007	0.422			
2016, offshore	1.82	24	calculated from Stolz 2016	0.118	calculated from Stolz 2016, diesel at regional storage		
2016	1.27		IOGP 2016	0	IOGP 2016	0.017	IOGP 2016
2015	0.98	**44**	http://oci.carnegieendowment.org/		http://oci.carnegieendowment.org/		
Norway	2.04	21	http://oci.carnegieendowment.org/	0.057	Schori 2012	0.025	IOGP 2016
2016	1.32		IOGP 2016		IOGP 2016	0.025	IOGP 2016
2015	1.93	**22**	http://oci.carnegieendowment.org/		http://oci.carnegieendowment.org/		
2006	1.08	40	Safronov 2014				
Iraq	4.26	10	http://oci.carnegieendowment.org/			0.013	IOGP 2016
2016	0.31		IOGP 2016			0.013	IOGP 2016
2015	4.02	**11**	http://oci.carnegieendowment.org/				
Mexico	5.22	8	http://oci.carnegieendowment.org/			0.051	IOGP 2016
2016	3.35		IOGP 2016			0.051	IOGP 2016
2015	2.21	**20**	http://oci.carnegieendowment.org/				
Saudi-Arabia	1.01	43	http://oci.carnegieendowment.org/			0.013	IOGP 2016
2016	0.31		IOGP 2016			0.013	IOGP 2016
2015	0.88	**49**	http://oci.carnegieendowment.org/		http://oci.carnegieendowment.org/		
2003	0.59	74	Near East, Jungbluth 2007	0.347	Near East, Jungbluth 2007	0.000	Near East, Jungbluth 2007
USA	4.65	9	http://oci.carnegieendowment.org/	0.026	Mean of 3 data sources	0.032	Mean of 3 data sources
2016	3.35		IOGP 2016	0	IOGP 2016	0.051	IOGP 2016
2015	5.15	**8**	http://oci.carnegieendowment.org/		http://oci.carnegieendowment.org/		
2009	3.67	12	NFA 2009	0.009	NFA 2009, Table 10, j/100j of crude oil	0.005	NFA 2009
2008	1.62	27	USLCI	0.069	USLCI	0.039	USLCI
2007	3.93	11	Safronov 2014		Safronov 2014		
Default GLO	**3.98**	**11**	**calculation with available data**	**0.150**	**estimate**	**0.020**	**estimate**

Tab. 8.2 Energy demand of heavy fuel oil, sweet gas and sour gas in MJ per kg crude oil extracted, white background: Data used in model, grey background: values considered for estimation

Origin / Reference Year	Heavy fuel oil, burned in equipment	source	Sweet gas, burned in gas turbine, production	source	Sour gas, burned in gas turbine, production	
Unit	MJ/kg OE		MJ/kg OE		MJ/kg OE	
Russia	0.043	Mean IOGP & Safronov			0.801	Mean IOGP & Safronov
2016	0.000	IOGP 2016			1.1902	IOGP 2016
2012	0.087	Safronov 2014			0.413	Safronov 2014
2000	0.240	Jungbluth 2007			0.090	Jungbluth 2007
Nigeria	0.000	IOGP 2016	1.420	IOGP 2016	0.000	IOGP 2016
2016	0.000	IOGP 2016	1.42	IOGP 2016	0.0000	IOGP 2016
Kazakhstan	0.022	IOGP 2016	0.0000	IOGP 2016	1.140	IOGP 2016
Kazakhstan, onshore	0.000	IOGP 2016		IOGP 2016	1.190	IOGP 2016
Kazakhstan, offshore	0.093	calculated from Stolz 2016, heavy		0	0.980	Estimate
2016, onshore	0.240	Stolz & Frischknecht 2017	0.000	Stolz & Frischknecht 2017	0.090	Stolz & Frischknecht 2017
2016, offshore	0.093	calculated from Stolz 2016, heavy				
2016	0.000	IOGP 2016	0.0000	IOGP 2016	1.1902	IOGP 2016
Norway	0.000	IOGP 2016	1.208	IOGP 2016	0.000	IOGP 2016
2016	0.000	IOGP 2016	1.21	IOGP 2016	0.0000	IOGP 2016
Iraq	0.000	IOGP 2016	0.246	IOGP 2016	0.000	IOGP 2016
2016	0.000	IOGP 2016	0.25	IOGP 2016	0.0000	IOGP 2016
Mexico	0.000	IOGP 2016	3.120	IOGP 2016	0.000	IOGP 2016
2016	0.000	IOGP 2016	3.12	IOGP 2016	0.0000	IOGP 2016
Saudi-Arabia	0.000	IOGP 2016	0.246	IOGP 2016	0.000	IOGP 2016
2016	0.000	IOGP 2016	0.25	IOGP 2016	0.0000	IOGP 2016
2003	0.240	Near East, Jungbluth 2007	0.000	Near East, Jungbluth 2007	0.000	Near East, Jungbluth 2007
USA	0.011	Mean of 3 data sources	2.650	Mean of 3 data sources		
2016	0.000	IOGP 2016	3.12	IOGP 2016	0.0000	IOGP 2016
2009	0.004	NFA 2009	3.639	NFA 2009		
2008	0.030	USLCI	1.190	USLCI		
Default GLO	**0.150**	**estimate**	**1.000**	**estimate**	**0.100**	**estimate**

9 Emissions to air

9.1 Flared natural gas

9.1.1 Definition

Flaring is the controlled and intentional burning of natural gas as part of production and processing of crude oil and natural gas.

Flaring is mainly done for the following reasons[20]:

- **Flaring for safety**
  By burning excess natural gas, flaring protects against the dangers of over-pressuring industrial equipment. Natural gas can be stored and transported instead of flared, but it is highly flammable. Between 2008 and 2012, there were 370 significant safety incidents at natural gas transmission pipelines. These incidents led to 10 fatalities and 85 injuries. Transporting natural gas from a rig to homes and businesses is high risk and many companies choose flaring as the alternative.
- **Flaring for disposal**
  One of the main reasons for gas flaring is the disposal and burning of natural gas as waste. Typically, when there are large volumes of hydrogen sulphide in natural gas, it cannot be safely extracted. To dispose of this gas, it is burned off. When the gas is burned, the hydrogen is converted into water and the sulphur becomes sulphur dioxide.
- **Flaring for remote locations**
  When petroleum crude oil is extracted and produced from onshore or offshore oil wells, natural gas associated with the oil is also brought to the surface. If companies do not have the infrastructure in place to capture natural gas and safely transport it – such as when oil rigs are in deep waters – natural gas is often flared.
- **Flaring for economics**
  There is a significant gap between oil and natural gas prices. Natural gas costs more than oil to produce on an energy-equivalent basis. For this reason, drillers are searching for oil, not gas, and companies are reluctant to invest in costly projects to capture and transport natural gas from oil wells to the market.

9.1.2 Allocation

Much of the flaring is done for maximizing profits in crude oil extraction and pure natural gas extraction facilities strive to keep flaring to a minimum and sell as much natural gas as possible. Therefore, it could be argued that all the emissions related to flaring should be allocated to the oil extraction.

However, many extraction sites sell oil and gas at the same time (e.g. 50% of APG in Russia in 2010) and the remaining gas must be flared as well (Carbon Limits 2013). Also, initially the dataset for flaring was created for the natural gas extraction (Faist Emmenegger et al. 2007, chapter 6.3.13).

[20] https://www.fluenta.com/news/companies-choose-flare-natural-gas/, online 11.04.2018

Therefore, in this study, emissions from flaring (and venting) are allocated to crude oil and natural gas extraction as explained in chapter 2.2.

9.1.3 Amount of flared gas

Estimates for flaring were available from different sources as shown in Tab. 9.1 (Cai et al. 2014; Carbon Limits 2013; IOGP 2017; Jungbluth 2007; NREL 2012; Pieprzyk & Hilje 2016; Schori et al. 2012; Stolz & Frischknecht 2017; Worden et al. 2017; World Bank 2017). Different data sources show a high variability for which simple explanations are difficult to be given.

Flaring data for this study are taken from the Global Gas Flaring Reduction Partnership (GGFR), which estimated the country specific amounts of flared gas based on satellite measurements done according to a methodology provided by the National Oceanic and Atmospheric Administration (NOAA), a part of the US department of Defence[21]. This measured flaring data for 2016, for the investigated countries, is provided publicly (World Bank 2017). These data are in the same order of magnitude as company specific data reported for different world regions (IOGP 2017).

Estimates for countries, based on satellite data are preferred in this study over company data as they are assumed to be more comprehensive and contain less uncertainties than extrapolations from single measurements. Furthermore, by using one single data source a bias in the comparison of different countries can be avoided.

In a study done for the BFE, company data was used to estimate flaring losses in Russia and Kazakhstan. There, a correction factor was applied on reported flaring data (Stolz & Frischknecht 2017; Tab3.1). The assumption here was also, that in general, such values reported by companies are much lower than what is measured with satellites. However, in the same study also values from satellite measurements are used for flaring in the USA and Mexico. There is no explanation in that report, why the latest satellite data was not used for all countries under investigation. In that specific study, it is not stated, what the assumed global production baseline is. And there, flaring data was only allocated to crude oil production. As mentioned before, in this study, flaring emissions are allocated to natural gas and crude oil extraction (see chapters 2.2 & 9.1). Therefore, the values used in this study are lower and might deviate due to different national production figures from the figures used by Stolz & Frischknecht 2017.

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21 Estimation of flare gas volumes: http://pubdocs.worldbank.org/en/251461483541510567/ACS.pdf, online 04.01.2018

Tab. 9.1 Amount of oil equivalents produced (kg oil equivalents per year), total amount of natural gas flared (million norm cubic meters per year) and intensities of flaring (norm cubic meters per kg oil equivalent). White background: values used/suggested for countries, grey background: values from other sources, for comparison only. (Sources cited in the text).

Origin / Reference Year	crude oil production	Flaring	Flaring intensity	Source
Unit	Mt/a	Mio. Nm3/a	Nm3/kg OE	
Russia	5.47E+02	2.41E+04	2.24E-02	World Bank 2017
2016	5.47E+02	2.41E+04	2.24E-02	World Bank 2017
2016			6.11E-03	Stolz 2017
2013			1.73E-02	Carbon Limits 2013
2011	5.23E+02	3.74E+04	3.44E-02	Cai et al 2014
2000			5.85E-02	Jungbluth 2007
Nigeria	1.03E+02	7.32E+03	5.35E-02	World Bank 2017
2016	1.03E+02	7.32E+03	5.35E-02	World Bank 2017
2011	1.30E+02	1.46E+04	8.99E-02	Cai et al 2014
2000	1.07E+02	1.40E+04	1.19E-01	Jungbluth 2007
Kazakhstan	7.90E+01	2.67E+03	2.44E-02	World Bank 2017
2016	7.90E+01	2.67E+03	2.44E-02	World Bank 2017
2016			3.40E-02	Stolz 2017
2013			8.68E-03	Carbon Limits 2013
2011	8.37E+01	4.70E+03	4.35E-02	Cai et al 2014
Norway	9.00E+01	3.56E+02	1.87E-03	World Bank 2017
2016	9.00E+01	3.56E+02	1.87E-03	World Bank 2017
2010	1.60E+02	6.87E+02	3.41E-03	Schori 2012
Iraq	1.93E+02	1.77E+04	8.80E-02	World Bank 2017
2016	1.93E+02	1.77E+04	8.80E-02	World Bank 2017
Mexico	1.20E+02	4.78E+03	3.11E-02	World Bank 2017
2016	1.20E+02	4.78E+03	3.11E-02	World Bank 2017
2016			4.00E-02	Stolz 2017
2011	4.34E+01	2.10E+03	2.48E-02	Cai et al 2014
Saudi-Arabia	5.98E+02	2.38E+03	3.54E-03	World Bank 2017
2016	5.98E+02	2.38E+03	3.54E-03	World Bank 2017
2011	5.75E+02	3.70E+03	5.80E-03	Cai et al 2014
USA	5.56E+02	8.86E+03	7.47E-03	World Bank 2017
2016	5.56E+02	8.86E+03	7.47E-03	World Bank 2017
2016			2.00E-02	Stolz 2017
2011	2.88E+02	7.10E+03	8.52E-03	Cai et al 2014
2011	1.83E+05	2.20E+03	1.20E-05	Cai et al 2014
Algeria	6.50E+01	9.10E+03	9.07E-02	World Bank 2017
2016	6.50E+01	9.10E+03	9.07E-02	World Bank 2017
2011	9.51E+01	5.00E+03	3.05E-02	Cai et al 2014
Egypt	3.20E+01	2.83E+03	3.70E-02	World Bank 2017
2016	3.20E+01	2.83E+03	3.70E-02	World Bank 2017
Great Britain	4.10E+01	1.34E+03	1.22E-02	World Bank 2017
2016	4.10E+01	1.34E+03	1.22E-02	World Bank 2017
African countries			5.13E-02	Jungbluth 2007
2000			5.13E-02	Jungbluth 2007
Region middle east			1.29E-01	Jungbluth 2007
2000			1.29E-01	Jungbluth 2007
Default GLO	**4.36E+03**	**1.50E+05**	**4.25E-02**	**Unweighted average of regional estimates**
Pieprzyk 2016, average estimate			7.58E-03	Pieprzyk 2016

9.1.4 Composition and emissions

Flaring losses of natural gas are modelled including the resource extraction from ground (which is not included in figures about natural gas production) and the emissions to air.

Flaring releases greenhouse gases like CO_2 and NO_x and other gases like sulphur dioxide (SO_2) into the atmosphere.

For the composition of flared gas new model data for CO_2, CO, NOx and SO_2 were found (Ezaina Umukoro & Saheed Ismail 2015). But, these figures seem to be unrealisticly high and they are not based on real measurements. Thus, they are not considered.

Thus, for all emissions of flared gas, numbers and estimates are taken from the former studies (Faist Emmenegger et al. 2007; Jungbluth 2007).

LCI data for natural gas (sweet and sour) burned in production flare, per Nm3 is presented in Tab. 9.2.

Tab. 9.2 LCI data for natural gas, sour and sweet, burned in production flare per Nm3

	Name	Unit	*natural gas, sour, burned in production flare*	*natural gas, sweet, burned in production flare*	UncertaintyType	StandardDeviation95%	GeneralComment
	Location		*GLO*	*GLO*			
	InfrastructureProcess		*0*	*0*			
	Unit		*Nm3*	*Nm3*			
resource, in ground	Gas, natural/m3	Nm3	1.00E+0	1.00E+0	1	1.05	(1,1,1,1,1,na);
emission air, low population density	Methane, fossil	kg	7.07E-4	7.07E-4	1	1.24	(2,2,3,3,3,na); OLF 2011, p.57 (table 29)
	Carbon dioxide, fossil	kg	3.71E+0	3.71E+0	1	1.58	(2,2,3,3,3,na); OLF 2011, p.57 (table 29)
	Carbon monoxide, fossil	kg	1.00E-3	1.00E-3	1	1.58	(2,2,3,3,3,na); Standard emission factor (EFDB 2011)
	NMVOC, non-methane volatile organic compounds, unspecified origin	kg	1.96E-4	1.96E-4	1	1.24	(2,2,3,3,3,na); OLF 2011, p.57 (table 29)
	Nitrogen oxides	kg	1.63E-3	1.63E-3	1	5.07	(2,2,3,3,3,na); OLF 2011, p.57 (table 29)
	Dinitrogen monoxide	kg	2.00E-5	2.00E-5	1	5.07	(2,2,3,3,3,na); Standard emission factor (EFDB 2011)
	Particulates, < 2.5 um	kg	5.40E-4	5.40E-4	1	1.83	(2,2,5,3,3,na); Estimation for refinery flare from (Jungbluth 2003)
	Sulfur dioxide	kg	0	8.07E-6	1	1.58	(2,2,3,3,3,na); OLF 2011
	Sulfur dioxide	kg	1.70E-1	0	1	1.58	(2,2,3,3,3,na); Estimate
	Mercury	kg	2.00E-7	2.00E-7	1	1.83	(2,2,5,3,3,na); Estimation, average value
	Radon-222	kBq	4.00E-1	4.00E-1	1	5.32	(2,2,5,3,3,na); Estimation, average value
	Heat, waste	MJ	3.60E+1	3.60E+1	1	1.83	(2,2,5,3,3,na); Estimation, average value

9.2 Vented natural gas and other direct VOC emissions

9.2.1 Definition

Venting is the word used to describe the release of unburned natural gas to the atmosphere, as a part of production and processing of crude oil and natural gas.

Venting is defined by the industry mainly as unwanted release of natural gas in the technical process chain, e.g. due to insufficient flaring and leakage in pipelines. However, it may also occur due to forced changes in geological structures (e.g. due to fracking)[22;23]. Like this, the sources of vented gas get more diffuse and less connected to the flaring rate than it is proposed in some studies described in chapter 9.2.4.

22 https://www.nrdc.org/sites/default/files/fracking-air-pollution-IB.pdf, online 27.09.2018
23 https://earthworks.org/issues/flaring_and_venting/, online 27.09.2018

9.2.2 Allocation

Emissions from venting are allocated to crude oil and natural gas extraction as explained in chapter 2.2.

9.2.3 Technical scope

In some studies, consulted and described below, values on methane release are given for the whole product chain of crude oil products. Therefore, these figures would need to be adjusted by subtracting emissions occurring in transportation, storage, and handling at later stages. According to the LCA methodology used for this project they are reported at distinct stages of the life cycle. The share of different stages in the life cycle for the total emissions is estimated in Tab. 9.3 (Jungbluth & Meili 2018; Meili et al. 2018). However, the following chapter will conclude, that the emissions from venting during extraction is of much greater importance than further losses downstream. These losses are therefore not subtracted in the final estimate for venting.

Tab. 9.3 Losses of methane outside of the extraction site, due to crude oil storage and transport to end-user. Value used for controlling of values for venting in Tab. 9.5 marked in blue

Direct losses	**kg methane/ kg crude oil**			**sources/ derivation described in:**
	Min	**Max**	**Average**	
Long distance transport	1.50E-06	1.50E-06	1.50E-06	Meili 2018 - LCI for long distance transport of crude oil
Storage	8.5E-06	4.45E-05	2.65E-05	Jungbluth 2018 - LCI of storage and distribution for oil products
Distribution	3.60E-07	3.60E-07	3.60E-07	Jungbluth 2018 - LCI of storage and distribution for oil products
Total	**1.00E-05**	**4.60E-05**	**2.80E-05**	

The amounts estimated in Jungbluth 2007 for other VOC emissions due to leakages from gas handling, ventilation of tanks and unexpected gas eruptions are considerable lower than the new figures for total venting emissions. The new estimates thus should already cover several possible sources of VOC (volatile organic compound) from leakage and accidents during extraction. Therefore, it is assumed that such additional emissions do not have to be added in the inventory anymore.

The percentage of methane in vented natural gas is estimated to be 88% by volume according to estimates on composition shown in chapter 9.2.5. Venting thus releases per m^3 of gas much more methane (CH_4) than flaring. For a time-horizon of 100 years, methane has a 30-times higher GWP-potential than CO_2 (IPCC 2013).

To simplify comparison of values in the following chapter, values given in billion cubic meters (bcm) of methane are recalculated to mega tons (Mt) using a generic density of 0.71kg methane per norm cubic meter (Nm^3), at normal temperature and pressure (NTP) = 20°C, 101,325 kPa).

Emission values estimated in the different literature sources presented below are summarized in Tab. 9.5. Where values are given for global production, the amount of produced oil equivalents are considered for the reference year of that study (cf. Tab. 9.4)[24].

[24] Enerdata 2016 https://yearbook.enerdata.net/crude-oil/world-production-statitistics.html, online 16.10.17

Tab. 9.4 Global crude oil production in megatons (Mt), natural gas production in billion cubic meters (bcm) and values for related energy production in Mega-Joules (MJ) and kilogram Oil equivalents (kg OE) for reference years in studies on venting.[24]

Origin / Reference Year	crude oil production	natural gas production	energy production	Oil equivalents	source
Unit	Mt/a	bcm/a	MJ/a	kg OE/a	
Default GLO	**4.36E+03**	**3.63E+03**	**3.20E+14**	**7.41E+12**	**Enerdata 2016**
2015	4.31E+03	3.55E+03	3.15E+14	7.30E+12	Enerdata 2015
2014	3.96E+03	2.86E+03	2.75E+14	6.36E+12	Enerdata 2014
2005	4.22E+03	3.52E+03	3.10E+14	7.18E+12	Enerdata 2005
2003	3.74E+03	2.71E+03	2.60E+14	6.01E+12	Enerdata 2003

Using the factors presented above, methane and/or natural gas emission factors found in studies are recalculated to the applied reference unit "Nm^3 natural gas vented per kg OE".

9.2.4 Amount of emissions

In the former study, country specific shares for venting (related to amount flared and vented) were investigated based on data from 1989 (Jungbluth 2007). The percentages estimated in 1989 had a range from 1.25% for Europe and North America and up to 7.5% for Russia, Iraq, and Iran.

9.2.4.1 Consulted studies

Different values found and used to estimate venting rates in investigated countries are presented in Tab. 9.5 (Cai et al. 2014; Edwards et al. 2014; Franco et al. 2016; Höglund-Isaksson 2012; IEA 2017b; IOGP 2017; Jungbluth 2007; Jungbluth & Meili 2018; Masnadi et al. 2018; Meili et al. 2018; NREL 2012; Picard 2006; Pieprzyk & Hilje 2016; Schori et al. 2012; Stolz & Frischknecht 2017; Worden et al. 2017).[25] Main findings of the cited studies are described in temporal order.

A study with reference year 2012 estimates that the amount of vented gas in the US and globally is equal to 2% of the volume of the associated gas flared (Cai et al. 2014). This study investigated different technologies in a bottom-up approach. Combined with flaring data presented in Tab. 9.1, this equals a value of 2.9 bcm (2.1 Mt) vented natural gas emitted globally per year. Country specific values presented in Tab. 9.5 are calculated using crude oil and natural gas production data for 2016.

A meta-study looked at several bottom-up studies. It comes to a range of estimates for the global venting rates due to oil production of 4bcm (2.9Mt) to 96.5bcm (69Mt) methane per year (Pieprzyk & Hilje 2016). The lower value of 4bcm was published by Edwards et al. 2014. This value is a projection of data from the International Association of Oil & Gas Producers (IOGP 2000[26]) onto global crude oil production. It is based on self-reported venting rates from oil and gas producing companies.

For the year 2016 the IOGP estimates a venting rate of 0.89 kg methane released per ton of crude oil produced. This would be equal to a global methane release of 6.6 Mt (9.2bcm) per year (IOGP 2017).

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25 EPA 2017 https://www.epa.gov/sites/production/files/2018-04/documents/9509_fastfacts_20180410v2_508.pdf

26 https://www.iogp.org/

The upper estimate of 96.5bcm (69Mt) for global methane emissions due to crude oil extraction in Pieprzyk & Hilje 2016 was taken from Höglund-Isaksson 2012. It is a projection of Canadian measurement findings onto global petroleum production. In that study, also emissions for natural gas extraction are derived. Combined, methane emissions of 110.9bcm (79.2Mt) are found for the crude oil and natural gas producing sector.

The meta-study done by Pieprzyk & Hilje 2016 was prepared on behalf of the Association of the German Biofuel Industry (VDB). It points out that despite great uncertainties there are many indications that the lower range of estimates (4bcm) considerably underestimates the global methane emissions of the petroleum industry. Local measurements in the USA and Mexico indicate extremely high methane emissions, (up to 11.7% of total extraction). Therefore, for crude oil production, a value between average and maximum, 70bcm (50Mt) of methane emitted per year is recommended by Pieprzyk to be applied as a global estimate. The estimate sounds reasonable, altough the figure might be considered as biased due to the commissioner of the study. The paper was not peer-reviewed.

A peer-reviewed article, published in *Natural Research Letters*, supports this estimate. It indicates that newer extraction methods, used in North America for the exploitation of shale gas and tight oil reservoirs, are responsible for a sharp rise in atmospheric abundance of ethane (C_2H_6) and methane (Franco et al. 2016). Values proposed there, are estimated based on Fourier transform infrared observations. For the US alone, in that study, a release of 35Mt (49bcm) per year, associated to crude oil and natural gas production is stated for 2014.

Another peer-reviewd article, published in *Nature*, estimated the post-2006 atmospheric methane budget (Worden et al. 2017). The authors found that extraction of fossil fuels (crude oil, natural gas, and coal) contributes to the global atmospheric methane <u>increase</u> with 12–19 Mt (17-27bcm) per year. This figure includes also emissions from coal extraction which are not investigated in the current study.

By the author of the current study, it is assumed that the values for the increase in methane concentration mentioned by Worden et al. are not representing the full release of methane by fossil fuels extraction. Since methane (CH_4) decomposes in the atmosphere in contact with oxygen (O_2) to CO_2 an H_2O within a few years, additional emissions must be generated to keep an existing concentration of fossil methane in the air constant.

This assumption seems to be supported by the International Energy Agency. In their world energy outlook with reference year 2015, they estimate 76 Mt (106bcm) methane emissions from oil and gas operations (IEA 2017a).

A study, published in *science* (Masnadi et al. 2018), refers to this IEA value (76Mt). The authors estimated the methane emission with ~2.6g CO_2eq./MJ crude oil averaged from all global fields (Masnadi et al. 2018). If this value is set in relation with the one of ~4.6 CO_2eq./MJ from IEA 2017a, a global emission of about 43Mt is calculated.

Tab. 9.5 Country specific and global values in billion cubic meter (bcm) and megatons (Mt) of methane released during crude oil and natural gas production, and calculated values for natural gas vented on production sites (norm cubic meters per kg oil equivalent). White background: values used/suggested for countries, grey background: values from other sources, for comparison only (sources cited in the text).

Origin / Reference Year	Methane emissions	Methane emissions	Venting	Source
Unit	bcm/a	Mt/a	Nm3/kg OE	
Russia	12.8	9.2	1.46E-02	Generic value according to IEA 2017
2016	0.4	0.3	4.48E-04	Cai et al 2014
2000			4.50E-03	Jungbluth 2007
Nigeria	1.6	1.2	1.46E-02	Generic value according to IEA 2017
2016	0.1	0.1	1.07E-03	Cai et al 2014
2000			2.20E-02	Jungbluth 2007
Kazakhstan	1.3	0.9	1.46E-02	Generic value according to IEA 2017
Kazakhstan, onshore	1.0	0.7	1.46E-02	Generic value according to IEA 2017
Kazakhstan, offshore	0.3	0.2	1.46E-02	Generic value according to IEA 2017
2016	0.0	0.0	4.88E-04	Cai et al 2014
Norway	2.3	1.6	1.46E-02	Generic value according to IEA 2017
2016	0.0	0.0	3.73E-05	Cai et al 2014
2010			2.95E-04	Schori 2012
Iraq	2.4	1.7	1.46E-02	Generic value according to IEA 2017
2016	0.3	0.2	1.76E-03	Cai et al 2014
Mexico	1.8	1.3	1.46E-02	Generic value according to IEA 2017
2016	0.1	0.1	6.22E-04	Cai et al 2014
2016			3.44E-04	calculated from Stolz 2017
Saudi-Arabia	8.0	5.7	1.46E-02	Generic value according to IEA 2017
2016	0.0	0.0	7.07E-05	Cai et al 2014
USA	14.2	10.1	1.46E-02	Generic value according to IEA 2017
2016	0.1	0.1	1.49E-04	Cai et al 2014
2016			4.97E-03	calculated from Stolz 2017
2016			1.21E-02	EPA 2017
2014			5.84E-03	Cai et al 2014
2014	49.0	35.0	4.22E-02	Franco et al 2016
2008			4.94E-03	USLCI 2008
Algeria	1.2	0.9	1.46E-02	Generic value according to IEA 2017
2016			1.81E-03	Cai et al 2014
Egypt	0.9	0.7	1.46E-02	Generic value according to IEA 2017
2016	0.0	0.0	7.40E-04	Cai et al 2014
Great Britain	1.3	0.9	1.46E-02	Generic value according to IEA 2017
2016	0.0	0.0	2.43E-04	Cai et al 2014
2000			3.11E-07	Jungbluth 2007
African countries	0.0	0.0	1.46E-02	Generic value according to IEA 2017
2000			3.75E-03	Jungbluth 2007
Region middle east	0.0	0.0	1.46E-02	Generic value according to IEA 2017
2000			1.27E-03	Jungbluth 2007
Default GLO	**106.4**	**76.0**	**1.46E-02**	**Generic value according to IEA 2017**
Sum for countries under study	**44.5**	**31.8**		
2016	9.2	6.6	1.52E-03	IOGP 2016
Pieprzyk 2016, average estimate	50.3	35.9	3.75E-02	Pieprzyk 2016
Pieprzyk 2016, low	4.0	2.9	2.98E-03	JEC: Edwards 2013 (in Pieprzyk 2016)
Pieprzyk 2016, high estimate	96.5	68.9	7.20E-02	Höglund-Isaksson 2012 (in Pieprzyk 2016)
Pieprzyk 2016, recommended	70.0	50.0	5.22E-02	Pieprzyk 2016
2015	106.4	76.0	1.46E-02	IEA 2017
2015	60.1	43.0	8.24E-03	Masnadi 2018
2014	26.6	19.0	5.10E-03	Worden 2017, high, increase without steady state emissions
2014	21.7	15.5	4.16E-03	Worden 2017, average, increase without steady state emissions
2014	16.8	12.0	3.22E-03	Worden 2017, low, increase without steady state emissions
2012	2.9	2.1	8.50E-04	Cai et al 2014
2006			8.97E-03	Picard 2006 (IPCC 2006), developed countries, bottom-up
2005	110.9	79.2	1.55E-02	Höglund-Isaksson 2012, table 6, crude oil and natural gas production
2005	195.4	139.6	2.72E-02	Höglund-Isaksson 2012, table 6, total fuel production

9.2.4.2 Discussion

The definition for venting used in Cai et al. 2014, IOGP 2000[26], Stolz & Frischknecht 2017, Schori et al. 2012, IOGP 2017 and in the former study by Jungbluth 2007 is more narrow than in the latest studies (c.f. chapter 9.2.1). As fugitive emissions e.g. from soil are missing in these studies they seem to heavily underestimate the total release of methane and/or natural gas due to crude oil and natural gas extraction.

The study by Worden et al. 2017 seems to cover only the increase in concentration and not the whole annual emissions of methane.

The estimates in Höglund-Isaksson 2012 are made using IPCC methodology and were peer-reviewed. Therefore, we consider them as reliable.

The study by Masnadi et al. 2018 gives no clear indication why these values might be to high.

The values by Franco et al. 2016 and IEA 2017b, are in the same range as Höglund-Isaksson 2012 and use more recent data (reference year 2015 instead of 2005).

Franco et al. 2016 only gives a value for the US. Other country specific values were not found. Therefore, to stay consistent in the study, for all countries the same generic value derived from the latest, most plausible estimate of 76 bcm (IEA 2017b) is applied for the life cycle inventory analysis.

9.2.4.3 Estimate used in this study

For all countries a generic value of 0.0146 norm cubic meters per kg oil equivalent (Nm3/kgOE) is used in this study. It is calculated based on the global methane emissions of 76bcm due to crude oil and natural gas production with reference year 2015 (IEA 2017b). This number is divided by the global production from crude oil and natural gas extraction in kg OE and divided by the volumetric share of methane in natural gas according to the composition presented in chapter 9.2.5.

9.2.4.4 Country specific differentiation and uncertainty

As mentioned above, methane emissions have a high GWP. Therefore, venting is a highly relevant factor regarding the environmental performance of crude oil production. The range of figures found in literature is extremly high. Differences are up-to 5 orders of magnitude between lowest and highest estimates. A country specific differentiation does not seem to make sense at this stage of knowledge and the reasonable research done for the US is not applied therefore.

Other reasons for the use of global estimates are:

- Scarcity of comprehensive measurements
- High geographical uncertainty
- Unknown share of different technologies applied per country (e.g. use of fracking)
- National company reports might only report methane directly extracted and released (smaller scope of measurement) and therefore miss diffuse sources on the field.

To reflect the extremely high uncertainty behind the generic estimate, a basic uncertainty of 10 is applied on this value in the EcoSpold format.

9.2.5 Composition of vented gas

Venting losses of natural gas are modelled including the resource extraction from ground (which is not included in figures about natural gas production) and the emissions to air.

It is assumed, that the composition of the gas did not change compared to the former studies (Faist Emmenegger et al. 2007; Jungbluth 2007). No distinction is made between sweet and sour gas. The respective emissions are presented in Tab. 9.6.

Tab. 9.6 LCI data for venting of natural gas

	Name	Location	InfrastructureProcess	Unit	*natural gas, vented*	UncertaintyType	StandardDeviation95%	GeneralComment
	Location				*GLO*			
	Unit				*Nm3*			
resource, in ground	Gas, natural/m3	-	-	Nm3	1.00E+0	1	1.53	(3,3,5,3,1,na); Calculation
emission air, low population density	Carbon dioxide, fossil	-	-	kg	1.40E-2	1	1.53	(3,3,5,3,1,na); Literature
	Helium	-	-	kg	1.00E-3	1	1.79	(3,3,5,3,1,na); Literature
	Mercury	-	-	kg	1.50E-8	1	5.28	(3,3,5,3,1,na); Literature
	Methane, fossil	-	-	kg	5.85E-1	1	1.79	(3,3,5,3,1,na); Literature
	NMVOC, non-methane volatile organic compounds, unspecified origin	-	-	kg	2.71E-1	1	1.79	(3,3,5,3,1,na); Literature
	Radon-222	-	-	kBq	1.00E-1	1	3.24	(3,3,5,3,1,na); Literature

9.3 Use and emissions of Halon and other chemicals in firefighting equipment

Halon 1301 was used in stationery firefighting equipment for offshore operations. Because of its ozone depletion potential, industrial states stopped the production of halon in 1994, in line with the requirements of the Montreal Protocol.[27] The use, however, continues to be permitted for certain critical uses as set out in Annex VI to Regulation (EC) No 1005/2009. These critical uses also include the protection of spaces where flammable liquid or gas could be released in oil, gas and petrochemicals facilities.[28]

- Halon is only required to support legacy facilities; all new facilities are halon - free.
- Legacy facilities in the far north (i.e. Alaskan North Slope in the United States and parts of the former Soviet Union) will continue to require the use of halons in occupied spaces owing to severe ambient (very low temperature) conditions.
- Facility owners neither own nor control the quantities of halons needed to support operations over the continually extended time horizons. This situation will continue to place demands on the level of available halon stocks. However, owing to the adoption of alternatives in new facilities, this sector has reduced its future demand for the diminishing supplies of halon (UNEP 2014)

[27] http://www.ecoinvent.org/support/ecoinvent-forum/topic.html?&tid=279, online 18.10.2017

[28] http://eur-lex.europa.eu/legal-content/EN/TXT/HTML/?uri=CELEX:32010R0744&from=EN, online 01.11.2017

In most cases, existing facilities with halon 1301 fixed systems were designed and constructed as an integral part of the safety system design as well as the physical layout of the facility. After extensive research, it has been determined that in some cases the retrofit of such facilities with currently available alternative systems is not economically feasible, and that current research is unlikely to lead to an economic solution. Thus, these facilities will likely rely on existing halon banks for their operating lifetimes (UNEP 2014).

For new facilities, companies are adopting an inherently safe design approach to the protection of their facilities. This means preventing the release of hydrocarbons and eliminating the availability of flammable or explosive materials. Only when all such measures have been considered, and a residual risk of the hazard remains, are other risk reducing measures considered. In most cases, new technology detection systems are employed to shut-down and blow-down processes and turn on high rate ventilation systems rather than closing the space and trying to inert it with an extinguishing agent. However, where an inerting agent is still required in occupied spaces, halon 1301 has been replaced by Trifluoromethane (HFC-23) or FK-5-1-12, if temperatures permit. Currently, HFC-23 is the only alternative that can be used in very cold climatic conditions. Halon 1301 is also used for fire and explosion suppression systems that protect offshore oil exploration platforms in the tropical climatic zone in Asia (UNEP 2014).

Parties in the Asia pacific region, including India, use halon 1301 systems in refineries, gas pumping stations and offshore oil platforms. Refineries and oil pumping stations have/are gradually switching over to dry powders in pumping stations, HFC-227ea, FK-5 -1-12, and inert gases in refineries where it is technically feasible given space and weight concerns. For offshore oil platforms, space and weight are still a big concern and thus the replacement of old legacy systems and those systems on new platforms have been delayed. Thus, for such applications halon requirements still exist. Oil companies are obtaining this halon from local sources of recovered halon, which they use to refill existing cylinders.

However, there is no halon recycling, banking or quality testing facility for such recovered halon in this part of Asia. Therefore, the quality and effectiveness of such recovered halon is currently a major concern. In onshore halon 1301 systems, where a clean agent is important, some oil companies are hesitating to switch over to HFCs because of their high GWP as they do not want to switch over twice. HFC-23 has never been used in this region by the oil industry (UNEP 2014).

It is assumed that for European offshore plants 0.7 $mg_{halon}/t_{crude\ oil}$ is emitted, for the remaining areas 58 $mg_{halon}/t_{crude\ oil}$. Because test flooding, false alarms, losses from filling and leakage cause 70-90% of the total emissions, halon demand to extinguish fires in case of accidents is not assigned (Jungbluth 2007).

Based on the above information it is assumed, that 20% of the oil platforms still use Halon 1301. As there is no ecoinvent data available for the production of FK-5-1-12, the remaining share of flame retardants (80%) is modelled with Trifluoromethane (HFC-23).

HFC-23 has a high global warming potential compared to the other flame retardants while FK-5-1-12 has a GWP of 1[29]. Therefore, this replacement will overestimate the impacts on climate change.

[29] Product documentation of special hazard fire protection fluid: https://web.archive.org/web/20110927030243/http://solutions.3m.com/wps/portal/3M/en_US/Novec/Home/Product_Information/Product_Navigator/?PC_7_RJH9U5230GE5D02J33P04L38E5_univid=1180599171161, online 14.12.2017

No such emissions are modelled for onshore operations.

The same amounts that are emitted are considered as an input for the products. As there is no dataset for the production of such flame retardants available in the current ecoinvent database, it is approximated with the general dataset for organic chemicals.

10 Emissions to water & soil

10.1 Produced water

10.1.1 Overview

Produced water may originate as natural water in the formations holding oil and gas or can be water that was previously injected into those formations through activities designed to increase oil production from the formations such as water flooding or steam flooding operations. In some situations, additional water from other formations adjacent to the hydrocarbon-bearing layers may become part of the produced water that comes to the surface.

When the oil and gas flows to the surface, the produced water is brought to the surface with the hydrocarbons. Produced water contains some of the chemical characteristics of the formation from which it was produced and from the associated hydrocarbons.

Most wells in unconventional oil and gas formations are stimulated using hydraulic fracturing, through which water is injected under pressure into the formation to create pathways allowing the oil or gas to be recovered in a cost-effective manner. Immediately following hydraulic fracturing in the well (a frack job), some of the injected water returns to the surface and is known as flowback water. Flowback water is often managed in a similar manner to produced water and some engineers in the industry consider it as part of the produced water flow stream.[30]

At the beginning of production of a new field this fraction of co-produced water is usually small. If water content exceeds the maximal content tolerable for transport in the pipeline, water is separated with a separator. From ca. 10-20% watering, the drilling usually stops conveying automatically. Then, e.g. subsurface pumps need to be installed. In total the entire load of produced water can exceed the amount of produced oil in an oil field by ten times during the economic lifetime. If watering is 90 to 95% (i.e. 10-20 times more water than oil) production usually ceases for economic reasons (Jungbluth 2007).

10.1.2 Disposal

Produced water receives various types of treatment before it is disposed, reused, or otherwise managed. Many types of processes and technologies can be used to treat produced water depending on how clean the water must be before it moves on to its destination. Produced water must be treated to remove oil and grease and toxic chemicals before discharging it to the ocean from an offshore platform. Produced water that is discharged to onshore freshwater rivers must be further treated to reduce salt content. Water that is injected for either enhanced recovery or for disposal is treated in a different way from water that is discharged. The treatment processes used prior to injection are designed to remove free oil, solids, and bacteria. Chemicals are often used to enhance treatment processes and to protect underground formations and equipment.

30 http://www.producedwatersociety.com/produced-water-101/, online 19.10.2017

As oil, gas, and water are produced from a well, the fluids need to be separated into separate streams. This is typically done using some type of gravity separation, such as API separators, free water knockout tanks, or gun barrel separators. In addition to separating the fluids, these devices allow for large solid particles to settle out. When the oil and water are emulsified, they can be separated by applying heat or appropriate chemical treatments.

In most instances, several technologies are used as stages in a pre-treatment/treatment system.

Most U.S. produced water was re-injected. About 91% of the produced water was re-injected underground (this included water injected for enhanced recovery, water injected for disposal, and water sent to offsite commercial disposal).[30] About 80% of the produced water from off-shore wells was treated on the platform and discharged to the ocean. Only about 3% of onshore produced water was discharged. The percentage discharged from all wells (onshore and off-shore combined) was about 5.6%.[30] From this it can be concluded that most of the water is injected again and only a small part of the extracted produced water therefore causes emissions into the environment.

10.1.3 Allocation

For combined oil and gas production, 100% of the produced water is allocated to oil production as the water is used for and released due to EOR.

10.1.4 Amount

Onshore, the amount of water disposed to surface water like river and ocean seems to stay rather constant, as shown in Tab. 10.1, as most of the produced water is reinjected to the ground[30] (Agip Division 2001; ANL 2009; Tiedeman et al. 2012; UKOOA 2001). For Russia and Nigeria specific values are available (ecoinvent Centre 2017; Shell 2001; Targulian & Hirsch 2000). Where no specific amount was available for a country average, a generic value of 1kg produced water per kg of crude oil was used in the model. This value lies in the upper half of the range of reported values.

Tab. 10.1 Amount of produced water from onshore production, disposed to surface water in different regions **(in bold: values used for this study)**

Origin / Reference Year	water disposal intensity, onshore	source/comment
Unit	kg/kg crude oil	
Russia	**1.37**	Targulian & Hirsch 2000
2000	1.37	Targulian & Hirsch 2000
Nigeria	**0.42**	Shell 2001
2000	0.42	Shell 2001
Kazakhstan	**1.37**	Targulian & Hirsch 2000
Kazakhstan, onshore	1.37	Targulian & Hirsch 2000
2016, onshore	1.37	Targulian & Hirsch 2000
Norway	**-**	Offshore production only
2000	1.35	OLF 2001
Iraq	**1.00**	Generic estimation
Mexico	**1.00**	Generic estimation
Saudi-Arabia	**1.00**	Generic estimation
USA	**0.94**	Produced water society 2012; for 21 states,
2016	0.42	Wernet 2016, Ecoinvent v3.4, approximated with data for Nigeria, Jungbluth 2007
2012	0.94	Produced water society 2012; for 21 states, 283MtOE
2007	0.27	Argonne 2009; more than 98% reinjected underground
Great Britain	0.77	UKOOA 2001
2000	0.77	UKOOA 2001
Default GLO	**1.00**	**Generic estimation**
Company data	0.42	Agip Division 2001
Tiedemann 2012	0.79	California, Tiedemann 2012
Jungbluth 2007, generic global value	1.00	global estimate

For offshore production a water disposal intensity of 1.25kg produced water per kg of crude oil was calculated from available values for the US and KZ (ANL 2009; Stolz & Frischknecht 2017). Values applied in this study are presented in Tab. 10.2.

Tab. 10.2 Amount of produced water from offshore production, disposed to surface water in different regions **(in bold: values used for this study)**

Origin / Reference Year	produced water, discharged into ocean, offshore	source/comment
Unit	kg/kg crude oil	
Kazakhstan, offshore	1.20	Stolz & Frischknecht 2017
2016, offshore	1.20	Stolz & Frischknecht 2017
Norway	1.00	Generic estimation
2009	0.67	Neff 2011
Mexico	1.00	Generic estimation
Saudi-Arabia	1.00	Generic estimation
USA	1.30	ANL 2009
2007, US offshore	0.57	Neff 2011
2007	1.30	ANL 2009, p. 10, Offshore: More than 91% is discharged to the ocean with minor treatment.
Great Britain		
2000	1.20	UKOOA 2001
Default GLO	**1.00**	**Generic estimation**
Neff 2011 / 2003	0.37	Underestimate according to report
Jungbluth 2007, generic global value	1.00	

If combined oil and gas production is inventoried, produced water is allocated to crude oil production by 100%.

10.1.5 Composition and pollutants

Although no update has been commissioned for the life cycle inventory describing the composition of produced water, new data is considered together with data from a former study to have more complete background-data (Jungbluth 2007; Neff et al. 2011).

The physical and chemical properties of produced water vary considerably depending on the geographic location of the field, the geologic formation from which the water was produced, and the type of hydrocarbon product being produced. The major constituents of concern according to the produced water society[30] are:

- *Salt content (often expressed as salinity, conductivity, or total dissolved solids (TDS).* Although some produced water is nearly fresh (<3,000 mg/L TDS), most produced water is saltier than seawater (~35,000 mg/L) and can be >300,000 mg/L). Removing salt is not difficult, but it is usually costly.
- *Oil and grease.* This is not a single chemical compound; the analytical method for oil and grease measures various organic compounds associated with hydrocarbons in the formation). Oil and grease can be found in different physical forms:
  - Free oil: large droplets - readily removable by gravity separation methods
  - Dispersed oil: small droplets - somewhat difficult to remove; and
  - Dissolved oil: hydrocarbons and other similar materials dissolved in the water stream - very challenging to eliminate.

- *Inorganic and organic toxic compounds.* The toxics may be introduced as chemical additives to improve drilling and production operations or they may leach into the produced water from the formation rock or the hydrocarbon.
- *Naturally occurring radioactive material (NORM).* Some hydrocarbon-bearing formations contain natural radiation that leaches into the produced water. The presence and concentration of NORM varies between formations.

Because data on oil emissions is available for different production areas, this value is not used directly at discharge of produced water but is assessed in the inventory of crude oil production directly (see chapter 10.3).

Formation water contains radionuclides from natural decay processes. The contents strongly depend on the geologic situation. A correlation between content of dissolved solids and content of nuclides does not exist. In fact, the content of ^{238}U and ^{232}Th in the adjacent rock is decisive. For scale formation, however, contents of solid matter in the formation water are relevant due to the chemical relationship of radium with strontium and barium (cf. chapter 11.1)

The data basis in the former study was narrow and therefore extended with new data to have more complete background-data (Neff et al. 2011). An additional discussion and compilation of information can be found in the appendix, in table A.12 and A.13 of a former study (Jungbluth 2007).

Tab. 10.3 shows the life cycle inventory for the chemical composition of discharged produced water in offshore production. For the discharge onshore, the same data is used, but as subcategory for water emissions “to river“ is indicated instead of “to ocean”. Uncertainties of this estimation are relatively high because different values are expected for different regions and there are only values for a random sample of the various regions. Considered literature is shown in Tab. 10.4).

The water balance for type of freshwater input and reinjection and discharge of (treated) produced water is modelled at country level as different countries and compartments are involved (see chapter 12).

Tab. 10.3 Life cycle inventory for the chemical composition of discharged produced water in off-shore production. Data for onshore emissions are recorded with the same numbers and with SubCategory river instead of ocean

Name	Location	Category	SubCategory	InfrastructureProcess	Unit	discharge, produced water, offshore	UncertaintyType	StandardDeviation95%	GeneralComment
Location						OCE			
InfrastructureProcess						0			
Unit						kg			
Acenaphthene	-	water	ocean	-	kg	2.36E-9	1	3.08	(2,3,3,3,3,na); Literature, specific PAH
Acenaphthylene	-	water	ocean	-	kg	1.17E-9	1	3.07	(2,2,3,3,3,na); Literature, specific PAH
Ammonium, ion	-	water	ocean	-	kg	1.62E-4	1	5.09	(2,2,3,3,3,na); Literature
Arsenic	-	water	ocean	-	kg	2.78E-8	1	5.09	(2,2,3,3,3,na); Literature
Barium	-	water	ocean	-	kg	1.29E-4	1	5.09	(2,2,3,3,3,na); Literature
Benzene	-	water	ocean	-	kg	3.72E-6	1	3.07	(2,2,3,3,3,na); Literature
Benzene, ethyl-	-	water	ocean	-	kg	1.34E-6	1	3.08	(3,2,3,3,3,na); Literature
Boron	-	water	ocean	-	kg	1.20E-5	1	5.09	(2,2,3,3,3,na); Literature
Bromine	-	water	ocean	-	kg	3.50E-5	1	3.30	(3,3,5,3,3,na); Literature
BOD5, Biological Oxygen Demand	-	water	ocean	-	kg	5.25E-4	1	1.65	(4,2,3,3,3,na); Threshold limit for IN
Cadmium	-	water	ocean	-	kg	3.51E-9	1	5.09	(2,2,3,3,3,na); Literature
Calcium	-	water	ocean	-	kg	8.58E-3	1	1.61	(3,2,3,3,3,na); Literature
Carbonate	-	water	ocean	-	kg	2.79E-4	1	5.09	(2,2,3,3,3,na); Literature
Carboxylic acids, unspecified	-	water	ocean	-	kg	1.84E-4	1	3.29	(2,3,5,3,3,na); Environmental report for NO
Cesium	-	water	ocean	-	kg	5.00E-8	1	5.34	(3,3,5,3,3,na); Literature
Chloride	-	water	ocean	-	kg	7.18E-2	1	1.61	(3,2,3,3,3,na); Literature
Chromium	-	water	ocean	-	kg	1.09E-8	1	5.09	(2,2,3,3,3,na); Literature
COD, Chemical Oxygen Demand	-	water	ocean	-	kg	3.50E-5	1	1.89	(4,3,5,3,3,na); Threshold limit for IN
Copper	-	water	ocean	-	kg	3.93E-8	1	5.09	(2,2,3,3,3,na); Literature
Fluoride	-	water	ocean	-	kg	5.00E-7	1	1.86	(3,3,5,3,3,na); Literature
Hydrocarbons, aliphatic, alkanes, unspecified	-	water	ocean	-	kg	6.50E-6	1	3.30	(3,3,5,3,3,na); Literature
Hydrocarbons, aliphatic, unsaturated	-	water	ocean	-	kg	6.00E-7	1	3.30	(3,3,5,3,3,na); Literature
Hydrocarbons, aromatic	-	water	ocean	-	kg	2.60E-5	1	3.30	(3,3,5,3,3,na); Literature
Iodide	-	water	ocean	-	kg	5.83E-5	1	1.61	(3,2,3,3,3,na); Literature
Iron	-	water	ocean	-	kg	1.19E-5	1	5.09	(2,2,3,3,3,na); Literature
Lead	-	water	ocean	-	kg	1.13E-8	1	5.09	(2,2,3,3,3,na); Literature
Lead-210	-	water	ocean	-	kBq	4.75E-2	1	5.09	(2,2,3,3,3,na); Literature
Lithium	-	water	ocean	-	kg	1.33E-5	1	5.09	(2,2,3,3,3,na); Literature
Manganese	-	water	ocean	-	kg	3.77E-6	1	5.10	(3,2,3,3,3,na); Literature
Magnesium	-	water	ocean	-	kg	1.46E-3	1	5.10	(3,2,3,3,3,na); Literature
Mercury	-	water	ocean	-	kg	2.50E-9	1	5.09	(2,2,3,3,3,na); Literature
Molybdenum	-	water	ocean	-	kg	6.25E-10	1	5.09	(2,2,3,3,3,na); Literature
Nickel	-	water	ocean	-	kg	1.09E-7	1	5.09	(2,2,3,3,3,na); Literature
Oils, unspecified	-	water	ocean	-	kg	-	1	3.07	(2,2,3,3,3,na); Directly reported for the single country
PAH, polycyclic aromatic hydrocarbons	-	water	ocean	-	kg	1.09E-6	1	3.07	(2,2,3,3,3,na); Literature
Phenol	-	water	ocean	-	kg	4.00E-6	1	3.29	(2,3,5,3,3,na); Environmental report for NO
Polonium-210	-	water	ocean	-	kBq	1.62E-6	1	5.09	(2,2,3,3,3,na); Literature
Potassium	-	water	ocean	-	kg	1.01E-3	1	1.61	(3,2,3,3,3,na); Literature
Radium-224	-	water	ocean	-	kBq	1.26E-2	1	3.08	(3,2,3,3,3,na); Literature
Radium-226	-	water	ocean	-	kBq	3.04E-1	1	3.07	(2,2,3,3,3,na); Literature
Radium-228	-	water	ocean	-	kBq	5.00E-2	1	3.08	(3,2,3,3,3,na); Literature
Rubidium	-	water	ocean	-	kg	5.00E-7	1	2.31	(3,3,5,3,3,na); Literature
Silver	-	water	ocean	-	kg	3.00E-8	1	5.34	(3,3,5,3,3,na); Literature
Sodium	-	water	ocean	-	kg	3.51E-2	1	2.09	(3,2,3,3,3,na); Literature
Strontium	-	water	ocean	-	kg	3.42E-4	1	5.10	(3,2,3,3,3,na); Literature
Sulfate	-	water	ocean	-	kg	3.45E-4	1	5.09	(2,2,3,3,3,na); Literature
Suspended solids, unspecified	-	water	ocean	-	kg	4.50E-5	1	1.89	(4,3,5,3,3,na); Threshold limit for IN
Thorium-228	-	water	ocean	-	kBq	1.00E-2	1	3.30	(3,3,5,3,3,na); Literature
Thorium-232	-	water	ocean	-	kBq	3.24E-7	1	5.09	(2,2,3,3,3,na); Literature
DOC, Dissolved Organic Carbon	-	water	ocean	-	kg	2.95E-4	1	1.86	(3,3,5,3,3,na); Literature
TOC, Total Organic Carbon	-	water	ocean	-	kg	3.05E-3	1	1.61	(3,2,3,3,3,na); Literature
Toluene	-	water	ocean	-	kg	5.85E-6	1	3.08	(3,2,3,3,3,na); Literature
Vanadium	-	water	ocean	-	kg	3.25E-10	1	5.09	(2,2,3,3,3,na); Literature
VOC, volatile organic compounds, unspecified origin	-	water	ocean	-	kg	1.75E-5	1	3.30	(3,3,5,3,3,na); Literature
Uranium-238	-	water	ocean	-	kBq	2.50E-5	1	5.09	(2,2,3,3,3,na); Literature
Xylene	-	water	ocean	-	kg	4.88E-6	1	3.08	(3,2,3,3,3,na); Literature
Zinc	-	water	ocean	-	kg	1.00E-5	1	5.09	(2,2,3,3,3,na); Literature

Tab. 10.4 Literature values considered for chemical composition of discharged produced water in offshore and onshore production (cf. Tab. 10.3).

	Name	Unit	discharge, produced water, offshore	Neff 2011, average	Neff 2011, average	Neff 2011, min	Neff 2011, max	Neff 2011, average	Jungbluth 2007
	Location		OCE	MX	IN	OCE	OCE	OCE	OCE
	InfrastructureProcess		0						
	Unit		kg	kg	kg	kg	kg	kg	kg
emission water, ocean	Acenaphthene	kg	2.36E-9	-	-	-	4.10E-9	2.05E-9	6.22E-10
	Acenaphthylene	kg	1.17E-9	-	-	-	2.30E-9	1.15E-9	3.89E-11
	Ammonium, ion	kg	1.62E-4	-	-	2.30E-5	3.00E-4	1.62E-4	
	Arsenic	kg	2.78E-8	1.58E-8	-	5.00E-10	9.00E-8	4.53E-8	1.03E-8
	Barium	kg	1.29E-4	-	-	3.01E-7	3.42E-4	1.71E-4	8.70E-5
	Benzene	kg	3.72E-6	1.62E-6	1.19E-6	8.40E-08	2.80E-06	1.44E-6	6.00E-06
	Benzene, ethyl-	kg	1.34E-6	2.84E-7	1.88E-7	3.80E-8	5.30E-7	2.84E-7	2.40E-6
	Boron	kg	1.20E-5	-	-	8.00E-6	4.00E-5	2.40E-5	-
	Bromine	kg	3.50E-5	-	-			-	7.00E-5
	BOD5, Biological Oxygen Demand	kg	5.25E-4	-	-	5.95E-4	1.44E-3	1.02E-3	3.00E-5
	Cadmium	kg	3.51E-9	5.25E-10	-	2.00E-11	1.00E-8	5.01E-9	2.00E-9
	Calcium	kg	8.58E-3	-	-	2.53E-3	2.58E-2	1.42E-2	3.00E-3
	Carbonate	kg	2.79E-4	-	-	1.07E-4	1.01E-3	5.59E-4	-
	Carboxylic acids, unspecified	kg	1.84E-4	-	-			-	3.68E-4
	Cesium	kg	5.00E-8	-	-			-	1.00E-7
	Chloride	kg	7.18E-2	-	-	4.61E-2	1.41E-1	9.36E-2	5.00E-2
	Chromium	kg	1.09E-8	7.50E-10	-	1.00E-10	3.40E-8	1.71E-8	4.65E-9
	COD, Chemical Oxygen Demand	kg	3.50E-5	-	-			-	7.00E-5
	Copper	kg	3.93E-8	2.00E-10	-	2.00E-10	1.37E-7	6.86E-8	1.00E-8
	Fluoride	kg	5.00E-7	-	-			-	1.00E-6
	Hydrocarbons, aliphatic, alkanes, unspecified	kg	6.50E-6	-	-			-	1.30E-5
	Hydrocarbons, aliphatic, unsaturated	kg	6.00E-7	-	-			-	1.20E-6
	Hydrocarbons, aromatic	kg	2.60E-5	-	-			-	5.20E-5
	Iodide	kg	5.83E-5	-	-	3.00E-6	2.10E-4	1.07E-4	1.00E-5
	Iron	kg	1.19E-5	-	-	1.91E-6	3.70E-5	1.95E-5	4.30E-6
	Lead	kg	1.13E-8	1.41E-8	-	9.00E-11	4.50E-8	2.25E-8	7.00E-13
	Lead-210	kBq	4.75E-2	-	-	5.00E-5	1.90E-1	9.49E-2	-
	Lithium	kg	1.33E-5	-	-	3.00E-6	5.00E-5	2.65E-5	-
	Manganese	kg	3.77E-6	4.00E-6	-	8.10E-8	7.00E-6	3.54E-6	4.00E-6
	Magnesium	kg	1.46E-3	-	-	5.30E-4	4.30E-3	2.42E-3	5.00E-4
	Mercury	kg	2.50E-9	1.05E-10	-	1.00E-11	1.00E-8	5.01E-9	1.90E-12
	Molybdenum	kg	6.25E-10	-	-	3.00E-10	2.20E-9	1.25E-9	-
	Nickel	kg	1.09E-7	4.00E-9	-	1.00E-10	4.20E-7	2.10E-7	6.99E-9
	Oils, unspecified	kg	-	-	-	2.90E-5	4.00E-5	3.45E-5	-
	PAH, polycyclic aromatic hydrocarbons	kg	1.09E-6	-	-	4.00E-8	2.15E-6	1.09E-6	4.68E-7
	Phenol	kg	4.00E-6	-	-			-	8.00E-6
	Polonium-210	kBq	1.62E-6	-	-	1.85E-7	6.29E-6	3.24E-6	-
	Potassium	kg	1.01E-3	-	-	1.30E-4	3.10E-3	1.62E-3	4.00E-4
	Radium-224	kBq	1.26E-2	-	-	5.00E-4	4.00E-2	2.02E-2	5.00E-3
	Radium-226	kBq	3.04E-1	-	-	1.85E-6	1.20E+0	5.99E-1	8.00E-3
	Radium-228	kBq	5.00E-2	-	-	3.00E-4	1.80E-1	9.01E-2	1.00E-2
	Rubidium	kg	5.00E-7	-	-			-	1.00E-6
	Silver	kg	3.00E-8	-	-			-	6.00E-8
	Sodium	kg	3.51E-2	-	-	2.30E-2	5.73E-2	4.02E-2	3.00E-2
	Strontium	kg	3.42E-4	-	-	7.00E-6	1.00E-3	5.04E-4	1.80E-4
	Sulfate	kg	3.45E-4	-	-	2.10E-4	1.17E-3	6.90E-4	-
	Suspended solids, unspecified	kg	4.50E-5	-	-			-	9.00E-5
	Thorium-228	kBq	1.00E-2	-	-			-	2.00E-2
	Thorium-232	kBq	3.24E-7	-	-	2.96E-7	9.99E-7	6.48E-7	-
	DOC, Dissolved Organic Carbon	kg	2.95E-4	-	-			-	5.90E-4
	TOC, Total Organic Carbon	kg	3.05E-3	-	-	1.00E-7	1.10E-2	5.50E-3	5.90E-4
	Toluene	kg	5.85E-6	1.02E-6	4.45E-7	8.90E-8	1.70E-6	8.95E-7	1.08E-5
	Vanadium	kg	3.25E-10	-	-	1.00E-10	1.20E-9	6.50E-10	-
	VOC, volatile organic compounds, unspecified origin	kg	1.75E-5	-	-			-	3.50E-5
	Uranium-238	kBq	2.50E-5	-	-	2.96E-7	9.99E-5	5.01E-5	-
	Xylene	kg	4.88E-6	4.40E-7	2.47E-7	1.30E-8	7.20E-7	3.67E-7	9.40E-6
	Zinc	kg	1.00E-5	1.81E-6	-	1.00E-9	2.60E-5	1.30E-5	7.00E-6

10.2 Production chemicals

It can be assumed that the emissions of production chemicals were already recorded with the composition of production water. The amount of chemicals that are injected depends on the possibility to force produced water into abandoned oil and gas fields or aquifers (Jungbluth 2007).

10.3 Oil spills to water

Operational oil spills include all types of spills that might occur during drilling and pumping and exclude spills related to transportation and refining.

According to self-reported data from oil extraction companies, operational spills and spills due to sabotage are decreasing due to better management and safety instructions.

In the former study, the values vary widely with 19 g oil/kg oil-eq spilled to water in Russia and 0.07 g/kg in Nigeria (Jungbluth 2007). These values also vary widely in corporate sustainability reports depending on whether major catastrophic oil spills such as "Deep Water Horizon" are considered (see Tab. 10.5).

It is not clear if the unpleasant situation investigated in the year 2000 in Russia has improved in the meantime (Lodewijkx et al. 2001). Actual information still mentions the high rate of losses (up to 10%) in Russia.[31]

However, current company data suggest that this rate is below 3.5g/t in 2016 (BP 2016; Chevron 2015, 2016; ConocoPhilips 2016; Shell 2016).

A calculation of regional averages from company data comes to an average emission of about 6g/t (IOGP 2017).

If catastrophic oil spills like Deep water horizon in 2010 are taken into account, where about 4.9 million barrels of oil were spilled, e.g. the ten year average per year increases to 409 g/t for the period from 2007 to 2016 (BP 2008, 2012, 2016; United States Coast Guard 2011).

As such catastrophic oil spills are rare events, a longer time frame is analysed in this study. From 1900 until 2010, the five largest, non-war-related oil spills at offshore extraction sites released about 3.3 Megatons of crude oil.[32] In the same timeframe around 153 Teratons (10^{12}) of crude oil and about 128 Tera-Nm^3 of natural gas were produced. As mentioned in chapter 4.2, offshore production has a share of about 30% of global oil production. From these numbers a ratio of 36g crude oil spilled / ton Oil equivalent produced offshore is calculated for such catastrophic events. This value is used in combination with the regional values summarized by the IOGP to describe oil emissions to water for all datasets where offshore production occurs (see Tab. 10.5).

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31 See e.g. https://www.greenpeace.de/sites/www.greenpeace.de/files/Schwarzbuch_f__r_Internet_0.pdf or https://de.wikipedia.org/wiki/%C3%96lkatastrophe_in_Westsibirien

32 https://en.wikipedia.org/wiki/List_of_oil_spills, online 03.10.2018

Tab. 10.5 Amount of oil spilled to sea, data considered, and values used in this study for offshore production

Origin / Reference Year	Oils, unspecified, to sea	Source / Comment
Unit	kg/kg OE	
Russia		Onshore production only
2016	3.20E-07	IOGP 2016
2000	1.90E-02	Jungbluth 2007
Nigeria	4.47E-05	IOGP 2016 plus breakdown of 5 biggest, non-war-related oil spills (catastrophes) on oil platforms between 1900 and 2010
2016	8.36E-06	IOGP 2016
2000	7.08E-05	Jungbluth 2007
Kazakhstan	6.78E-04	Stolz & Frischknecht 2017 plus breakdown of 5 biggest, non-war-related oil spills (catastrophes) on oil platforms between 1900 and 2010
Kazakhstan, offshore	6.78E-04	Stolz & Frischknecht 2017 plus breakdown of 5 biggest, non-war-related oil spills (catastrophes) on oil platforms between 1900 and 2010
2016, onshore	2.00E-02	Jungbluth 2007
2016, offshore	6.41E-04	Stolz & Frischknecht 2017
2016	3.20E-07	IOGP 2016
Norway	4.72E-05	IOGP 2016 plus breakdown of 5 biggest, non-war-related oil spills (catastrophes) on oil platforms between 1900 and 2010
2016	1.09E-05	IOGP 2016
2010	1.59E-05	Schori 2012
Iraq		onshore production only
2016	1.60E-07	IOGP 2016
Mexico	4.29E-05	IOGP 2016 plus breakdown of 5 biggest, non-war-related oil spills (catastrophes) on oil platforms between 1900 and 2010
2016	6.62E-06	IOGP 2016
Saudi-Arabia	3.65E-05	IOGP 2016 plus breakdown of 5 biggest, non-war-related oil spills (catastrophes) on oil platforms between 1900 and 2010
2016	1.60E-07	IOGP 2016
USA	4.29E-05	IOGP 2016 plus breakdown of 5 biggest, non-war-related oil spills (catastrophes) on oil platforms between 1900 and 2010
2016	6.39E-05	Wernet 2016, Ecoinvent v3.4, approximated with data for Nigeria, Jungbluth 2007
2016	6.62E-06	IOGP 2016
Default GLO	**4.05E-05**	**Generic value - average IOGP data plus breakdown of 5 biggest, non-war-related oil spills (catastrophes) on oil platforms between 1900 and 2010**

Tab. 10.6 Amount of oil spilled to rivers, data considered, and values used in this study for onshore production

Origin / Reference Year	Oils, unspecified, to river	Source / Comment
Unit	kg/kg OE	
Russia	2.05E-07	Mean IOGP 2014 & 2015
2016	0.00E+00	IOGP 2016
2015	3.50E-07	IOGP 2015
2014	6.00E-08	IOGP 2014
2000	1.90E-02	Jungbluth 2007
Nigeria	3.44E-06	IOGP 2016
2016	3.44E-06	IOGP 2016
2000	7.08E-05	Jungbluth 2007
Kazakhstan	0.00E+00	IOGP 2016
Kazakhstan, onshore	2.05E-07	Mean IOGP 2014 & 2015
2016, onshore	1.90E-02	Jungbluth 2007
2016	0.00E+00	IOGP 2016
2015	3.50E-07	IOGP 2015
2014	6.00E-08	IOGP 2014
Norway	1.00E-08	IOGP 2016
2016	1.00E-08	IOGP 2016
2010	1.59E-05	Schori 2012
Iraq	0.00E+00	IOGP 2016
2016	0.00E+00	IOGP 2016
Mexico	2.81E-06	IOGP 2016
2016	2.81E-06	IOGP 2016
Saudi-Arabia	0.00E+00	IOGP 2016
2016	0.00E+00	IOGP 2016
USA	2.81E-06	IOGP 2016
2016	6.39E-05	Wernet 2016, Ecoinvent v3.4, approximated with data for Nigeria, Jungbluth 2007
2016	2.81E-06	IOGP 2016

10.4 Oil spills to soil

A calculation of regional averages with company data has been used for the estimation of oil emissions to soil during onshore operations (IOGP 2017). Further data were available from the former study for Russia and single company reports.

To estimate the values for single countries the regional values of IOGP are applied. Consulted literature and values used in the model are shown in Tab. 10.7.

Tab. 10.7 Amount of oil spilled to soil per kg of oil equivalent extracted (onshore); data considered (grey background), and values used in this study (white background)

Origin / Reference Year	Oils, unspecified, to soil	Source/Comment
Unit	kg/kg OE	
Russia	4.56E-06	IOGP 2016
2016	4.56E-06	IOGP 2016
2000	2.50E-02	Jungbluth 2007
Nigeria	4.66E-05	IOGP 2016
2016	4.66E-05	IOGP 2016
Kazakhstan	4.56E-06	IOGP 2016
Kazakhstan, onshore	4.56E-06	IOGP 2016
Kazakhstan, offshore	0.00E+00	Offshore production only
2016	4.56E-06	IOGP 2016
Norway	7.63E-06	IOGP 2016
2016	7.63E-06	IOGP 2016
Iraq	2.33E-06	IOGP 2016
2016	2.33E-06	IOGP 2016
Mexico	7.60E-06	IOGP 2016
2016	7.60E-06	IOGP 2016
Saudi-Arabia	2.33E-06	IOGP 2016
2016	2.33E-06	IOGP 2016
USA	7.60E-06	IOGP 2016
2016	7.60E-06	IOGP 2016
Default GLO	**2.06E-05**	**Generic value - average country and company data**

11 Waste

11.1 Scale

In oil production, the mineral substances dissolved in water precipitate and are deposited in the equipment (pumps, separator, valves etc.). The deposition of scale is estimated with a dataset for low radioactive waste. For Norway, a country specific value is available (Schori et al. 2012). For all other countries, a generic value assessed in (Jungbluth 2007) is considered (see Tab. 11.1).

11.2 Other wastes

For disposal of other wastes that form during crude oil production, data from Nigeria: 363 g/t (Shell 2001) and Norway 86.6g/t (Schori et al. 2012) is available. For other regions, 100 g/t are used as generic assumption (see Tab. 11.1).

Tab. 11.1 Amount of waste considered in this study

Origin / Reference Year	low active radioactive waste	disposal, municipal solid waste, 22.9%water	Source/comment
Unit	m3/kg OE	kg/ kg OE	
Russia	2.00E-07	1.00E-04	Generic assumption
2000	2.00E-07	1.00E-04	Jungbluth 2007
Nigeria	2.00E-09	3.63E-04	Shell 2001
2000	2.00E-09	3.63E-04	Shell 2001
Kazakhstan	2.00E-07	1.00E-04	Jungbluth 2007
2016, onshore	2.00E-07	1.00E-04	Jungbluth 2007
2016, offshore	2.00E-07	1.00E-04	Jungbluth 2007
Norway	1.58E-07	8.66E-05	Schori 2012
2010	1.58E-07	8.66E-05	Schori 2012
Iraq	2.00E-07	1.00E-04	Generic assumption
Mexico	2.00E-07	1.00E-04	Generic assumption
Saudi-Arabia	2.00E-07	1.00E-04	Generic assumption
USA	2.00E-07	1.00E-04	Generic assumption
2016	1.99E-09	3.63E-04	Wernet 2016, Ecoinvent v3.3, approximated with data for Nigeria, Jungbluth 2007
Default GLO	**2.00E-07**	**1.00E-04**	**Generic assumption**

12 Summary of life cycle inventory data

For the updated datasets on crude oil extraction, the most relevant changes compared to the assessment in 2007 (Jungbluth 2007) are:

- Harmonized and updated assessment of total energy uses per country based mainly on regional averages
- New country specific data for share of on- and offshore production, well drilling and flaring
- Generic assessment for venting emissions
- Regional average data for fresh water use, emission of oil to soil and water
- Replacement of halon in fire extinguishers with less ozone depleting substances
- Harmonized generic estimates for chemical use, oil spills due to accidents, other emissions to soil, water, and air

Not changed due to lesser relevance are e.g. LCI for basic infrastructure for platform and production plants and background data for machinery use on these plants.

In the subchapters and tables below, the life cycle inventories for the newly modelled and updated processes are presented. All data are provided as unit process raw data in the EcoSpold v1 format. The electronic data is including full EcoSpold v1 documentation.

For each investigated process, two types of tables (X-Process and X-Exchange) are provided in this report. Tab. 12.1 shows meta information and Tab. 12.2 to Tab. 12.9 show the modelled life cycle inventory (unit process raw data) for crude oil extraction in investigated countries.

Please note that reference units for the processes are not shown if they are equal to one to increase visibility of other aspects in the tables.

Please further note, that the reference unit for flaring in this study is per Nm3, where in the former study it was MJ (Jungbluth 2007). In the following tables the difference is therefore smaller than it seems at first glance.

12.1 Russia

Updated unit process raw data for Russia is presented in Tab. 12.2.

12.2 Nigeria

Updated unit process raw data for Nigeria is presented in Tab. 12.3.

12.3 Kazakhstan

Updated unit process raw data for Kazakhstan for on- and offshore production is presented in Tab. 12.4. In this table, data is presented differently than for other countries. This is because the table structure was taken from a former study which now had been partially updated (Stolz & Frischknecht 2017). Besides changes mentioned at the beginning of chapter 12, allocation of emissions related to construction of infrastructure and extraction of crude oil and natural between crude oil and natural gas production is adapted to production volumes in 2016.

12.4 Norway

Updated unit process raw data for Norway is presented in Tab. 12.6.

Besides changes mentioned at the beginning of chapter 12, allocation of emissions related to construction of infrastructure and extraction of crude oil and natural gas is adapted to production volumes of crude oil and natural gas in 2016 (3 times higher natural gas production and ~2 times lower oil production compared to 2010).

12.5 Iraq

New unit process raw data for Iraq is presented in Tab. 12.7.

12.6 Mexico

New unit process raw data for Mexico is presented in Tab. 12.8.

12.7 Saudi Arabia

New unit process raw data for Saudi Arabia is presented in Tab. 12.9.

12.8 USA

Updated unit process raw data for USA is presented in Tab. 12.10.

Besides changes mentioned at the beginning of chapter 12, for the USA, in this study, besides onshore, now also offshore production is investigated.

In another study for the BFE onshore oil production in the USA and Mexico has been based on the life cycle inventory for crude oil production in the Middle East, with the reasoning that flaring losses seem similarly high (Stolz & Frischknecht 2017). The detailed evaluation in this study shows that the flaring rate is of lesser relevance and that the two production sites differ widely due to more challenging geology, higher energy needs and higher venting rates in the USA.

12.9 Country mix onshore/offshore

For countries that produce crude oil and/or natural gas onshore and offshore, the production mixes are shown in Tab. 12.11. These countries are Kazakhstan, Mexico, Saudi-Arabia and USA. For Nigeria which also produces on- and offshore, the data is directly aggregated to a production mix in Tab. 12.3.

Tab. 12.1 Meta information for the investigated life cycle inventories, part1

Name	well for exploration and production, offshore	well for exploration and production, onshore	platform, crude oil, offshore	production plant crude oil, onshore
Location	OCE	GLO	OCE	GLO
InfrastructureProcess	1	1	1	1
Unit	m	m	unit	unit
IncludedProcesses	All energy uses, materials and emissions for drilling of an offshore bore hole and finishing of the well.	All energy uses, materials, land use and emissions for drilling of an onshore bore hole and finishing of the well.	Materials for construction, energy use for erection. Land use and transformation. Disposal of the platform after use. Wells are not included and are considered separately. Manufacturing of facilities partly not included.	Materials for construction, energy use for construction. Land use and transformation. Disposal of materials after use. Wells are not included and are considered separately. Manufacturing of facilities partly not included.
GeneralComment	Process for all types of offshore drilling operations.	Process for all types of onshore drilling operations.	Construction and dismantling of an offshore production platform with a weight of 2500t. Life time 15 years.	Construction and dismantling of an onshore production field with 100 wells. Life time 30 years.
InfrastructureIncluded	1	1	1	1
Category	oil	oil	oil	oil
SubCategory	production	production	production	production
LocalCategory	Erdöl	Erdöl	Erdöl	Erdöl
LocalSubCategory	Bereitstellung	Bereitstellung	Bereitstellung	Bereitstellung
StartDate	1990	1990	1990	1990
EndDate	2016	2016	2016	2016
DataValidForEntirePeriod	1	1	1	1
OtherPeriodText	Time of publication in literature and environmental reports. Most data are valid for the end of the 90ties.	Time of publication in literature and environmental reports. Most data are valid for the end of the 90ties.	Data for materials based on information from 1990. New data for energy and material uses during construction.	Data for materials and land use based on information from 1990. New data for energy and material uses during construction.
Text	Data mainly found for GB and NO.	Data investigated for NG, IN and multinational companies.	Type of platform used in the North Sea.	Data for fields in RU, US and multinational companies.
Text	Drilling in the North Sea	Onshore drilling.	Mix of 80% steel and 20% concrete platforms.	Onshore crude oil production in the Northern hemisphere.
Percent				
ProductionVolume	About 50km in NO and 100km in GB per year.	About 30km in NG and 80km in India and 15km of a company in one year.	In 1998 there were 263 production platforms in use in the North Sea.	Unknown.
SamplingProcedure	Publication in environmental reports and other literature.	Publication in environmental reports and other literature.	Publication in environmental reports and other literature.	Publication in environmental reports and other literature.
Extrapolations	Applied on all offshore drilling operations. There might be differences depending on depth of sea and type of geological formation	Applied on all onshore drilling operations. There might be differences depending on type of geological formation.	Applied on all offshore operations. There might be differences depending on depth of sea.	Applied on all onshore operations. Data vary considerable depending on infrastructure necessary to access the place. No data for Middle East.
UncertaintyAdjustments	none	none	none	none

Meta information for the investigated life cycle inventories, part2

Name	discharge, produced water, offshore	discharge, produced water, onshore	crude oil, at production onshore	crude oil, at production onshore
Location	OCE	GLO	RU	KZ
InfrastructureProcess	0	0	0	0
Unit	kg	kg	kg	kg
IncludedProcesses	Emissions of water pollutants with produced water discharged to sea after treatment. Oil emissions are not included and are considered separately.	Emissions of water pollutants with produced water discharged to rivers after treatment. Oil emissions are not included and are considered separately.	Production of oil including energy use, infrastructure and emissions.	Production of oil including energy use, infrastructure and emissions.
GeneralComment	Emissions related to discharge of produced water	Emissions related to discharge of produced water	The multioutput-process 'combined gas and oil production' delivers the co-products crude oil and natural gas. Allocation for co-products is based on heating value. Production mainly in Siberia.	The onshore oil production delivers the product crude oil
InfrastructureIncluded			1	1
Category	oil	oil	oil	oil
SubCategory	production	production	production	production
LocalCategory	Erdöl	Erdöl	Erdöl	Erdöl
LocalSubCategory	Bereitstellung	Bereitstellung	Bereitstellung	Bereitstellung
StartDate	1980	1980	2000	2000
EndDate	2016	2016	2016	2016
DataValidForEntirePeriod	1	1	1	1
OtherPeriodText	Time of publications. Most figures could be verified for 2000.	Time of publications. Most figures could be verified for 2000.	Time of most relevant publications and statistics. Other generic data, e.g. for infrastructure are based on older publications.	Time of most relevant publications and statistics. Other generic data, e.g. for infrastructure are based on older publications.
Text	Data mainly for NO with some additional information from other countries.	Data mainly for offshore NO with some additional information from other countries.	Data valid for RU.	Data valid for KZ.
Text	Discharge after pre-treatment.	Discharge after pre-treatment.	0 % offshore and 100 % onshore production	24 % offshore and 76 % onshore production
Percent			100	100
ProductionVolume	About 1m3 of water is discharged per tonne of crude oil produced.	About 1m3 of water is discharged per tonne of crude oil produced.	Onshore: 547 Megatons crude oil per year in 2016	Onshore: 60 Mt per year in 2016
SamplingProcedure	Publication in environmental reports and other literature.	Publication in environmental reports and other literature.	Independent investigation of Greenpeace and international statistics.	Statistics and use of generic data
Extrapolations	Only single measurements mainly from NO available. Applied on all offshore operations.	Concentration data for offshore discharges in NO are applied on global onshore. Measurements for onshore were not available.	A part of the data has been estimated with generic assumptions for onshore production.	A part of the data has been estimated with generic assumptions for onshore production.
UncertaintyAdjustments	none	none	none	none

Meta information for the investigated life cycle inventories, part3

Name	crude oil, at production offshore	crude oil, at production	combined gas and oil production	crude oil, at production	natural gas, at production
Location	KZ	KZ	NG	NG	NG
InfrastructureProcess	0	0	0	0	0
Unit	kg	kg	a	kg	Nm3
IncludedProcesses	Production of oil including energy use, infrastructure and emissions.	Production of oil including energy use, infrastructure and emissions.	Production of oil and gas including energy use, infrastructure and emissions.	Production of oil including energy use, infrastructure and emissions.	Production of natural gas including energy use, infrastructure and emissions.
GeneralComment	The offshore oil production delivers the product crude oil	Offshore and onshore production	The multioutput-process 'combined gas and oil production' delivers the co-products crude oil and natural gas. Allocation for co-products is based on heating value.	The multioutput-process 'combined gas and oil production' delivers the co-products crude oil and natural gas. Allocation for co-products is based on heating value.	The multioutput-process 'combined gas and oil production' delivers the co-products crude oil and natural gas. Allocation for co-products is based on heating value.
InfrastructureIncluded	1	1	1	1	1
Category	oil	oil	oil	oil	natural gas
SubCategory	production	production	production	production	production
LocalCategory	Erdöl	Erdöl	Erdöl	Erdöl	Erdgas
LocalSubCategory	Bereitstellung	Bereitstellung	Bereitstellung	Bereitstellung	Bereitstellung
StartDate	2000	2016	2000	2000	2000
EndDate	2016	2016	2016	2016	2016
DataValidForEntirePeriod	1	1	1	1	1
OtherPeriodText	Time of most relevant publications and statistics. Other generic data, e.g. for infrastructure are based on older publications.	Time of most relevant publications and statistics. Other generic data, e.g. for infrastructure are based on older publications.	Most data could be found for 1999-2000.	Time of most relevant publications and statistics. Other generic data, e.g. for infrastructure are based on older publications.	Time of most relevant publications and statistics. Other generic data, e.g. for infrastructure are based on older publications.
Text	Data valid for KZ.	Data valid for KZ.	Data are valid for two companies in NG.	Data valid for NG.	Data valid for NG.
Text	24 % offshore and 76 % onshore production	24 % offshore and 76 % onshore production	Mainly onshore production in the Niger delta and a small part of offshore production.	25 % offshore and 75 % onshore production	25 % offshore and 75 % onshore production
Percent	100	100	57	100	100
ProductionVolume	Offshore: 19 Mt per year in 2016	On- and offshore: 79 Mt per year in 2016	107Mio. t of crude oil and 13.5 Mrd. m3 of gas in 2000.	On- and offshore: 103 Megatons crude oil per year in 2016	On- and offshore: 40 billion Nm3 natural gas per year in 2016
SamplingProcedure	Statistics and use of generic data	Statistics and use of generic data	Environmental report and questionnaire.	Literature	Literature
Extrapolations	A part of the data has been estimated with generic assumptions for offshore production.	A part of the data has been estimated with generic assumptions for on- and offshore production.	Emission data are calculated with generic assumptions. Generic assumptions also applied for chemical uses and some other exchanges.	A part of the data has been estimated with generic assumptions for on- and offshore production.	A part of the data has been estimated with generic assumptions for on- and offshore production.
UncertaintyAdjustments	none	none	none	none	none

Meta information for the investigated life cycle inventories, part4

Name	combined offshore gas and oil production	crude oil, at production offshore	natural gas, at production offshore	combined gas and oil production
Location	NO	NO	NO	IQ
InfrastructureProcess	0	0	0	0
Unit	a	kg	Nm3	a
IncludedProcesses	Production of oil and gas including energy use, infrastructure and emissions. Transport by pipeline to the coast.	exploration and production of oil on the Norwegian Continental Shelf (offshore). Data doesn't include combusted fuels for turbines, motors etc. It includes well testing (fuel requirements and emissions).	Production of natural gas including energy use, infrastructure and emissions.	Production of oil and gas including energy use, infrastructure and emissions.
GeneralComment	The multioutput-process 'combined offshore gas and oil production' delivers the co-products crude oil and natural gas. Allocation for co-products is based on heating value.	The data are valid for the Norway offshore production. It can be assumed that they are valid for production in the North Sea in mature fields. The weighted parts of ethane, butane etc. in Kollsnes and Karsto gas has been used to break down NMVOC emissions in their different parts. The multioutput-process 'combined offshore gas and oil production' delivers the co-products 'natural gas' and 'crude oil'.	The multioutput-process 'combined gas and oil production' delivers the co-products crude oil and natural gas. Allocation for co-products is based on heating value.	The multioutput-process 'combined gas and oil production' delivers the co-products crude oil and natural gas. Allocation for co-products is based on heating value.
InfrastructureIncluded	1	1	1	1
Category	natural gas	oil	natural gas	oil
SubCategory	production	production	production	production
LocalCategory	Erdgas	Erdöl	Erdgas	Erdöl
LocalSubCategory	Bereitstellung	Bereitstellung	Bereitstellung	Bereitstellung
StartDate	2016	2000	2000	2016
EndDate	2016	2016	2016	2016
DataValidForEntirePeriod	1	1	1	1
OtherPeriodText	Time of most relevant publications and statistics. Other generic data, e.g. for infrastructure are based on older publications.	Time of most relevant publications and statistics. Other generic data, e.g. for infrastructure are based on older publications.	Time of most relevant publications and statistics. Other generic data, e.g. for infrastructure are based on older publications.	Time of most relevant publications and statistics. Other generic data, e.g. for infrastructure are based on older publications.
Text	Data valid for NO.	Data valid for NO.	Data valid for NO.	Data valid for IQ.
Text	100 % offshore and 0 % onshore production	100 % offshore and 0 % onshore production	100 % offshore and 0 % onshore production	0 % offshore and 100 % onshore production
Percent	100	100	100	100
ProductionVolume	Offshore: 90 Megatons crude oil and 120 billion Nm3 natural gas per year in 2016	Offshore: 90 Megatons crude oil per year in 2016	Offshore: 120 billion Nm3 natural gas per year in 2016	Onshore: 193 Megatons crude oil and 10 billion Nm3 natural gas per year in 2016
SamplingProcedure	Statistics and use of generic data	Literature	Literature, statistics and use of generic data	Statistics and use of generic data
Extrapolations	A part of the data has been estimated with generic assumptions for offshore production.	A part of the data has been estimated with generic assumptions for offshore production.	A part of the data has been estimated with generic assumptions for offshore production.	A part of the data has been estimated with generic assumptions for onshore production.
UncertaintyAdjustments	none	none	none	none

Meta information for the investigated life cycle inventories, part5

Name	crude oil, at production	natural gas, at production	combined gas and oil production	combined gas and oil production offshore
Location	IQ	IQ	MX	MX
InfrastructureProcess	0	0	0	0
Unit	kg	Nm3	a	a
IncludedProcesses	Production of crude oil including energy use, infrastructure and emissions.	Production of oil and gas including energy use, infrastructure and emissions. Transport by pipeline to the coast.	Production of oil and gas including energy use, infrastructure and emissions.	Production of oil and gas including energy use, infrastructure and emissions.
GeneralComment	The multioutput-process 'combined gas and oil production' delivers the co-products crude oil and natural gas. Allocation for co-products is based on heating value.	The multioutput-process 'combined offshore gas and oil production' delivers the co-products crude oil and natural gas. Allocation for co-products is based on heating value.	The multioutput-process 'combined offshore gas and oil production' delivers the co-products crude oil and natural gas. Allocation for co-products is based on heating value.	The multioutput-process 'combined offshore gas and oil production' delivers the co-products crude oil and natural gas. Allocation for co-products is based on heating value.
InfrastructureIncluded	1	1	1	1
Category	oil	oil	oil	oil
SubCategory	production	production	production	production
LocalCategory	Erdöl	Erdöl	Erdöl	Erdöl
LocalSubCategory	Bereitstellung	Bereitstellung	Bereitstellung	Bereitstellung
StartDate	2016	2016	2016	2016
EndDate	2016	2016	2016	2016
DataValidForEntirePeriod	1	1	1	1
OtherPeriodText	Time of most relevant publications and statistics. Other generic data, e.g. for infrastructure are based on older publications.	Time of most relevant publications and statistics. Other generic data, e.g. for infrastructure are based on older publications.	Time of most relevant publications and statistics. Other generic data, e.g. for infrastructure are based on older publications.	Time of most relevant publications and statistics. Other generic data, e.g. for infrastructure are based on older publications.
Text	Data valid for IQ.	Data valid for IQ.	Data valid for MX.	Data valid for MX.
Text	0 % offshore and 100 % onshore production	0 % offshore and 100 % onshore production	75 % offshore and 25 % onshore production	75 % offshore and 25 % onshore production
Percent	100	100	100	100
ProductionVolume	Onshore: 193 Megatons crude oil per year in 2016	Onshore: 10 billion Nm3 natural gas per year in 2016	On- and offshore: 120 Megatons crude oil and 40 billion Nm3 natural gas per year in 2016	Offshore: 90 Megatons crude oil and 30 billion Nm3 natural gas per year in 2016
SamplingProcedure	Statistics and use of generic data	Statistics and use of generic data	Statistics and use of generic data	Statistics and use of generic data
Extrapolations	A part of the data has been estimated with generic assumptions for onshore production.	A part of the data has been estimated with generic assumptions for onshore production.	A part of the data has been estimated with generic assumptions for onshore production.	A part of the data has been estimated with generic assumptions for offshore production.
UncertaintyAdjustments	none	none	none	none

Meta information for the investigated life cycle inventories, part6

Name	combined gas and oil production onshore	crude oil, at production offshore	crude oil, at production onshore	natural gas, at production offshore
Location	MX	MX	MX	MX
InfrastructureProcess	0	0	0	0
Unit	a	kg	kg	Nm3
IncludedProcesses	Production of oil and gas including energy use, infrastructure and emissions.	Production of crude oil including energy use, infrastructure and emissions.	Production of crude oil including energy use, infrastructure and emissions.	Production of natural gas including energy use, infrastructure and emissions.
GeneralComment	The multioutput-process 'combined offshore gas and oil production' delivers the co-products crude oil and natural gas. Allocation for co-products is based on heating value.	The offshore oil production delivers the product crude oil. The values are derived from a multioutput-process "combined offshore gas and oil production" by allocation based on heating values for crude oil and natural gas	The onshore oil production delivers the product crude oil. The values are derived from a multioutput-process "combined onshore gas and oil production" by allocation based on heating values for crude oil and natural gas	The offshore natural gas production delivers the product natural gas. The values are derived from a multioutput-process "combined offshore gas and oil production" by allocation based on heating values for crude oil and natural gas
InfrastructureIncluded	1	1	1	1
Category	oil	oil	oil	natural gas
SubCategory	production	production	production	production
LocalCategory	Erdöl	Erdöl	Erdöl	Erdgas
LocalSubCategory	Bereitstellung	Bereitstellung	Bereitstellung	Bereitstellung
StartDate	2016	2016	2016	2016
EndDate	2016	2016	2016	2016
DataValidForEntirePeriod	1	1	1	1
OtherPeriodText	Time of most relevant publications and statistics. Other generic data, e.g. for infrastructure are based on older publications.	Time of most relevant publications and statistics. Other generic data, e.g. for infrastructure are based on older publications.	Time of most relevant publications and statistics. Other generic data, e.g. for infrastructure are based on older publications.	Time of most relevant publications and statistics. Other generic data, e.g. for infrastructure are based on older publications.
Text	Data valid for MX.	Data valid for MX.	Data valid for MX.	Data valid for MX.
Text	75 % offshore and 25 % onshore production	75 % offshore and 25 % onshore production	75 % offshore and 25 % onshore production	75 % offshore and 25 % onshore production
Percent	100	100	100	100
ProductionVolume	Onshore: 30 Megatons crude oil and 10 billion Nm3 natural gas per year in 2016	Offshore: 90 Megatons crude oil per year in 2016	Onshore: 30 Megatons crude oil per year in 2016	Offshore: 30 billion Nm3 natural gas per year in 2016
SamplingProcedure	Statistics and use of generic data	Statistics and use of generic data	Statistics and use of generic data	Statistics and use of generic data for NG.
Extrapolations	A part of the data has been estimated with generic assumptions for onshore production.	A part of the data has been estimated with generic assumptions for offshore production.	A part of the data has been estimated with generic assumptions for onshore production.	A part of the data has been estimated with generic assumptions for offshore production.
UncertaintyAdjustments	none	none	none	none

Meta information for the investigated life cycle inventories, part7

Name	natural gas, at production onshore	crude oil, at production	natural gas, at production	combined gas and oil production
Location	MX	MX	MX	SA
InfrastructureProcess	0	0	0	0
Unit	Nm3	kg	Nm3	a
IncludedProcesses	Production of natural gas including energy use, infrastructure and emissions.	Production of crude oil including energy use, infrastructure and emissions.	Production of natural gas including energy use, infrastructure and emissions.	Production of oil and gas including energy use, infrastructure and emissions.
GeneralComment	The onshore oil production delivers the product natural gas. The values are derived from a multioutput-process "combined onshore gas and oil production" by allocation based on heating values for crude oil and natural gas	Offshore and Onshore production	Offshore and Onshore production	The multioutput-process 'combined offshore gas and oil production' delivers the co-products crude oil and natural gas. Allocation for co-products is based on heating value.
InfrastructureIncluded	1	1	1	1
Category	natural gas	oil	natural gas	oil
SubCategory	production	production	production	production
LocalCategory	Erdgas	Erdöl	Erdgas	Erdöl
LocalSubCategory	Bereitstellung	Bereitstellung	Bereitstellung	Bereitstellung
StartDate	2016	2016	2016	2016
EndDate	2016	2016	2016	2016
DataValidForEntirePeriod	1	1	1	1
OtherPeriodText	Time of most relevant publications and statistics. Other generic data, e.g. for infrastructure are based on older publications.	Time of most relevant publications and statistics. Other generic data, e.g. for infrastructure are based on older publications.	Time of most relevant publications and statistics. Other generic data, e.g. for infrastructure are based on older publications.	Time of most relevant publications and statistics. Other generic data, e.g. for infrastructure are based on older publications.
Text	Data valid for MX.	Data valid for MX.	Data valid for MX.	Data valid for SA.
Text	75 % offshore and 25 % onshore production	75 % offshore and 25 % onshore production	75 % offshore and 25 % onshore production	22 % offshore and 78 % onshore production
Percent	100	100	100	100
ProductionVolume	Onshore: 10 billion Nm3 natural gas per year in 2016	On- and offshore: 120 Megatons crude oil per year in 2016	On- and offshore: 40 billion Nm3 natural gas per year in 2016	On- and offshore: 598 Megatons crude oil and 90 billion Nm3 natural gas per year in 2016
SamplingProcedure	Statistics and use of generic data for NG.	Statistics and use of generic data	Statistics and use of generic data	Statistics and use of generic data
Extrapolations	A part of the data has been estimated with generic assumptions for onshore production.	A part of the data has been estimated with generic assumptions for on- and offshore production.	A part of the data has been estimated with generic assumptions for on- and offshore production.	A part of the data has been estimated with generic assumptions for on- and offshore production.
UncertaintyAdjustments	none	none	none	none

Meta information for the investigated life cycle inventories, part8

Name	combined gas and oil production offshore	combined gas and oil production onshore	crude oil, at production offshore	crude oil, at production onshore
Location	SA	SA	SA	SA
InfrastructureProcess	0	0	0	0
Unit	a	a	kg	kg
IncludedProcesses	Production of oil and gas including energy use, infrastructure and emissions.	Production of oil and gas including energy use, infrastructure and emissions.	Production of crude oil including energy use, infrastructure and emissions.	Production of crude oil including energy use, infrastructure and emissions.
GeneralComment	The multioutput-process 'combined offshore gas and oil production' delivers the co-products crude oil and natural gas. Allocation for co-products is based on heating value.	The multioutput-process 'combined offshore gas and oil production' delivers the co-products crude oil and natural gas. Allocation for co-products is based on heating value.	The offshore oil production delivers the product crude oil. The values are derived from a multioutput-process "combined offshore gas and oil production" by allocation based on heating values for crude oil and natural gas	The onshore oil production delivers the product crude oil. The values are derived from a multioutput-process "combined onshore gas and oil production" by allocation based on heating values for crude oil and natural gas
InfrastructureIncluded	1	1	1	1
Category	oil	oil	oil	oil
SubCategory	production	production	production	production
LocalCategory	Erdöl	Erdöl	Erdöl	Erdöl
LocalSubCategory	Bereitstellung	Bereitstellung	Bereitstellung	Bereitstellung
StartDate	2016	2016	2016	2016
EndDate	2016	2016	2016	2016
DataValidForEntirePeriod	1	1	1	1
OtherPeriodText	Time of most relevant publications and statistics. Other generic data, e.g. for infrastructure are based on older publications.	Time of most relevant publications and statistics. Other generic data, e.g. for infrastructure are based on older publications.	Time of most relevant publications and statistics. Other generic data, e.g. for infrastructure are based on older publications.	Time of most relevant publications and statistics. Other generic data, e.g. for infrastructure are based on older publications.
Text	Data valid for SA.	Data valid for SA.	Data valid for SA.	Data valid for SA.
Text	22 % offshore and 78 % onshore production	22 % offshore and 78 % onshore production	22 % offshore and 78 % onshore production	22 % offshore and 78 % onshore production
Percent	100	100	100	100
ProductionVolume	Offshore: 132 Megatons crude oil and 20 billion Nm3 natural gas per year in 2016	Onshore: 466 Megatons crude oil and 70 billion Nm3 natural gas per year in 2016	Offshore: 132 Megatons crude oil per year in 2016	Onshore: 466 Megatons crude oil per year in 2016
SamplingProcedure	Statistics and use of generic data	Statistics and use of generic data	Statistics and use of generic data	Statistics and use of generic data
Extrapolations	A part of the data has been estimated with generic assumptions for offshore production.	A part of the data has been estimated with generic assumptions for onshore production.	A part of the data has been estimated with generic assumptions for offshore production.	A part of the data has been estimated with generic assumptions for onshore production.
UncertaintyAdjustments	none	none	none	none

Meta information for the investigated life cycle inventories, part9

Name	natural gas, at production offshore	natural gas, at production onshore	crude oil, at production	natural gas, at production
Location	SA	SA	SA	SA
InfrastructureProcess	0	0	0	0
Unit	Nm3	Nm3	kg	Nm3
IncludedProcesses	Production of natural gas including energy use, infrastructure and emissions.	Production of natural gas including energy use, infrastructure and emissions.	Production of crude oil including energy use, infrastructure and emissions.	Production of natural gas including energy use, infrastructure and emissions.
GeneralComment	The offshore natural gas production delivers the product natural gas. The values are derived from a multioutput-process "combined offshore gas and oil production" by allocation based on heating values for crude oil and natural gas	The onshore oil production delivers the product natural gas. The values are derived from a multioutput-process "combined onshore gas and oil production" by allocation based on heating values for crude oil and natural gas	Offshore and Onshore production	Offshore and Onshore production
InfrastructureIncluded	1	1	1	1
Category	oil	oil	oil	natural gas
SubCategory	production	production	production	production
LocalCategory	Erdöl	Erdöl	Erdöl	Erdgas
LocalSubCategory	Bereitstellung	Bereitstellung	Bereitstellung	Bereitstellung
StartDate	2016	2016	2016	2016
EndDate	2016	2016	2016	2016
DataValidForEntirePeriod	1	1	1	1
OtherPeriodText	Time of most relevant publications and statistics. Other generic data, e.g. for infrastructure are based on older publications.	Time of most relevant publications and statistics. Other generic data, e.g. for infrastructure are based on older publications.	Time of most relevant publications and statistics. Other generic data, e.g. for infrastructure are based on older publications.	Time of most relevant publications and statistics. Other generic data, e.g. for infrastructure are based on older publications.
Text	Data valid for SA.	Data valid for SA.	Data valid for SA.	Data valid for SA.
Text	22 % offshore and 78 % onshore production	22 % offshore and 78 % onshore production	22 % offshore and 78 % onshore production	22 % offshore and 78 % onshore production
Percent	100	100	100	100
ProductionVolume	Offshore: 20 billion Nm3 natural gas per year in 2016	Onshore: 70 billion Nm3 natural gas per year in 2016	On- and offshore: 598 Megatons crude oil per year in 2016	On- and offshore: 90 billion Nm3 natural gas per year in 2016
SamplingProcedure	Statistics and use of generic data	Statistics and use of generic data	Statistics and use of generic data	Statistics and use of generic data
Extrapolations	A part of the data has been estimated with generic assumptions for offshore production.	A part of the data has been estimated with generic assumptions for onshore production.	A part of the data has been estimated with generic assumptions for on- and offshore production.	A part of the data has been estimated with generic assumptions for on- and offshore production.
UncertaintyAdjustments	none	none	none	none

Meta information for the investigated life cycle inventories, part10

Name	combined gas and oil production	combined gas and oil production offshore	combined gas and oil production onshore	crude oil, at production offshore
Location	US	US	US	US
InfrastructureProcess	0	0	0	0
Unit	a	a	a	kg
IncludedProcesses	Production of oil and gas including energy use, infrastructure and emissions.	Production of oil and gas including energy use, infrastructure and emissions.	Production of oil and gas including energy use, infrastructure and emissions.	Production of crude oil including energy use, infrastructure and emissions.
GeneralComment	The multioutput-process 'combined offshore gas and oil production' delivers the co-products crude oil and natural gas. Allocation for co-products is based on heating value.	The multioutput-process 'combined offshore gas and oil production' delivers the co-products crude oil and natural gas. Allocation for co-products is based on heating value.	The multioutput-process 'combined offshore gas and oil production' delivers the co-products crude oil and natural gas. Allocation for co-products is based on heating value.	The offshore oil production delivers the product crude oil. The values are derived from a multioutput-process "combined offshore gas and oil production" by allocation based on heating values for crude oil and natural gas
InfrastructureIncluded	1	1	1	1
Category	oil	oil	oil	oil
SubCategory	production	production	production	production
LocalCategory	Erdöl	Erdöl	Erdöl	Erdöl
LocalSubCategory	Bereitstellung	Bereitstellung	Bereitstellung	Bereitstellung
StartDate	2016	2016	2016	2016
EndDate	2016	2016	2016	2016
DataValidForEntirePeriod	1	1	1	1
OtherPeriodText	Time of most relevant publications and statistics. Other generic data, e.g. for infrastructure are based on older publications.	Time of most relevant publications and statistics. Other generic data, e.g. for infrastructure are based on older publications.	Time of most relevant publications and statistics. Other generic data, e.g. for infrastructure are based on older publications.	Time of most relevant publications and statistics. Other generic data, e.g. for infrastructure are based on older publications.
Text	Data valid for US.	Data valid for US.	Data valid for US.	Data valid for US.
Text	18 % offshore and 82 % onshore production	18 % offshore and 82 % onshore production	18 % offshore and 82 % onshore production	18 % offshore and 82 % onshore production
Percent	100	100	100	100
ProductionVolume	On- and offshore: 556 Megatons crude oil and 750 billion Nm3 natural gas per year in 2016	Offshore: 102 Megatons crude oil and 138 billion Nm3 natural gas per year in 2016	Onshore: 454 Megatons crude oil and 612 billion Nm3 natural gas per year in 2016	Offshore: 102 Megatons crude oil per year in 2016
SamplingProcedure	Statistics and use of generic data	Statistics and use of generic data	Statistics and use of generic data	Statistics and use of generic data
Extrapolations	A part of the data has been estimated with generic assumptions for on- and offshore production.	A part of the data has been estimated with generic assumptions for offshore production.	A part of the data has been estimated with generic assumptions for onshore production.	A part of the data has been estimated with generic assumptions for offshore production.
UncertaintyAdjustments	none	none	none	none

Meta information for the investigated life cycle inventories, part11

Name	crude oil, at production, onshore	natural gas, at production offshore	natural gas, at production onshore	crude oil, at production	natural gas, at production
Location	US	US	US	US	US
InfrastructureProcess	0	0	0	0	0
Unit	kg	Nm3	Nm3	kg	Nm3
IncludedProcesses	Production of crude oil including energy use, infrastructure and emissions.	Production of natural gas including energy use, infrastructure and emissions.	Production of natural gas including energy use, infrastructure and emissions.	Production of crude oil including energy use, infrastructure and emissions.	Production of natural gas including energy use, infrastructure and emissions.
GeneralComment	The onshore oil production delivers the product crude oil. The values are derived from a multioutput-process "combined onshore gas and oil production" by allocation based on heating values for crude oil and natural gas	The offshore natural gas production delivers the product natural gas. The values are derived from a multioutput-process "combined offshore gas and oil production" by allocation based on heating values for crude oil and natural gas	The onshore oil production delivers the product natural gas. The values are derived from a multioutput-process "combined onshore gas and oil production" by allocation based on heating values for crude oil and natural gas	Offshore and Onshore production	Offshore and Onshore production
InfrastructureIncluded	1	1	1	1	1
Category	oil	natural gas	natural gas	oil	natural gas
SubCategory	production	production	production	production	production
LocalCategory	Erdöl	Erdgas	Erdgas	Erdöl	Erdgas
LocalSubCategory	Bereitstellung	Bereitstellung	Bereitstellung	Bereitstellung	Bereitstellung
StartDate	2016	2016	2016	2016	2016
EndDate	2016	2016	2016	2016	2016
DataValidForEntirePeriod	1	1	1	1	1
OtherPeriodText	Time of most relevant publications and statistics. Other generic data, e.g. for infrastructure are based on older publications.	Time of most relevant publications and statistics. Other generic data, e.g. for infrastructure are based on older publications.	Time of most relevant publications and statistics. Other generic data, e.g. for infrastructure are based on older publications.	Time of most relevant publications and statistics. Other generic data, e.g. for infrastructure are based on older publications.	Time of most relevant publications and statistics. Other generic data, e.g. for infrastructure are based on older publications.
Text	Data valid for US.	Data valid for US.	Data valid for US.	Data valid for US.	Data valid for US.
Text	18 % offshore and 82 % onshore production	18 % offshore and 82 % onshore production	18 % offshore and 82 % onshore production	18 % offshore and 82 % onshore production	18 % offshore and 82 % onshore production
Percent	100	100	100	100	100
ProductionVolume	Onshore: 454 Megatons crude oil per year in 2016	Offshore: 138 billion Nm3 natural gas per year in 2016	Onshore: 612 billion Nm3 natural gas per year in 2016	On- and offshore: 556 Megatons crude oil per year in 2016	On- and offshore: 750 billion Nm3 natural gas per year in 2016
SamplingProcedure	Statistics and use of generic data	Statistics and use of generic data	Statistics and use of generic data	Statistics and use of generic data	Statistics and use of generic data
Extrapolations	A part of the data has been estimated with generic assumptions for onshore production.	A part of the data has been estimated with generic assumptions for offshore production.	A part of the data has been estimated with generic assumptions for onshore production.	A part of the data has been estimated with generic assumptions for on- and offshore production.	A part of the data has been estimated with generic assumptions for on- and offshore production.
UncertaintyAdjustments	none	none	none	none	none

Tab. 12.2 Life Cycle Inventory of Natural Gas and Crude Oil Production, onshore, in Russia in 2016, part1

	Name	Location	Category	SubCategory	InfrastructureProcess	Unit	*crude oil, at production onshore*	UncertaintyType	StandardDeviation95%	GeneralComment	*crude oil, at production onshore*	*crude oil, at production onshore*
	Location						*RU*				*RU*	*RU*
	InfrastructureProcess						*0*				*2016*	*2007*
	Unit						*kg*				*kg*	*kg*
product	crude oil, at production onshore	RU	-	-	0	kg	1.00E+0				5.47E+11	1.00E+0
resource, in ground	Gas, natural/m3	-	resour	in ground	-	Nm3	0	1	1.25	(3,3,1,1,3,na); considered in venting	-	8.00E-5
	Oil, crude	-	resour	in ground	-	kg	1.00E+0	1	1.23	(2,3,1,3,3,na); including losses due to oil spills	1.00E+0	1.02E+0
water resource	Water, unspecified natural origin, RU	-	resour	in water	-	m3	1.66E-5	1	1.26	(2,3,3,1,3,na); IOGP 2016	1.66E-5	1.36E-3
	Water, fossil	-	resour	in water	-	m3	1.35E-3	1	1.26	(2,3,3,1,3,na); IOGP 2016	1.35E-3	1.36E-3
water emission	Water, RU	-	water	river	-	m3	1.37E-3	1	1.59	(2,3,3,1,3,na); IOGP 2016	1.37E-3	1.36E-3
	Water, RU	-	water	fossil-	-	m3	0	1	1.59	(2,3,3,1,3,na); IOGP 2016	-	1.36E-3
	discharge, produced water, onshore	GLO	-	-	0	kg	1.37E+0	1	1.58	(2,3,5,3,3,na); Targulian & Hirsch 2000	1.37E+0	1.37E+0
technosphere	chemicals inorganic, at plant	GLO	-	-	0	kg	5.53E-4	1	1.60	(3,4,5,3,3,na); Generic value from Jungbluth 2007 calculated for 15% instead of 3% enhanced oil recovery.	5.53E-4	1.20E-4
	chemicals organic, at plant	GLO	-	-	0	kg	4.22E-4	1	1.60	(3,4,5,3,3,na); Generic value from Jungbluth 2007 calculated for 15% instead of 3% enhanced oil recovery.	4.22E-4	9.00E-5
	transport, lorry >16t, fleet average	RER	-	-	0	tkm	9.75E-5	1	2.34	(3,5,5,3,3,na); Standard distance 100km	9.75E-5	3.10E-5
	transport, freight, rail	RER	-	-	0	tkm	5.85E-4	1	2.34	(3,5,5,3,3,na); Standard distance 600km	5.85E-4	1.26E-4
	well for exploration and production, onshore	GLO	-	-	1	m	2.55E-5	1	3.07	(2,3,3,1,3,na); Data from Rosneft and Lukoil	2.55E-5	2.55E-5
	pipeline, crude oil, onshore	RER	-	-	1	km	3.29E-8	1	3.28	(2,3,5,1,3,na); Lodewijkx et al. 2001, p28, 20tsd km pipeline, 62 Mio. tonnes	3.29E-8	3.29E-8
	production plant crude oil, onshore	GLO	-	-	1	unit	5.13E-9	1	3.28	(2,3,5,1,3,na); Lodewijkx et al. 2001	5.13E-9	5.13E-9
energy	diesel, burned in diesel-electric generating set	GLO	-	-	0	MJ	1.44E-2	1	2.06	(2,3,2,1,3,na); Mean IOGP & Safronov	1.44E-2	4.22E-1
	electricity, low voltage, at grid	RU	-	-	0	kWh	6.03E-2	1	2.06	(2,3,2,1,3,na); Mean IOGP & Safronov	6.03E-2	4.50E-3
	heavy fuel oil, burned in industrial furnace 1MW, non-modulating	RER	-	-	0	MJ	4.33E-2	1	2.06	(2,3,2,1,3,na); Mean IOGP & Safronov	4.33E-2	2.40E-1
	sour gas, burned in gas turbine, production	NO	-	-	0	MJ	8.01E-1	1	2.06	(2,3,2,1,3,na); Mean IOGP & Safronov	8.01E-1	9.04E-2
	natural gas, vented	GLO	-	-	0	Nm3	1.46E-2	1	10.11	(2,3,1,5,3,na); Generic value according to IEA 2017	1.46E-2	4.50E-3
	natural gas, sour, burned in production flare	GLO	-	-	0	Nm3	2.24E-2	1	1.22	(1,1,1,1,3,na); World Bank 2017	2.24E-2	2.28E+0
waste	low active radioactive waste	CH	-	-	0	m3	2.00E-7	1	1.58	(2,3,5,3,3,na); Generic assumption	2.00E-7	2.00E-7
	disposal, municipal solid waste, 22.9% water, to municipal incineration	CH	-	-	0	kg	1.00E-4	1	1.32	(2,3,4,3,3,na); Jungbluth 2007	1.00E-4	1.00E-4
Source											This study	Jungbluth 2007

Life Cycle Inventory of Natural Gas and Crude Oil Production, onshore, in Russia 2016, part2

	Name	Location	Category	SubCategory	InfrastructureProcess	Unit	crude oil, at production onshore	UncertaintyType	StandardDeviation95%	GeneralComment	crude oil, at production onshore	crude oil, at production onshore
	Location						RU				RU	RU
	InfrastructureProcess						0				2016	2007
	Unit						kg				kg	kg
emission water, river	Oils, unspecified	-	water	river	-	kg	2.05E-7	1	1.84	(2,3,5,1,3,na); Mean IOGP 2014 & 2015	2.05E-7	2.00E-2
	BOD5, Biological Oxygen Demand	-	water	river	-	kg	6.46E-7	1	1.85	(3,3,5,1,3,na); Extrapolation for sum parameter	6.46E-7	6.30E-2
	COD, Chemical Oxygen Demand	-	water	river	-	kg	6.46E-7	1	1.85	(3,3,5,1,3,na); Extrapolation for sum parameter	6.46E-7	6.30E-2
	DOC, Dissolved Organic Carbon	-	water	river	-	kg	1.77E-7	1	1.85	(3,3,5,1,3,na); Extrapolation for sum parameter	1.77E-7	1.73E-2
	TOC, Total Organic Carbon	-	water	river	-	kg	1.77E-7	1	1.85	(3,3,5,1,3,na); Extrapolation for sum parameter	1.77E-7	1.73E-2
	AOX, Adsorbable Organic Halogen as Cl	-	water	river	-	kg	2.11E-12	1	1.85	(3,3,5,1,3,na); Extrapolation for sum parameter	2.11E-12	2.06E-7
	Nitrogen	-	water	river	-	kg	1.58E-10	1	1.85	(3,3,5,1,3,na); Extrapolation for sum parameter	1.58E-10	1.55E-5
	Sulfur	-	water	river	-	kg	5.49E-10	1	1.85	(3,3,5,1,3,na); Extrapolation for sum parameter	5.49E-10	5.36E-5
emission to soil	Oils, unspecified	-	soil	unspecified	-	kg	4.56E-6	1	1.85	(3,3,5,1,3,na); IOGP 2016	4.56E-6	2.50E-2
emission air, low population density	Methane, bromotrifluoro-, Halon 1301	-	air	low population density	-	kg	0	1	1.64	(3,5,1,3,3,na); only offshore		5.82E-8
	Methane, trifluoro-, HFC-23	-	air	low population density	-	kg	0	1	1.64	(3,5,1,3,3,na); only offshore		
	Methane, fossil	-	air	low population density	-	kg	0	1	1.86	(3,4,5,3,3,na); considered in venting	-	2.50E-5
	NMVOC, non-methane volatile organic compounds, unspecified origin	-	air	low population density	-	kg	0	1	1.86	(3,4,5,3,3,na); Jungbluth 2007	-	7.50E-5
land use	Transformation, from forest, unspecified	-	resour	land	-	m2	0	1	2.30	(3,3,5,3,3,na); included in production well and productin plant	-	1.71E-3
	Transformation, to dump site	-	resour	land	-	m2	0	1	2.30	(3,3,5,3,3,na); included in production well and productin plant	-	1.71E-3
Source											This study	Jungbluth 2007

Tab. 12.3 Life Cycle Inventory of Natural Gas and Crude Oil Production, on- and offshore, in Nigeria 2016, part 1

	Name	Location	Category	SubCategory	InfrastructureProcess	Unit	combined gas and oil production	crude oil, at production	natural gas, at production	UncertaintyType	StandardDeviation95%	GeneralComment	Total	crude oil, at production onshore	combined gas and oil production
	Location						NG	NG	NG				NG	NG	NG
	InfrastructureProcess						0	0	0				2016	2000	2000
	Unit						a	kg	Nm3				kg OE	kg	a
product	crude oil, at production	NG	-	-	0	kg	1.03E+11	100%	0%				1.03E+11		1.07E+11
	natural gas, at production	NG	-	-	0	Nm3	4.00E+10	0%	100%				4.00E+10		1.35E+10
resource, in ground	Oil, crude	-	resource	in ground	-	kg	1.03E+11	100%	0%	1	1.24	(3,3,1,1,3,na); including losses due to oil spills	1.03E+11		
	Gas, natural/m3	-	resource	in ground	-	Nm3	4.00E+10	0%	100%	1	1.24	(3,3,1,1,3,na); Enerdata 2016	4.00E+10		1.35E+10
	Gas, natural/m3	-	resource	in ground	-	Nm3	0	75%	25%	1	1.25	(2,3,3,3,3,na); considered in venting	-		
water resource	Water, unspecified natural origin, NG	-	resource	in water	-	m3	6.87E+6	100%	0%	1	1.23	(2,3,2,1,3,na); IOGP 2016	5.03E-5		
	Water, fossil	-	resource	in water	-	m3	5.12E+7	100%	0%	1	1.23	(2,3,2,1,3,na); IOGP 2016	3.75E-4		
water emission	Water, NG	-	water	river	-	m3	5.81E+7	100%	0%	1	1.57	(2,3,2,1,3,na); IOGP 2016	4.25E-4		
	Water, NG	-	water	fossil-	-	m3	0	100%	0%	1	1.57	(2,3,2,1,3,na); IOGP 2016	-		
	discharge, produced water, onshore	GLO	-	-	0	kg	4.38E+10	100%	0%	1	1.60	(3,4,5,3,3,na); Shell 2001	4.25E-1	4.25E-01	4.54E+10
technosphere	chemicals inorganic, at plant	GLO	-	-	0	kg	7.56E+7	75%	25%	1	1.60	(3,4,5,3,3,na); Generic value from Jungbluth 2007 calculated for 15% instead of 3% enhanced oil recovery.	5.53E-4	1.20E-04	1.41E+05
	chemicals organic, at plant	GLO	-	-	0	kg	5.76E+7	75%	25%	1	1.60	(3,4,5,3,3,na); Generic value from Jungbluth 2007 calculated for 15% instead of 3% enhanced oil recovery.	4.22E-4	9.00E-05	1.06E+05
	transport, lorry >16t, fleet average	RER	-	-	0	tkm	1.83E+7	75%	25%	1	2.34	(3,5,5,3,3,na); Standard distance 100km	1.34E-04	5.75E-05	4.31E+06
	transport, freight, rail	RER	-	-	0	tkm	7.99E+7	75%	25%	1	2.34	(3,5,5,3,3,na); Standard distance 600km	5.85E-04	1.26E-04	1.48E+05
	well for exploration and production, onshore	GLO	-	-	1	m	5.61E+5	75%	25%	1	3.01	(1,2,3,1,1,na); Jungbluth 2007	4.10E-6	4.10E-06	4.82E+05
	production plant crude oil, onshore	GLO	-	-	1	unit	1.70E+1	75%	25%	1	3.23	(1,3,5,1,1,na); Questionnaire	1.25E-10	1.25E-10	1.47E+01
	platform, crude oil, offshore	OCE	-	-	1	unit	5.68E+0	75%	25%	1	3.23	(1,3,5,1,1,na); Questionnaire	4.16E-11	4.18E-11	4.91E+00
	pipeline, crude oil, onshore	RER	-	-	1	km	9.50E+2	75%	25%	1	3.23	(1,2,5,1,1,na); Jungbluth 2007	6.96E-9	6.99E-09	8.22E+02
energy	diesel, burned in diesel-electric generating set	GLO	-	-	0	MJ	0	75%	25%	1	2.06	(2,3,2,1,3,na); Calculation based on literature	-		
	electricity, low voltage, production GLO, at grid	GLO	-	-	0	kWh	1.70E+9	75%	25%	1	2.06	(2,3,2,1,3,na); IOGP 2016	1.24E-2		
Source													This study	Jungbluth 2007	Total 2000

Life Cycle Inventory of Natural Gas and Crude Oil Production, on- and offshore, in Nigeria 2016, part 2

	Name	Location	Category	SubCategory	InfrastructureProcess	Unit	combined gas and oil production	crude oil, at production	natural gas, at production	UncertaintyType	StandardDeviation95%	GeneralComment	Total	crude oil, at production onshore	combined gas and oil production
	Location						NG	NG	NG				NG	NG	NG
	InfrastructureProcess						0	0	0				2016	2000	2000
	Unit						a	kg	Nm3				kg OE	kg	a
	heavy fuel oil, burned in industrial furnace 1MW, non-modulating	RER	-	-	0	MJ	0	75%	25%	1	2.06	(2,3,2,1,3,na); IOGP 2016	-		
	sweet gas, burned in gas turbine, production	NO	-	-	0	MJ	1.94E+11	75%	25%	1	2.06	(2,3,2,1,3,na); IOGP 2016	1.42E+0		1.61E+11
	natural gas, vented	GLO	-	-	0	Nm3	1.99E+9	75%	25%	1	10.10	(2,3,1,5,3,na); Generic value according to IEA 2017	1.46E-2	2.21E-02	2.60E+09
	natural gas, sweet, burned in production flare	GLO	-	-	0	Nm3	7.32E+9	75%	25%	1	1.22	(2,3,1,1,3,na); World Bank 2017	5.35E-2	4.66E+00	5.48E+11
waste	low active radioactive waste	CH	-	-	0	m3	2.73E+2	75%	25%	1	3.30	(3,4,5,3,3,na); Jungbluth 2007	2.00E-9	2.00E-09	2.35E+02
	disposal, municipal solid waste, 22.9% water, to municipal incineration	CH	-	-	0	kg	4.96E+7	75%	25%	1	1.31	(2,3,4,1,3,na); Shell 2001	3.63E-4	3.65E-04	4.29E+07
emission air, low population density	Methane, bromotrifluoro-, Halon 1301	-	air	low population	-	kg	3.98E+2	75%	25%	1	1.50	(1,2,1,1,1,na); assuming 20% halon compared to Jungbluth 2007	2.91E-9	5.85E-08	6.88E+03
emission air, low population density	Methane, trifluoro-, HFC-23	-	air	low population	-	kg	1.59E+3	75%	25%	1	1.59	(3,4,1,3,3,na); assuming 80% HFC-23 compared to Jungbluth 2007	1.16E-8		6.88E+03
emission soil	Oils, unspecified	-	soil	unspecified	-	kg	4.78E+6	75%	25%	1	1.83	(2,3,5,1,3,na); IOGP 2016	3.50E-5	6.44E-05	7.56E+06
emission water, river	Oils, unspecified	-	water	river	-	kg	3.52E+5	75%	25%	1	1.83	(2,3,5,1,3,na); IOGP 2016	2.58E-6	6.44E-05	7.56E+06
	BOD5, Biological Oxygen Demand	-	water	river	-	kg	1.11E+6	75%	25%	1	1.84	(3,3,5,1,3,na); Extrapolation for sum parameter	8.13E-6	2.03E-04	2.38E+07
	COD, Chemical Oxygen Demand	-	water	river	-	kg	1.11E+6	75%	25%	1	1.84	(3,3,5,1,3,na); Extrapolation for sum parameter	8.13E-6	2.03E-04	2.38E+07
	DOC, Dissolved Organic Carbon	-	water	river	-	kg	3.05E+5	75%	25%	1	1.84	(3,3,5,1,3,na); Extrapolation for sum parameter	2.23E-6	5.57E-05	6.54E+06
	TOC, Total Organic Carbon	-	water	river	-	kg	3.05E+5	75%	25%	1	1.84	(3,3,5,1,3,na); Extrapolation for sum parameter	2.23E-6	5.57E-05	6.54E+06
	AOX, Adsorbable Organic Halogen as Cl	-	water	river	-	kg	3.63E+0	75%	25%	1	1.84	(3,3,5,1,3,na); Extrapolation for sum parameter	2.66E-11	6.63E-10	7.79E+01
	Nitrogen	-	water	river	-	kg	2.72E+2	75%	25%	1	1.84	(3,3,5,1,3,na); Extrapolation for sum parameter	1.99E-9	4.97E-08	5.84E+03
Source													This study	Jungbluth 2007	Total 2000

Life Cycle Inventory of Natural Gas and Crude Oil Production, on- and offshore, in Nigeria 2016, part 3

	Name	Location	Category	SubCategory	InfrastructureProcess	Unit	*combined gas and oil production*	*crude oil, at production*	*natural gas, at production*	UncertaintyType	StandardDeviation95%	GeneralComment	*Total*	crude oil, at production onshore	combined gas and oil production
	Location						*NG*	*NG*	*NG*				*NG*	NG	*NG*
	InfrastructureProcess						*0*	*0*	*0*				*2016*	2000	*2000*
	Unit						*a*	*kg*	*Nm3*				*kg OE*	kg	*a*
	Sulfur	-	water	river	-	kg	9.44E+2	75%	25%	1	1.84	(3,3,5,1,3,na); Extrapolation for sum parameter	6.91E-9	1.72E-07	2.03E+04
emission water, river	Oils, unspecified	-	water	ocean	-	kg	1.53E+6	75%	25%	1	1.83	(2,3,5,1,3,na); IOGP 2016 plus breakdown of 5 biggest, non-war-	1.12E-5	6.44E-05	7.56E+06
	BOD5, Biological Oxygen Demand	-	water	ocean	-	kg	4.81E+6	75%	25%	1	1.84	(3,3,5,1,3,na); Extrapolation for sum parameter	3.52E-5	2.03E-04	2.38E+07
	COD, Chemical Oxygen Demand	-	water	ocean	-	kg	4.81E+6	75%	25%	1	1.84	(3,3,5,1,3,na); Extrapolation for sum parameter	3.52E-5	2.03E-04	2.38E+07
	DOC, Dissolved Organic Carbon	-	water	ocean	-	kg	1.32E+6	75%	25%	1	1.84	(3,3,5,1,3,na); Extrapolation for sum parameter	9.67E-6	5.57E-05	6.54E+06
	TOC, Total Organic Carbon	-	water	ocean	-	kg	1.32E+6	75%	25%	1	1.84	(3,3,5,1,3,na); Extrapolation for sum parameter	9.67E-6	5.57E-05	6.54E+06
	AOX, Adsorbable Organic Halogen as Cl	-	water	ocean	-	kg	1.57E+1	75%	25%	1	1.84	(3,3,5,1,3,na); Extrapolation for sum parameter	1.15E-10	6.63E-10	7.79E+01
	Nitrogen	-	water	ocean	-	kg	1.18E+3	75%	25%	1	1.84	(3,3,5,1,3,na); Extrapolation for sum parameter	8.63E-9	4.97E-08	5.84E+03
	Sulfur	-	water	ocean	-	kg	4.09E+3	75%	25%	1	1.84	(3,3,5,1,3,na); Extrapolation for sum parameter	2.99E-8	1.72E-07	2.03E+04
land use	Transformation, from forest, unspecified	-	resource	land	-	m2	0	75%	25%	1	2.29	(3,3,5,3,3,na); included in production well and productin plant	-	1.71E-03	T
	Transformation, to dump site	-	resource	land	-	m2	0	75%	25%	1	2.29	(3,3,5,3,3,na); included in production well and productin plant	-	1.71E-03	
Source													This study	Jungbluth 2007	Total 2000

Tab. 12.4 Life Cycle Inventory of Crude Oil Production in Kazakhstan, onshore 2016, part1

	Name	Location	Category	SubCategory	InfrastructureProcess	Unit	crude oil, at production onshore	UncertaintyType	StandardDeviation95%	GeneralComment	crude oil, at production onshore	crude oil, at production onshore
	Location						KZ				KZ	KZ
	InfrastructureProcess						0				2016	2016
	Unit						kg				kg	kg
product	crude oil, at production onshore	KZ	-	-	0	kg	1.00E+0				7.90E+10	1.00E+0
resource, in ground	Gas, natural/m3	-	resour	in ground	-	Nm3	0	1	1.25	(3,3,1,1,3,na); considered in venting	-	8.00E-5
	Oil, crude	-	resour	in ground	-	kg	1.00E+0	1	1.23	(2,3,1,3,3,na); including losses due to oil spills	1.00E+0	1.02E+0
water resource	Water, unspecified natural origin, KZ	-	resour	in water	-	m3	1.66E-5	1	1.26	(2,3,3,1,3,na); IOGP 2016	1.66E-5	1.36E-3
	Water, fossil	-	resour	in water	-	m3	1.35E-3	1	1.26	(2,3,3,1,3,na); IOGP 2016	1.35E-3	1.36E-3
water emission	Water, KZ	-	water	river	-	m3	1.37E-3	1	1.59	(2,3,3,1,3,na); IOGP 2016	1.37E-3	1.36E-3
3	Water, KZ	-	water	fossil-	-	m3	0	1	1.59	(2,3,3,1,3,na); IOGP 2016	-	1.36E-3
	discharge, produced water, onshore	GLO	-	-	0	kg	1.37E+0	1	1.57	(4,3,5,1,1,na); Targulian & Hirsch 2000	1.37E+0	1.37E+0
technosphere	chemicals inorganic, at plant	GLO	-	-	0	kg	5.53E-4	1	1.60	(3,4,5,3,3,na); Generic value from Jungbluth 2007 calculated for 15% instead of 3% enhanced oil recovery.	5.53E-4	1.20E-4
	chemicals organic, at plant	GLO	-	-	0	kg	4.22E-4	1	1.60	(3,4,5,3,3,na); Generic value from Jungbluth 2007 calculated for 15% instead of 3% enhanced oil recovery.	4.22E-4	9.00E-5
	transport, lorry >16t, fleet average	RER	-	-	0	tkm	9.75E-5	1	2.34	(3,5,5,3,3,na); Standard distance 100km	9.75E-5	3.10E-5
	transport, freight, rail	RER	-	-	0	tkm	5.85E-4	1	2.34	(3,5,5,3,3,na); Standard distance 600km	5.85E-4	1.26E-4
	well for exploration and production, onshore	GLO	-	-	1	m	2.55E-5	1	3.03	(3,1,3,1,1,na); Data from Rosneft and Lukoil	2.55E-5	2.55E-5
	pipeline, crude oil, onshore	RER	-	-	1	km	1.99E-8	1	3.28	(4,3,5,1,1,na); Average of literature	1.99E-8	3.29E-8
	production plant crude oil, onshore	GLO	-	-	1	unit	5.13E-9	1	3.28	(4,3,5,1,1,na); Lodewijkx et al. 2001	5.13E-9	5.13E-9
energy	diesel, burned in diesel-electric generating set	GLO	-	-	0	MJ	0	1	2.09	(3,4,2,5,3,na); IOGP 2016	-	4.22E-1
4-005	electricity, low voltage, at grid	RU	-	-	0	kWh	1.70E-2	1	2.09	(3,4,2,5,3,na); IOGP 2016	1.70E-2	
	heavy fuel oil, burned in industrial furnace 1MW, non-modulating	RER	-	-	0	MJ	0	1	2.06	(4,3,2,1,1,na); IOGP 2016	-	2.40E-1
	sour gas, burned in gas turbine, production	NO	-	-	0	MJ	1.19E+0	1	2.09	(3,4,2,5,3,na); IOGP 2016	1.19E+0	9.04E-2
	natural gas, vented	GLO	-	-	0	Nm3	1.46E-2	1	10.14	(3,4,1,5,3,na); Generic value according to IEA 2017	1.46E-2	2.82E-3
Source											This study	Stolz 2016

Life Cycle Inventory of Crude Oil Production in Kazakhstan, onshore 2016, part2

	Name	Location	Category	SubCategory	InfrastructureProcess	Unit	crude oil, at production onshore	UncertaintyType	StandardDeviation95%	GeneralComment	crude oil, at production onshore	crude oil, at production onshore
	Location						KZ				KZ	KZ
	InfrastructureProcess						0				2016	2016
	Unit						kg				kg	kg
product	crude oil, at production onshore	KZ	-	-	0	kg	1.00E+0				7.90E+10	1.00E+0
	natural gas, sour, burned in production flare	GLO	-	-	0	Nm3	2.44E-2	1	1.22	(4,3,1,1,1,na); World Bank 2017	2.44E-2	1.42E+0
waste	low active radioactive waste	CH	-	-	0	m3	2.00E-7	1	1.61	(3,4,5,5,3,na); Stolz & Frischknecht 2017	2.00E-7	2.00E-7
	disposal, municipal solid waste, 22.9% water, to municipal incineration	CH	-	-	0	kg	1.00E-4	1	1.37	(3,4,4,5,3,na); Jungbluth 2007	1.00E-4	1.00E-4
emission to soil	Oils, unspecified	-	soil	unspecified	-	kg	4.56E-6	1	1.83	(4,3,5,1,1,na); IOGP 2016	4.56E-6	2.00E-2
emission water, river	Oils, unspecified	-	water	river	-	kg	2.05E-7	1	1.83	(4,3,5,1,1,na); Mean IOGP 2014 & 2015	2.05E-7	2.00E-2
	BOD5, Biological Oxygen Demand	-	water	river	-	kg	0	1	1.83	(4,3,5,1,1,na); Extrapolation for sum parameter	-	6.30E-2
	COD, Chemical Oxygen Demand	-	water	river	-	kg	0	1	1.83	(4,3,5,1,1,na); Extrapolation for sum parameter	-	6.30E-2
	DOC, Dissolved Organic Carbon	-	water	river	-	kg	0	1	1.83	(4,3,5,1,1,na); Extrapolation for sum parameter	-	1.73E-2
	TOC, Total Organic Carbon	-	water	river	-	kg	0	1	1.83	(4,3,5,1,1,na); Extrapolation for sum parameter	-	1.73E-2
	AOX, Adsorbable Organic Halogen as Cl	-	water	river	-	kg	0	1	1.83	(4,3,5,1,1,na); Extrapolation for sum parameter	-	2.06E-7
	Nitrogen	-	water	river	-	kg	0	1	1.83	(4,3,5,1,1,na); Extrapolation for sum parameter	-	1.55E-5
	Sulfur	-	water	river	-	kg	0	1	1.83	(4,3,5,1,1,na); Extrapolation for sum parameter	-	5.36E-5
emission to soil	Oils, unspecified	-	soil	unspecified	-	kg	4.56E-6	1	1.57	(4,3,2,1,1,na); IOGP 2016	4.56E-6	2.50E-2
emission air, low population density	Methane, bromotrifluoro-, Halon 1301	-	air	low population density	-	kg	0	1	3.09	(3,4,1,5,3,na); only offshore	-	5.82E-8
	Methane, trifluoro-, HFC-23	-	air	low population density	-	kg	0	1	3.09	(3,4,1,5,3,na); only offshore	-	
	Methane, fossil	-	air	low population density	-	kg	0	1	3.30	(3,4,5,3,3,na); considered in venting	-	2.50E-5
	NMVOC, non-methane volatile organic compounds, unspecified origin	-	air	low population density	-	kg	0	1	3.30	(3,4,5,3,3,na); Generic value	-	7.50E-5
land use	Transformation, from forest, unspecified	-	resour	land	-	m2	0	1	2.28	(4,3,5,1,1,na); included in production well and productin plant	-	1.71E-3
	Transformation, to dump site	-	resour	land	-	m2	0	1	2.28	(4,3,5,1,1,na); included in production well and productin plant	-	1.71E-3
Source											This study	Stolz 2016

Tab. 12.5 Life Cycle Inventory of Crude Oil Production in Kazakhstan, offshore 2016, part1

	Name	Location	Category	SubCategory	InfrastructureProcess	Unit	*crude oil, at production offshore*	UncertaintyType	StandardDeviation95%	GeneralComment	*crude oil, at production offshore*	*crude oil, at production offshore*
	Location						*KZ*				*KZ*	*KZ*
	InfrastructureProcess						*0*				*2016*	*2016*
	Unit						*kg*				*kg*	*kg*
product	crude oil, at production offshore	KZ	-	-	0	kg	1.00E+0				7.90E+10	1.00E+0
resource, in ground	Gas, natural/m3	-	resour	in ground	-	Nm3	0	1	1.24	(3,3,1,1,3,na); considered in venting	-	4.61E-2
	Oil, crude	-	resour	in ground	-	kg	1.0007E+0	1	1.22	(2,3,1,3,3,na); including losses due to oil spills	1.001E+0	1.00E+0
water resource	Water, salt, ocean	-	resour	in water	-	m3	1.66E-5	1	1.22	(2,3,1,3,3,na); calculation	1.66E-5	1.00E+0
	Water, fossil	-	resour	in water	-	m3	1.18E-3	1	1.22	(2,3,1,3,3,na); Water in crude oil	1.18E-3	1.36E-3
water emission	Water, KZ	-	water	ocean	-	m3	1.20E-3	1	1.58	(2,3,3,1,3,na); calculation	1.20E-3	
8	Water, KZ	-	water	fossil-	-	m3	0	1	1.58	(2,3,3,1,3,na); calculation	-	
	discharge, produced water, offshore	OCE	-	-	0	kg	1.20E+0	1	1.50	(1,1,5,1,1,na); Stolz & Frischknecht 2017	1.20E+0	1.20E+0
technosphere	chemicals inorganic, at plant	GLO	-	-	0	kg	5.53E-4	1	1.60	(3,4,5,3,3,na); Generic value from Jungbluth 2007 calculated for 15% instead of 3% enhanced oil recovery.	5.53E-4	5.67E-5
	chemicals organic, at plant	GLO	-	-	0	kg	4.22E-4	1	1.60	(3,4,5,3,3,na); Generic value from Jungbluth 2007 calculated for 15% instead of 3% enhanced oil recovery.	4.22E-4	5.03E-5
	transport, lorry >16t, fleet average	RER	-	-	0	tkm	9.75E-5	1	2.34	(3,5,5,3,3,na); Standard distance 100km	9.75E-5	1.09E-5
	transport, freight, rail	RER	-	-	0	tkm	5.85E-4	1	2.34	(3,5,5,3,3,na); Standard distance 600km	5.85E-4	6.42E-5
	well for exploration and production, offshore	OCE	-	-	1	m	4.81E-6	1	3.01	(1,1,3,1,1,na); Environmental report	4.81E-6	4.81E-6
	platform, crude oil, offshore	OCE	-	-	1	unit	3.36E-11	1	3.23	(1,1,5,1,1,na); Environmental report	3.36E-11	3.36E-11
	pipeline, crude oil, onshore	RER	-	-	1	km	3.41E-9	1	3.23	(1,1,5,1,1,na); Stolz & Frischknecht 2017	3.41E-9	3.41E-9
	production plant crude oil, onshore	GLO	-	-	1	unit	0	1	3.27	(4,3,5,1,1,na); Lodewijkx et al. 2001	-	
energy	diesel, burned in diesel-electric generating set	GLO	-	-	0	MJ	1.18E-1	1	2.09	(3,4,2,5,3,na); calculated from Stolz 2016, diesel at regional storage	1.18E-1	
	diesel, at regional storage	RER	-	-	0	kg	0	1	2.00	(1,1,2,1,1,na); Calculation based on literature	-	2.74E-3
	heavy fuel oil, at regional storage	RER	-	-	0	kg	0	1	2.00	(1,1,2,1,1,na); Environmental report	-	2.25E-3
	heavy fuel oil, burned in industrial furnace 1MW, non-modulating	RER	-	-	0	MJ	9.25E-2	1	2.05	(4,3,2,1,1,na); Calculation based on literature	9.25E-2	
Source											This study	Stolz 2016

Life Cycle Inventory of Crude Oil Production in Kazakhstan, offshore 2016, part2

	Name	Location	Category	SubCategory	InfrastructureProcess	Unit	crude oil, at production offshore	UncertaintyType	StandardDeviation95 %	GeneralComment	crude oil, at production offshore	crude oil, at production offshore
	Location						KZ				KZ	KZ
	InfrastructureProcess						0				2016	2016
	Unit						kg				kg	kg
	sour gas, burned in gas turbine, production	NO	-	-	0	MJ	9.80E-1	1	2.09	(3,4,2,5,3,na); Calculation based on literature	9.80E-1	
	natural gas, vented	GLO	-	-	0	Nm3	1.46E-2	1	10.13	(3,4,1,5,3,na); Generic value according to IEA 2017	1.46E-2	2.82E-3
	natural gas, sour, burned in production flare	GLO	-	-	0	Nm3	2.44E-2	1	1.07	(2,1,1,1,1,na); World Bank 2017	2.44E-2	1.42E+0
waste	low active radioactive waste	CH	-	-	0	m3	2.00E-7	1	1.50	(1,1,5,1,1,na); Stolz & Frischknecht 2017	2.00E-7	1.31E-7
	disposal, municipal solid waste, 22.9% water, to municipal incineration	CH	-	-	0	kg	1.00E-4	1	1.21	(1,1,4,1,1,na); Jungbluth 2007	1.00E-4	1.80E-6
emission water, ocean	Oils, unspecified	-	water	ocean	-	kg	6.78E-4	1	1.50	(1,1,2,1,1,na); Stolz & Frischknecht 2017 plus breakdown of 5 biggest, non-war-related oil spills (catastrophes) on oil platforms between 1900 and 2010	6.78E-4	6.41E-4
	BOD5, Biological Oxygen Demand	-	water	ocean	-	kg	1.53E-3	1	1.58	(3,3,2,1,3,na); Extrapolation for sum parameter	1.53E-3	2.02E-3
	COD, Chemical Oxygen Demand	-	water	ocean	-	kg	1.53E-3	1	1.58	(3,3,2,1,3,na); Extrapolation for sum parameter	1.53E-3	2.02E-3
	DOC, Dissolved Organic Carbon	-	water	ocean	-	kg	2.89E-4	1	1.58	(3,3,2,1,3,na); Extrapolation for sum parameter	2.89E-4	5.55E-4
	TOC, Total Organic Carbon	-	water	ocean	-	kg	2.89E-4	1	1.58	(3,3,2,1,3,na); Extrapolation for sum parameter	2.89E-4	5.55E-4
	AOX, Adsorbable Organic Halogen as Cl	-	water	ocean	-	kg	3.44E-9	1	1.58	(3,3,2,1,3,na); Extrapolation for sum parameter	3.44E-9	6.61E-9
	Nitrogen	-	water	ocean	-	kg	2.58E-7	1	1.58	(3,3,2,1,3,na); Extrapolation for sum parameter	2.58E-7	4.95E-7
	Sulfur	-	water	ocean	-	kg	8.94E-7	1	1.58	(3,3,2,1,3,na); Extrapolation for sum parameter	8.94E-7	1.72E-6
emission air, low population density	Methane, bromotrifluoro-, Halon 1301	-	air	low population density	-	kg	1.16E-8	1	1.59	(4,4,1,5,1,na); assuming 20% halon compared to Jungbluth 2007	1.16E-8	4.79E-10
emission air, low population density	Methane, trifluoro-, HFC-23	-	air	low population density	-	kg	4.66E-8	1	1.61	(3,4,1,5,3,na); assuming 80% HFC-23 compared to Jungbluth 2007	4.66E-8	
	Methane, fossil	-	air	low population density	-	kg	0	1	1.84	(3,3,5,1,3,na); considered in venting	-	2.59E-5
	NMVOC, non-methane volatile organic compounds, unspecified origin	-	air	low population density	-	kg	0	1	1.84	(3,3,5,1,3,na); Extrapolation from 1998	-	8.95E-4

Tab. 12.6 Life Cycle Inventory of Natural Gas and Crude Oil Production in Norway, offshore, 2016, part1

Explanations	Name	Location	Category	SubCategory	InfrastructureProcess	Unit	combined offshore gas and oil production	natural gas, at production offshore	crude oil, at production offshore	UncertaintyType	StandardDeviation95%	GeneralComment	Total	Total
	Location						NO	NO	NO				NO	NO
	InfrastructureProcess						0	0	0				2016	2010
	Unit						a	Nm3	kg				kg OE	a
product	crude oil, at production offshore	NO	-	-	0	kg	9.00E+10		100%				9.00E+10	
product	natural gas, at production offshore	NO	-	-	0	Nm3	1.20E+11	100%					1.20E+11	
Resources, in ground	Oil, crude	-	resource	in ground	-	kg	9.00E+10	0%	100%	1	1.00	(1,1,1,1,3,na); including losses due to oil spills	9.00E+10	1.60E+11
	Gas, natural/m3	-	resource	in ground	-	Nm3	1.20E+11	100%	0%	1	1.21	(1,1,1,1,3,na); Enerdata 2016	1.20E+11	4.96E+10
	Gas, natural/m3	-	resource	in ground	-	Nm3	0	53%	47%	1	1.21	(1,1,1,1,3,na); considered in venting	-	4.96E+10
water resource	Water, salt, sole	-	resource	in water	-	m3	1.05E+8	0%	100%	1	1.21	(1,1,3,1,3,na); IOGP 2016	5.52E-4	1.11E+08
	Water, salt, ocean	-	resource	in water	-	m3	2.06E+8	0%	100%	1	1.24	(1,1,3,1,3,na); environmental report for the total Norwegian production, partly with standard factors.	1.08E-3	2.17E+08
water emission	Water, NO	-	water	river	-	m3	0	0%	100%	1	1.15	(3,4,2,3,1,na); calculation		
	Water, NO	-	water	ocean	-	m3	9.00E+7	0%	100%	1	1.15	(3,4,2,3,1,na); calculation	1.00E-3	
	Water, NO	-	water	fossil-	-	m3	2.21E+8	0%	100%	1	1.15	(3,4,2,3,1,na); calculation		
	discharge, produced water, offshore	OCE	-	-	0	kg	9.00E+10	0%	100%	1	1.25	(3,4,2,3,1,na); Generic estimation	1.00E+0	
Technosphere	chemicals organic, at plant	GLO	-	-	0	kg	3.15E+7	53%	47%	1	1.24	(3,4,5,3,3,na); Generic value from Jungbluth 2007 calculated for 15% instead of 3% enhanced oil recovery.	1.65E-4	3.32E+07
	chemicals inorganic, at plant	GLO	-	-	0	kg	4.17E+7	53%	47%	1	1.60	(3,4,5,3,3,na); Generic value from Jungbluth 2007 calculated for 15% instead of 3% enhanced oil recovery.	2.19E-4	4.40E+07
	transport, lorry >16t, fleet average	RER	-	-	0	tkm	7.32E+6	53%	47%	1	1.60	(3,5,5,3,3,na); Standard distance for chemical transport and disposal100km	3.84E-05	8.97E+06
	transport, freight, rail	RER	-	-	0	tkm	4.39E+7	53%	47%	1	2.34	(3,5,5,3,3,na); Standard distance for chemical transport 600km	2.30E-04	4.63E+07
	well for exploration and production, offshore	OCE	-	-	1	m	4.95E+5	53%	47%	1	2.34	(2,3,3,1,3,na); environmental report for the total Norwegian production, standard module	2.60E-6	5.23E+05
	platform, crude oil, offshore	OCE	-	-	1	unit	3.65E+0	0%	100%	1	3.06	(2,3,5,1,3,na); Data for GB	4.05E-11	8.15E+00
	plant offshore, natural gas, production	OCE	-	-	1	unit	1.07E+0	100%	0%	1	3.28	(2,3,5,1,3,na); environmental report for the total Norwegian production, standard module	8.90E-12	1.79E+00
Energy	diesel, burned in diesel-electric generating set	GLO	-	-	0	MJ	1.09E+10	53%	47%	1	3.28	(2,3,2,1,3,na); Schori 2012	5.71E-2	1.15E+10
	diesel, at regional storage	RER	-	-	0	kg	3.26E+7	53%	47%	1	2.06	(2,3,2,1,3,na); Calculation based on literature	1.71E-4	3.44E+07
	electricity, low voltage, at grid	NO	-	-	0	kWh	4.84E+9	53%	47%	1	2.06	(2,3,2,1,3,na); IOGP 2016	2.54E-2	
	heavy fuel oil, burned in industrial furnace 1MW, non-modulating	RER	-	-	0	MJ	0	53%	47%	1	2.06	(2,3,2,1,3,na); IOGP 2016	-	
	sweet gas, burned in gas turbine, production	NO	-	-	0	MJ	2.31E+11	53%	47%	1	2.06	(2,3,2,1,3,na); IOGP 2016	1.21E+0	3.11E+09
	natural gas, vented	GLO	-	-	0	Nm3	2.78E+9	53%	47%	1	2.06	(2,3,1,5,3,na); Generic value according to IEA 2017	1.46E-2	
	natural gas, sweet, burned in production flare	GLO	-	-	0	Nm3	3.56E+8	53%	47%	1	10.10	(1,1,1,1,3,na); World Bank 2017	1.87E-3	6.87E+08
	drying, natural gas	NO	-	-	0	Nm3	1.76E+10	100%	0%	1	1.21	(2,3,3,1,3,na); environmental report for the total Norwegian production.	1.47E-1	2.95E+10
waste	disposal, used mineral oil, 10% water, to hazardous waste incineration	CH	-	-	0	kg	7.18E+6	53%	47%	1	1.25	(2,3,3,1,3,na); environmental report for the total Norwegian production, standard module	3.76E-5	7.57E+06
	disposal, municipal solid waste, 22.9% water, to sanitary landfill	CH	-	-	0	kg	6.39E+6	53%	47%	1	1.25	(2,3,3,1,3,na); environmental report for the total Norwegian production, standard module	3.35E-5	6.74E+06
	disposal, wood untreated, 20% water, to municipal incineration	CH	-	-	0	kg	1.39E+6	53%	47%	1	1.25	(2,3,3,1,3,na); environmental report for the total Norwegian production, standard module	7.29E-6	1.47E+06
	disposal, hazardous waste, 0% water, to underground deposit	DE	-	-	0	kg	8.64E+6	53%	47%	1	1.25	(2,3,3,1,3,na); environmental report for the total Norwegian production, standard module	4.53E-5	9.12E+06
Sources													This study	Schori S. 2012

Life Cycle Inventory of Natural Gas and Crude Oil Production in Norway, offshore, 2016, part 2

Explanations	Name	Location	Category	SubCategory	InfrastructureProcess	Unit	combined offshore gas and oil production	natural gas, at production offshore	crude oil, at production offshore	UncertaintyType	StandardDeviation95 %	GeneralComment	Total	Total
	Location						NO	NO	NO				NO	NO
	InfrastructureProcess						0	0	0				2016	2010
	Unit						a	Nm3	kg				kg OE	a
	disposal, antifreezer liquid, 51.8% water, to hazardous waste incineration	CH	-	-	0	kg	1.96E+4	53%	47%	1	1.25	(2,3,3,1,3,na); environmental report for the total Norwegian production, standard module	1.02E-7	2.06E+04
	disposal, emulsion paint remains, 0% water, to hazardous waste incineration	CH	-	-	0	kg	8.63E+4	53%	47%	1	1.25	(2,3,3,1,3,na); environmental report for the total Norwegian production, standard module	4.52E-7	9.10E+04
	low active radioactive waste	CH	-	-	0	m3	1.42E+4	0%	100%	1	1.25	(2,3,3,1,3,na); Schori 2012	1.58E-7	3.18E+04
Emissions, in air, low population density	Methane, fossil	-	air	low population density		kg	3.29E+7	53%	47%	1	1.25	(2,3,3,1,3,na); environmental report for the total Norwegian production, partly with standard factors.	1.72E-4	3.47E+07
	Ethane	-	air	low population density		kg	4.75E+6	53%	47%	1	1.58	(2,3,3,1,3,na); environmental report for the total Norwegian production, partly with standard factors.	2.49E-5	5.01E+06
	Propane	-	air	low population density		kg	2.51E+6	53%	47%	1	3.06	(2,3,3,1,3,na); environmental report for the total Norwegian production, partly with standard factors.	1.32E-5	2.65E+06
	Butane	-	air	low population density		kg	1.31E+6	53%	47%	1	1.25	(2,3,3,1,3,na); environmental report for the total Norwegian production, partly with standard factors.	6.87E-6	1.38E+06
	Carbon dioxide, fossil	-	air	low population density		kg	1.78E+8	53%	47%	1	3.06	(2,3,3,1,3,na); environmental report for the total Norwegian production, partly with standard factors.	9.35E-4	1.88E+08
	NMVOC, non-methane volatile organic compounds, unspecified origin	-	air	low population density		kg	1.98E+8	53%	47%	1	1.25	(2,3,3,1,3,na); environmental report for the total Norwegian production, partly with standard factors.	1.04E-3	2.09E+08
	Nitrogen oxides	-	air	low population density		kg	2.37E+5	53%	47%	1	2.07	(2,3,3,1,3,na); environmental report for the total Norwegian production, partly with standard factors.	1.24E-6	2.50E+05
	Mercury	-	air	low population density		kg	2.96E+0	53%	47%	1	3.06	(2,3,3,1,3,na); data calculated on the basis of losses and gas composition	1.55E-11	3.12E+00
	Radon-222	-	air	low population density		kBq	5.91E+6	53%	47%	1	1.25	(2,3,3,1,3,na); data calculated on the basis of losses and gas composition	3.10E-5	6.24E+06
	Methane, bromotrifluoro-, Halon 1301	-	air	low population density		kg	2.79E+1	53%	47%	1	1.25	(3,4,3,3,3,na); assuming 20% halon compared to Schori 2012	1.46E-10	0.00E+00
	Methane, trifluoro-, HFC-23	-	air	low population density		kg	1.11E+2	53%	47%	1	1.29	(3,4,3,3,3,na); assuming 80% HFC-23 compared to Schori 2012	5.84E-10	
	Heat, waste	-	air	low population density		MJ	1.20E+9	53%	47%	1	2.09	(2,3,3,1,3,na); environmental report for the total Norwegian production, standard factors.	6.29E-3	1.27E+09
Emissions, in water, ocean	Carboxylic acids, unspecified	-	water	ocean		kg	2.67E+7	53%	47%	1	1.25	(2,3,3,1,3,na); environmental report for the total Norwegian production, partly with standard factors.	1.40E-4	2.81E+07
	PAH, polycyclic aromatic hydrocarbons	-	water	ocean		kg	4.24E+4	53%	47%	1	1.25	(2,3,3,1,3,na); environmental report for the total Norwegian production, assumption for the break down of BTX.	2.22E-7	4.48E+04
	Phenol	-	water	ocean		kg	6.08E+5	53%	47%	1	3.06	(2,3,3,1,3,na); environmental report for the total Norwegian production, assumption for the break down of BTX.	3.19E-6	6.42E+05
Sources													This study	Schori S. 2012

Life Cycle Inventory of Natural Gas and Crude Oil Production in Norway, offshore, 2016, part 3

Explanations	Name	Location	Category	SubCategory	InfrastructureProcess	Unit	combined offshore gas and oil production	natural gas, at production offshore	crude oil, at production offshore	UncertaintyType	StandardDeviation95%	GeneralComment	Total	Total
	Location						NO	NO	NO				NO	NO
	InfrastructureProcess						0	0	0				2016	2010
	Unit						a	Nm3	kg				kg OE	a
	Benzene	-	water	ocean		kg	3.21E+5	53%	47%	1	3.06	(2,3,3,1,3,na); environmental report for the total Norwegian production, assumption for the break down of BTX.	1.68E-6	3.38E+05
	Toluene	-	water	ocean		kg	3.21E+5	53%	47%	1	2.07	(2,3,3,1,3,na); environmental report for the total Norwegian production, partly with standard factors.	1.68E-6	3.38E+05
	Xylene	-	water	ocean		kg	3.21E+5	53%	47%	1	3.06	(2,3,3,1,3,na); environmental report for the total Norwegian production, partly with standard factors.	1.68E-6	3.38E+05
	Oils, unspecified	-	water	ocean		kg	9.01E+6	53%	47%	1	1.25	(2,3,3,1,3,na); IOGP 2016 plus breakdown of 5 biggest, non-war-related oil spills (catastrophes) on oil platforms between 1900 and 2010	4.72E-5	3.20E+06
	Arsenic	-	water	ocean		kg	1.08E+3	53%	47%	1	1.25	(2,3,3,1,3,na); environmental report for the total Norwegian production, partly with standard factors.	5.68E-9	1.14E+03
	Lead	-	water	ocean		kg	5.17E+2	53%	47%	1	2.07	(2,3,3,1,3,na); environmental report for the total Norwegian production, partly with standard factors.	2.71E-9	5.45E+02
	Cadmium	-	water	ocean		kg	1.33E+2	53%	47%	1	1.25	(2,3,3,1,3,na); environmental report for the total Norwegian production, partly with standard factors.	6.95E-10	1.40E+02
	Copper	-	water	ocean		kg	4.14E+2	53%	47%	1	5.07	(2,3,3,1,3,na); environmental report for the total Norwegian production, partly with standard factors.	2.17E-9	4.37E+02
	Chromium	-	water	ocean		kg	4.90E+2	53%	47%	1	5.07	(2,3,3,1,3,na); environmental report for the total Norwegian production, partly with standard factors.	2.57E-9	5.17E+02
	Mercury	-	water	ocean		kg	4.74E+0	53%	47%	1	5.07	(2,3,3,1,3,na); environmental report for the total Norwegian production, partly with standard factors.	2.48E-11	5.00E+00
	Nickel	-	water	ocean		kg	7.36E+2	53%	47%	1	5.07	(2,3,3,1,3,na); environmental report for the total Norwegian production, partly with standard factors.	3.85E-9	7.76E+02
	Zinc	-	water	ocean		kg	1.42E+4	53%	47%	1	1.25	(2,3,3,1,3,na); environmental report for the total Norwegian production, partly with standard factors.	7.42E-8	1.49E+04
	BOD5, Biological Oxygen Demand	-	water	ocean	-	kg	2.84E+7	53%	47%	1	1.25	(3,3,3,1,3,na); Extrapolation for sum parameter	1.49E-4	4.35E+7
	COD, Chemical Oxygen Demand	-	water	ocean	-	kg	2.84E+7	53%	47%	1	1.60	(3,3,3,1,3,na); Extrapolation for sum parameter	1.49E-4	4.35E+7
	DOC, Dissolved Organic Carbon	-	water	ocean	-	kg	7.80E+6	53%	47%	1	1.60	(3,3,3,1,3,na); Extrapolation for sum parameter	4.08E-5	1.55E+7
	TOC, Total Organic Carbon	-	water	ocean	-	kg	7.80E+6	53%	47%	1	1.60	(3,3,3,1,3,na); Extrapolation for sum parameter	4.08E-5	1.55E+7
	AOX, Adsorbable Organic Halogen as Cl	-	water	ocean	-	kg	9.28E+1	53%	47%	1	1.60	(3,3,3,1,3,na); Extrapolation for sum parameter	4.86E-10	3.29E+1
	Nitrogen	-	water	ocean	-	kg	6.96E+3	53%	47%	1	1.60	(3,3,3,1,3,na); Extrapolation for sum parameter	3.65E-8	2.47E+3
	Sulfur	-	water	ocean	-	kg	2.41E+4	53%	47%	1	1.60	(3,3,3,1,3,na); Extrapolation for sum parameter	1.26E-7	8.56E+3
Sources													This study	Schori S. 2012

Tab. 12.7 Life Cycle Inventory of Natural Gas and Crude Oil Production in Iraq, onshore 2016, part 1

	Name	Location	Category	SubCategory	InfrastructureProcess	Unit	combined gas and oil production	crude oil, at production	natural gas, at production	UncertaintyType	StandardDeviation95 %	GeneralComment
	Location						IQ	IQ	IQ			
	InfrastructureProcess						0	0	0			
	Unit						a	kg	Nm3			
product	crude oil, at production	IQ	-	-	0	kg	1.93E+11	100%				
	natural gas, at production	IQ	-	-	0	Nm3	1.00E+10		100%			
resource, in ground	Oil, crude	-	resource	in ground	-	kg	1.93E+11	100%	0%	1	1.05E+0	(1,1,1,1,1,na); including losses due to oil spills
	Gas, natural/m3	-	resource	in ground	-	Nm3	1.00E+10	0%	100%	1	1.05E+0	(1,1,1,1,1,na); Enerdata 2016
	Gas, natural/m3	-	resource	in ground	-	Nm3	0	9.58E-1	4.17E-2	1	1.27E+0	(3,3,3,1,3,na); considered in venting
water resource	Water, unspecified natural origin, IQ	-	resource	in water	-	m3	6.06E+5	100%	0%	1	1.24E+0	(3,3,2,1,3,na); IOGP 2016
	Water, fossil	-	resource	in water	-	m3	1.92E+8	100%	0%	1	1.24E+0	(3,3,2,1,3,na); Balancing of input-output
water emission	Water, IQ	-	water	river	-	m3	1.93E+8	100%	0%	1	1.58E+0	(3,3,2,1,3,na); calculation
	Water, IQ	-	water	fossil-	-	m3	0	100%	0%	1	1.58E+0	(3,3,2,1,3,na); calculation
	discharge, produced water, onshore	GLO	-	-	0	kg	1.93E+11	100%	0%	1	2.06E+0	(2,3,2,1,3,na); Generic estimation
technosphere	chemicals inorganic, at plant	GLO	-	-	0	kg	1.11E+8	96%	4%	1	1.60E+0	(3,4,5,3,3,na); Generic value from Jungbluth 2007 calculated for 15% instead of 3% enhanced oil recovery.
	chemicals organic, at plant	GLO	-	-	0	kg	8.50E+7	96%	4%	1	1.60E+0	(3,4,5,3,3,na); Generic value from Jungbluth 2007 calculated for 15% instead of 3% enhanced oil recovery.
	transport, lorry >16t, fleet average	RER	-	-	0	tkm	2.17E+7	96%	4%	1	2.34E+0	(3,5,5,3,3,na); Standard distance for chemical transport and disposal100km
	transport, freight, rail	RER	-	-	0	tkm	1.18E+8	96%	4%	1	2.34E+0	(3,5,5,3,3,na); Standard distance for chemical transport 600km
	well for exploration and production, onshore	GLO	-	-	1	m	6.73E+5	96%	4%	1	3.05E+0	(2,3,2,1,3,na); FAS
	pipeline, crude oil, onshore	RER	-	-	1	km	4.01E+3	96%	4%	1	3.30E+0	(3,4,5,3,3,na); Average of literature
	production plant crude oil, onshore	GLO	-	-	1	unit	1.03E+3	96%	4%	1	3.30E+0	(3,4,5,3,3,na); Lodewijkx et al. 2001
energy	diesel, burned in diesel-electric generating set	GLO	-	-	0	MJ	0	96%	4%	1	2.07E+0	(2,3,3,1,3,na); Calculation based on literature
	electricity, low voltage, at grid	SA	-	-	0	kWh	2.72E+9	96%	4%	1	2.07E+0	(2,3,3,1,3,na); IOGP 2016
	heavy fuel oil, burned in industrial furnace 1MW, non-modulating	RER	-	-	0	MJ	0	96%	4%	1	2.07E+0	(2,3,3,1,3,na); Calculation based on literature
	sweet gas, burned in gas turbine, production	NO	-	-	0	MJ	4.95E+10	96%	4%	1	2.07E+0	(2,3,3,1,3,na); IOGP 2016
	natural gas, vented	GLO	-	-	0	Nm3	2.94E+9	96%	4%	1	1.01E+1	(2,3,1,5,3,na); Generic value according to IEA 2017
	natural gas, sweet, burned in production flare	GLO	-	-	0	Nm3	1.77E+10	96%	4%	1	1.21E+0	(1,1,1,1,3,na); World Bank 2017

Life Cycle Inventory of Natural Gas and Crude Oil Production in Iraq, onshore 2016, part 2

	Name	Location	Category	SubCategory	InfrastructureProcess	Unit	combined gas and oil production	crude oil, at production	natural gas, at production	UncertaintyType	StandardDeviation95%	GeneralComment
	Location						IQ	IQ	IQ			
	InfrastructureProcess						0	0	0			
	Unit						a	kg	Nm3			
waste	low active radioactive waste	CH	-	-	0	m3	4.03E+4	96%	4%	1	1.57E+0	(2,3,5,3,3,na); Generic assumption
	disposal, municipal solid waste, 22.9% water, to municipal incineration	CH	-	-	0	kg	2.01E+7	96%	4%	1	1.31E+0	(2,3,4,3,3,na); Generic assumption
emission to soil	Oils, unspecified	-	soil	unspecified	-	kg	4.69E+5	9.58E-1	4.17E-2	1	1.58E+0	(3,3,1,1,3,na); IOGP 2016
emission water, river	Oils, unspecified	-	water	river	-	kg	0	9.58E-1	4.17E-2	1	1.58E+0	(3,3,1,1,3,na); IOGP 2016
	BOD5, Biological Oxygen Demand	-	water	river	-	kg	0	9.58E-1	4.17E-2	1	3.06E+0	(3,3,2,1,3,na); Extrapolation for sum parameter
	COD, Chemical Oxygen Demand	-	water	river	-	kg	0	9.58E-1	4.17E-2	1	3.06E+0	(3,3,2,1,3,na); Extrapolation for sum parameter
	DOC, Dissolved Organic Carbon	-	water	river	-	kg	0	9.58E-1	4.17E-2	1	3.06E+0	(3,3,2,1,3,na); Extrapolation for sum parameter
	TOC, Total Organic Carbon	-	water	river	-	kg	0	9.58E-1	4.17E-2	1	3.06E+0	(3,3,2,1,3,na); Extrapolation for sum parameter
	AOX, Adsorbable Organic Halogen as Cl	-	water	river	-	kg	0	9.58E-1	4.17E-2	1	3.06E+0	(3,3,2,1,3,na); Extrapolation for sum parameter
	Nitrogen	-	water	river	-	kg	0	9.58E-1	4.17E-2	1	3.06E+0	(3,3,2,1,3,na); Extrapolation for sum parameter
	Sulfur	-	water	river	-	kg	0	9.58E-1	4.17E-2	1	3.06E+0	(3,3,2,1,3,na); Extrapolation for sum parameter
emission air, low population density	Methane, bromotrifluoro-, Halon 1301	-	air	low population density	-	kg	0	9.58E-1	4.17E-2	1	3.05E+0	(2,3,1,3,3,na); only offshore
emission air, low population density	Methane, trifluoro-, HFC-23	-	air	low population density	-	kg	0	9.58E-1	4.17E-2	1	3.05E+0	(2,3,1,3,3,na); only offshore
	Methane, fossil	-	air	low population density	-	kg	0	9.58E-1	4.17E-2	1	3.28E+0	(2,3,5,3,3,na); considered in venting
	NMVOC, non-methane volatile organic compounds, unspecified origin	-	air	low population density	-	kg	0	9.58E-1	4.17E-2	1	3.28E+0	(2,3,5,3,3,na); Generic data
	Transformation, from forest, unspecified	-	resource	land	-	m2	0	9.58E-1	4.17E-2	1	3.28E+0	(2,3,5,3,3,na); included in production well and productin plant
	Transformation, to dump site	-	resource	land	-	m2	0	9.58E-1	4.17E-2	1	3.28E+0	(2,3,5,3,3,na); included in production well and productin plant

Tab. 12.8 Life Cycle Inventory of Natural Gas and Crude Oil Production, off- and onshore, in Mexico 2016, part1

	Name	Location	Category	SubCategory	InfrastructureProcess	Unit	combined gas and oil production	combined gas and oil production offshore	combined gas and oil production onshore	crude oil, at production offshore	crude oil, at production onshore	natural gas, at production offshore	natural gas, at production onshore	UncertaintyType	StandardDeviation95%	GeneralComment
	Location						MX	MX	MX	MX	MX	MX	MX			
	InfrastructureProcess						0	0	0	0	0	0	0			
	Unit						a	a	a	kg	kg	Nm3	Nm3			
product	crude oil, at production offshore	MX	-	-	0	kg	2.66E+10	2.66E+10		100%						
	crude oil, at production onshore	MX	-	-	0	kg	9.34E+10		9.34E+10		100%					
	natural gas, at production offshore	MX	-	-	0	Nm3	8.85E+9	8.85E+9				100%				
	natural gas, at production onshore	MX	-	-	0	Nm3	3.11E+10		3.11E+10				100%			
resource, in ground	Oil, crude	-	resour	in ground	-	kg	1.20E+11	2.66E+10	9.34E+10	100%	100%			1	1.05	(1,1,1,1,1,na); Enerdata 2016
	Oil, crude	-	resour	in ground	-	kg	2.38E+6	1.46E+6	5.14E+6	78%	78%	22%	22%	1	1.11	(1,1,3,1,1,na); including losses due to oil spills
	Gas, natural/m3	-	resour	in ground	-	Nm3	4.00E+10	8.85E+9	3.11E+10			100%	100%	1	1.05	(1,1,1,1,1,na); Enerdata 2016
	Gas, natural/m3	-	resour	in ground	-	Nm3	0	0	0	78%	78%	22%	22%	1	1.13	(2,2,3,1,1,na); considered in venting
water resource	Water, unspecified natural origin, MX	MX	resour	in water	-	m3	3.37E+7	0	3.37E+7	100%	100%	0%	0%	1	1.16	(3,4,2,3,1,na); IOGP 2016
	Water, salt, ocean	GLO	resour	in water	-	m3	9.56E+6	9.56E+6	0	100%	100%	0%	0%	1	1.16	(3,4,2,3,1,na); IOGP 2016
	Water, fossil	GLO	resour	in water	-	m3	7.68E+7	1.70E+7	5.98E+7	100%	100%	0%	0%	1	1.16	(3,4,2,3,1,na); Balancing of input-output
water emission	Water, MX	-	water	river	-	m3	9.34E+7	0	9.34E+7	100%	100%	0%	0%	1	1.50	(3,4,2,3,1,na); calculation
	Water, MX	-	water	ocean	-	m3	2.66E+7	2.66E+7	0	100%	100%	0%	0%	1	1.50	(3,4,2,3,1,na); calculation
	Water, MX	-	water	fossil-	-	m3	0.00E+00	0.00E+00	0.00E+00	100%	100%	0%	0%	1	1.50	(3,4,2,3,1,na); calculation
	discharge, produced water, offshore	OCE	-	-	0	kg	2.66E+10	2.66E+10	0	100%	100%	0%	0%	1	1.26	(3,4,2,3,3,na); Generic estimation
	discharge, produced water, onshore	GLO	-	-	0	kg	9.34E+10	0	9.34E+10	100%	100%	0%	0%	1	1.26	(3,4,2,3,3,na); Generic estimation
technosphere	chemicals inorganic, at plant	GLO	-	-	0	kg	3.06E+7	1.88E+7	6.62E+7	78%	78%	22%	22%	1	1.60	(3,4,5,3,3,na); Generic value from Jungbluth 2007 calculated for 15% instead of 3% enhanced oil recovery.
	chemicals organic, at plant	GLO	-	-	0	kg	2.34E+7	1.43E+7	5.05E+7	78%	78%	22%	22%	1	1.60	(3,4,5,3,3,na); Generic value from Jungbluth 2007 calculated for 15% instead of 3% enhanced oil recovery.
	transport, lorry >16t, fleet average	RER	-	-	0	tkm	1.78E+8	1.09E+8	3.84E+8	78%	78%	22%	22%	1	2.34	(3,5,5,3,3,na); Standard distance for chemical transport 100km
	transport, freight, rail	RER	-	-	0	tkm	3.24E+7	1.99E+7	7.00E+7	78%	78%	22%	22%	1	2.34	(3,5,5,3,3,na); Standard distance for chemical transport 600km
	well for exploration and production, onshore	GLO	-	-	1	m	1.11E+6	0	4.44E+6	0%	78%	0%	22%	1	3.06	(2,3,3,1,3,na); Default GLO
	well for exploration and production, offshore	OCE	-	-	1	m	9.44E+4	1.26E+5	0	78%	0%	22%	0%	1	3.06	(2,3,3,1,3,na); Literature, lifetime 15a, length 2.4km
	pipeline, crude oil, onshore	RER	-	-	1	km	1.10E+3	6.77E+2	2.38E+3	0%	78%	0%	22%	1	3.30	(3,4,5,3,3,na); Average of literature
	production plant crude oil, onshore	GLO	-	-	1	unit	1.53E+2	0	6.14E+2	0%	78%	0%	22%	1	3.30	(3,4,5,3,3,na); Lodewijkx et al. 2001
	platform, crude oil, offshore	OCE	-	-	1	unit	1.05E+0	1.39E+0	0	78%	0%	22%	0%	1	3.30	(3,4,5,3,3,na); Generic data
energy	diesel, burned in diesel-electric generating set	GLO	-	-	0	MJ	0	0	0	78%	78%	22%	22%	1	2.06	(2,3,2,1,3,na); Calculation based on literature
	electricity, low voltage, at grid	MX	-	-	0	kWh	2.83E+9	1.74E+9	6.12E+9	78%	78%	22%	22%	1	2.06	(2,3,2,1,3,na); IOGP 2016
	heavy fuel oil, burned in industrial furnace 1MW, non-modulating	RER	-	-	0	MJ	0	0	0	78%	78%	22%	22%	1	2.06	(2,3,2,1,3,na); Calculation based on literature
	sweet gas, burned in gas turbine, production	NO	-	-	0	MJ	1.73E+11	1.06E+11	3.73E+11	78%	78%	22%	22%	1	2.06	(2,3,2,1,3,na); IOGP 2016
	natural gas, vented	GLO	-	-	0	Nm3	8.08E+8	4.96E+8	1.74E+9	78%	78%	22%	22%	1	10.10	(2,3,1,5,3,na); Generic value according to IEA 2017
	natural gas, sweet, burned in production flare	GLO	-	-	0	Nm3	1.72E+9	1.06E+9	3.72E+9	78%	78%	22%	22%	1	1.21	(1,1,1,1,3,na); World Bank 2017

Life Cycle Inventory of Natural Gas and Crude Oil Production, off- and onshore, in Mexico 2016, part2

	Name	Location	Category	SubCategory	InfrastructureProcess	Unit	combined gas and oil production	combined gas and oil production offshore	combined gas and oil production onshore	crude oil, at production offshore	crude oil, at production onshore	natural gas, at production offshore	natural gas, at production onshore	UncertaintyType	StandardDeviation95%	GeneralComment
	Location						MX	MX	MX	MX	MX	MX	MX			
	InfrastructureProcess						0	0	0	0	0	0	0			
	Unit						a	a	a	kg	kg	Nm3	Nm3			
waste	low active radioactive waste	CH	-	-	0	m3	1.11E+4	6.80E+3	2.39E+4	78%	78%	22%	22%	1	1.60	(3,4,5,3,3,na); Generic assumption
	disposal, municipal solid waste, 22.9% water, to municipal incineration	CH	-	-	0	kg	5.54E+6	3.40E+6	1.20E+7	78%	78%	22%	22%	1	1.34	(3,4,4,3,3,na); Generic assumption
emission water, river	Oils, unspecified	-	water	river	-	kg	8.40E+4	0	3.36E+5	0%	78%	0%	22%	1	1.59	(3,4,2,3,3,na); IOGP 2016
	BOD5, Biological Oxygen Demand	-	water	river	-	kg	2.65E+5	0	1.06E+6	0%	78%	0%	22%	1	1.54	(3,4,2,3,1,na); Extrapolation for sum parameter
	COD, Chemical Oxygen Demand	-	water	river	-	kg	2.65E+5	0	1.06E+6	0%	78%	0%	22%	1	1.54	(3,4,2,3,1,na); Extrapolation for sum parameter
	DOC, Dissolved Organic Carbon	-	water	river	-	kg	7.27E+4	0	2.91E+5	0%	78%	0%	22%	1	1.54	(3,4,2,3,1,na); Extrapolation for sum parameter
	TOC, Total Organic Carbon	-	water	river	-	kg	7.27E+4	0	2.91E+5	0%	78%	0%	22%	1	1.54	(3,4,2,3,1,na); Extrapolation for sum parameter
	AOX, Adsorbable Organic Halogen as Cl	-	water	river	-	kg	8.66E-1	0	3.46E+0	0%	78%	0%	22%	1	1.54	(3,4,2,3,1,na); Extrapolation for sum parameter
	Nitrogen	-	water	river	-	kg	6.49E+1	0	2.60E+2	0%	78%	0%	22%	1	1.54	(3,4,2,3,1,na); Extrapolation for sum parameter
	Sulfur	-	water	river	-	kg	2.25E+2	0	9.00E+2	0%	78%	0%	22%	1	1.54	(3,4,2,3,1,na); Extrapolation for sum parameter
emission water, ocean	Oils, unspecified	-	water	ocean	-	kg	1.09E+6	1.46E+6	0	78%	0%	22%	0%	1	1.59	(3,4,1,3,3,na); IOGP 2016 plus breakdown of 5 biggest, non-war-related oil spills (catastrophes)
	BOD5, Biological Oxygen Demand	-	water	ocean	-	kg	3.45E+6	4.60E+6	0	78%	0%	22%	0%	1	1.53	(3,4,1,3,1,na); Extrapolation for sum parameter
	COD, Chemical Oxygen Demand	-	water	ocean	-	kg	3.45E+6	4.60E+6	0	78%	0%	22%	0%	1	1.53	(3,4,1,3,1,na); Extrapolation for sum parameter
	DOC, Dissolved Organic Carbon	-	water	ocean	-	kg	9.47E+5	1.26E+6	0	78%	0%	22%	0%	1	1.53	(3,4,1,3,1,na); Extrapolation for sum parameter
	TOC, Total Organic Carbon	-	water	ocean	-	kg	9.47E+5	1.26E+6	0	78%	0%	22%	0%	1	1.53	(3,4,1,3,1,na); Extrapolation for sum parameter
	AOX, Adsorbable Organic Halogen as Cl	-	water	ocean	-	kg	1.13E+1	1.50E+1	0	78%	0%	22%	0%	1	1.53	(3,4,1,3,1,na); Extrapolation for sum parameter
	Nitrogen	-	water	ocean	-	kg	8.46E+2	1.13E+3	0	78%	0%	22%	0%	1	1.53	(3,4,1,3,1,na); Extrapolation for sum parameter
	Sulfur	-	water	ocean	-	kg	2.93E+3	3.91E+3	0	78%	0%	22%	0%	1	1.53	(3,4,1,3,1,na); Extrapolation for sum parameter
emission to soil	Oils, unspecified	-	soil	unspecified	-	kg	2.27E+5	0	9.09E+5	0%	78%	0%	22%	1	1.85	(3,4,5,3,3,na); IOGP 2016
emission air, low population density	Methane, bromotrifluoro-, Halon 1301	-	air	low population density	-	kg	2.97E+2	3.96E+2		78%	78%	22%	22%	1	1.59	(3,4,1,3,3,na); assuming 20% halon compared to Jungbluth 2007
	Methane, trifluoro-, HFC-23	-	air	low population density	-	kg	1.19E+3	1.58E+3		78%	78%	22%	22%	1	1.59	(3,4,1,3,3,na); assuming 80% HFC-23 compared to Jungbluth 2007
	Methane, fossil	-	air	low population density	-	kg	0	0	0	78%	78%	22%	22%	1	1.85	(3,4,5,3,3,na); considered in venting
	NMVOC, non-methane volatile organic compounds, unspecified origin	-	air	low population density	-	kg	0	0	0	78%	78%	22%	22%	1	1.85	(3,4,5,3,3,na); Generic data
	Transformation, from forest, unspecified	-	resour	land	-	m2	0	0	0	0%	78%	0%	22%	1	2.30	(3,4,5,3,3,na); included in production well and productin plant
	Transformation, to dump site	-	resour	land	-	m2	0	0	0	0%	78%	0%	22%	1	2.30	(3,4,5,3,3,na); included in production well and productin plant

Tab. 12.9 Life Cycle Inventory of Natural Gas and Crude Oil Production, off- and onshore, in Saudi Arabia 2016, part 1

	Name	Location	Category	SubCategory	InfrastructureProcess	Unit	combined gas and oil production	combined gas and oil production offshore	combined gas and oil production onshore	crude oil, at production offshore	crude oil, at production onshore	natural gas, at production offshore	natural gas, at production onshore	UncertaintyType	StandardDeviation95%	GeneralComment
	Location						SA	SA	SA	SA	SA	SA	SA			
	InfrastructureProcess						0	0	0	0	0	0	0			
	Unit						a	a	a	kg	kg	Nm3	Nm3			
	crude oil, at production offshore	SA	-	-	0	kg	1.32E+11	1.32E+11		100%						
	crude oil, at production onshore	SA	-	-	0	kg	4.66E+11		4.66E+11		100%					
	natural gas, at production offshore	SA	-	-	0	Nm3	1.99E+10	1.99E+10				100%				
	natural gas, at production onshore	SA	-	-	0	Nm3	7.01E+10		7.01E+10				100%			
resource, in ground	Oil, crude	-	resource	in ground	-	kg	5.98E+11	1.32E+11	4.66E+11	100%	100%			1	1.05	(1,1,1,1,1,na); Enerdata 2016
	Oil, crude	-	resource	in ground	-	kg	1.61E+7	5.44E+6	1.91E+7	100%	100%			1	1.05	(1,1,3,1,1,na); including losses due to oil spills
	Gas, natural/m3	-	resource	in ground	-	Nm3	9.00E+10	1.99E+10	7.01E+10			100%	100%	1	1.05	(1,1,1,1,1,na); Enerdata 2016
	Gas, natural/m3	-	resource	in ground	-	Nm3	0	0	0			100%	100%	1	1.05	(2,2,3,1,1,na); considered in venting
water resource	Water, unspecified natural origin, SA	GLO	resource	in water	-	m3	1.46E+6	0	1.46E+6	100%	100%	0%	0%	1	1.05	(3,4,2,3,1,na); IOGP 2016
	Water, salt, ocean	GLO	resource	in water	-	m3	4.15E+5	4.15E+5	0	100%	100%	0%	0%	1	1.05	(3,4,2,3,1,na); IOGP 2016
	Water, fossil	GLO	resource	in water	-	m3	5.96E+8	1.32E+8	4.64E+8	100%	100%	0%	0%	1	1.05	(3,4,2,3,1,na); IOGP 2016
water emission	Water, SA	-	water	river	-	m3	4.66E+8	0	4.66E+8	100%	100%	0%	0%	1	1.50	(3,4,2,3,1,na); calculation
	Water, SA	-	water	ocean	-	m3	1.32E+8	1.32E+8	0	100%	100%	0%	0%	1	1.50	(3,4,2,3,1,na); calculation
	Water, SA	-	water	fossil-	-	m3	0	0	0	100%	100%	0%	0%	1	1.50	(3,4,2,3,1,na); calculation
	discharge, produced water, offshore	OCE	-	-	0	kg	1.32E+11	1.32E+11	0	100%	100%	0%	0%	1	1.05	(3,4,2,3,3,na); Generic estimation
	discharge, produced water, onshore	GLO	-	-	0	kg	4.66E+11	0	4.66E+11	100%	100%	0%	0%	1	1.05	(3,4,2,3,3,na); Generic estimation
technosphere	chemicals inorganic, at plant	GLO	-	-	0	kg	2.44E+8	8.24E+7	2.90E+8	89%	89%	11%	11%	1	1.05	(3,4,5,3,3,na); Generic value from Jungbluth 2007 calculated for 15% instead of 3% enhanced oil recovery.
	chemicals organic, at plant	GLO	-	-	0	kg	1.86E+8	6.29E+7	2.21E+8	89%	89%	11%	11%	1	1.05	(3,4,5,3,3,na); Generic value from Jungbluth 2007 calculated for 15% instead of 3% enhanced oil recovery.
	transport, lorry >16t, fleet average	RER	-	-	0	tkm	1.99E+8	6.72E+7	2.37E+8	89%	89%	11%	11%	1	2.00	(3,5,5,3,3,na); Standard distance for chemical transport 100km
	transport, freight, rail	RER	-	-	0	tkm	2.58E+8	8.72E+7	3.07E+8	89%	89%	11%	11%	1	2.00	(3,5,5,3,3,na); Standard distance for chemical transport 600km
	well for exploration and production, onshore	GLO	-	-	1	m	3.10E+5	0	3.99E+5	0%	89%	0%	11%	1	3.00	(2,3,3,1,3,na); data for IQ
	well for exploration and production, offshore	OCE	-	-	1	m	1.22E+5	5.52E+5	0	89%	0%	11%	0%	1	3.00	(2,3,3,1,3,na); Literature, lifetime 15a, length 2.4km
	pipeline, crude oil, onshore	RER	-	-	1	km	8.80E+3	2.97E+3	1.05E+4	0%	89%	0%	11%	1	3.00	(3,4,5,3,3,na); Average of literature
	production plant crude oil, onshore	GLO	-	-	1	unit	2.10E+3	0	2.69E+3	0%	89%	0%	11%	1	3.00	(3,4,5,3,3,na); Lodewijkx et al. 2001
	platform, crude oil, offshore	OCE	-	-	1	unit	1.35E+0	6.11E+0	0	89%	0%	11%	0%	1	3.00	(3,4,5,3,3,na); Generic data
energy	diesel, burned in diesel-electric generating set	GLO	-	-	0	MJ	0	0	0	89%	89%	11%	11%	1	2.00	(2,3,2,1,3,na); Calculation based on literature
	electricity, low voltage, at grid	SA	-	-	0	kWh	5.96E+9	2.01E+9	7.08E+9	89%	89%	11%	11%	1	2.00	(2,3,2,1,3,na); IOGP 2016
	heavy fuel oil, burned in industrial furnace 1MW, non-modulating	RER	-	-	0	MJ	0	0	0	89%	89%	11%	11%	1	2.00	(2,3,2,1,3,na); Calculation based on literature
	sweet gas, burned in gas turbine, production	NO	-	-	0	MJ	1.08E+11	3.66E+10	1.29E+11	89%	89%	11%	11%	1	2.00	(2,3,2,1,3,na); IOGP 2016
technosphere	natural gas, vented	GLO	-	-	0	Nm3	6.44E+9	2.17E+9	7.65E+9	89%	89%	11%	11%	1	10.00	(2,3,1,5,3,na); Generic value according to IEA 2017
	natural gas, sweet, burned in production flare	GLO	-	-	0	Nm3	1.56E+9	5.27E+8	1.85E+9	89%	89%	11%	11%	1	2.00	(1,1,1,1,3,na); World Bank 2017

Life Cycle Inventory of Natural Gas and Crude Oil Production, off- and onshore, in Saudi Arabia 2016, part 2

	Name	Location	Category	SubCategory	InfrastructureProcess	Unit	combined gas and oil production	combined gas and oil production offshore	combined gas and oil production onshore	crude oil, at production offshore	crude oil, at production onshore	natural gas, at production offshore	natural gas, at production onshore	UncertaintyType	StandardDeviation95%	GeneralComment
	Location						SA	SA	SA	SA	SA	SA	SA			
	InfrastructureProcess						0	0	0	0	0	0	0			
	Unit						a	a	a	kg	kg	Nm3	Nm3			
	low active radioactive waste	CH	-	-	0	m3	8.83E+4	2.98E+4	1.05E+5	89%	89%	11%	11%	1	1.05	(3,4,5,3,3,na); Generic assumption
	disposal, municipal solid waste, 22.9% water, to municipal incineration	CH	-	-	0	kg	4.41E+7	1.49E+7	5.25E+7	89%	89%	11%	11%	1	1.05	(3,4,4,3,3,na); Generic assumption
emission water, river	Oils, unspecified	-	water	river	-	kg	0	0	0	0%	89%	0%	11%	1	1.50	(3,4,2,3,3,na); IOGP 2016
	BOD5, Biological Oxygen Demand	-	water	river	-	kg	0	0	0	0%	89%	0%	11%	1	1.50	(3,4,2,3,1,na); Extrapolation for sum parameter
	COD, Chemical Oxygen Demand	-	water	river	-	kg	0	0	0	0%	89%	0%	11%	1	1.50	(3,4,2,3,1,na); Extrapolation for sum parameter
	DOC, Dissolved Organic Carbon	-	water	river	-	kg	0	0	0	0%	89%	0%	11%	1	1.50	(3,4,2,3,1,na); Extrapolation for sum parameter
	TOC, Total Organic Carbon	-	water	river	-	kg	0	0	0	0%	89%	0%	11%	1	1.50	(3,4,2,3,1,na); Extrapolation for sum parameter
	AOX, Adsorbable Organic Halogen as Cl	-	water	river	-	kg	0	0	0	0%	89%	0%	11%	1	1.50	(3,4,2,3,1,na); Extrapolation for sum parameter
	Nitrogen	-	water	river	-	kg	0	0	0	0%	89%	0%	11%	1	1.50	(3,4,2,3,1,na); Extrapolation for sum parameter
	Sulfur	-	water	river	-	kg	0	0	0	0%	89%	0%	11%	1	1.50	(3,4,2,3,1,na); Extrapolation for sum parameter
emission water, ocean	Oils, unspecified	-	water	ocean	-	kg	1.20E+6	5.44E+6	0	89%	0%	11%	0%	1	1.50	(3,4,1,3,3,na); IOGP 2016 plus breakdown of 5 biggest, non-war-related oil spills (catastrophes) on oil platforms between
	BOD5, Biological Oxygen Demand	-	water	ocean	-	kg	3.79E+6	1.71E+7	0	89%	0%	11%	0%	1	1.50	(3,4,1,3,1,na); Extrapolation for sum parameter
	COD, Chemical Oxygen Demand	-	water	ocean	-	kg	3.79E+6	1.71E+7	0	89%	0%	11%	0%	1	1.50	(3,4,1,3,1,na); Extrapolation for sum parameter
	DOC, Dissolved Organic Carbon	-	water	ocean	-	kg	1.04E+6	4.71E+6	0	89%	0%	11%	0%	1	1.50	(3,4,1,3,1,na); Extrapolation for sum parameter
	TOC, Total Organic Carbon	-	water	ocean	-	kg	1.04E+6	4.71E+6	0	89%	0%	11%	0%	1	1.50	(3,4,1,3,1,na); Extrapolation for sum parameter
	AOX, Adsorbable Organic Halogen as Cl	-	water	ocean	-	kg	1.24E+1	5.60E+1	0	89%	0%	11%	0%	1	1.50	(3,4,1,3,1,na); Extrapolation for sum parameter
	Nitrogen	-	water	ocean	-	kg	9.30E+2	4.20E+3	0	89%	0%	11%	0%	1	1.50	(3,4,1,3,1,na); Extrapolation for sum parameter
	Sulfur	-	water	ocean	-	kg	3.22E+3	1.46E+4	0	89%	0%	11%	0%	1	1.50	(3,4,1,3,1,na); Extrapolation for sum parameter
emission to soil	Oils, unspecified	-	soil	unspecified	-	kg	9.51E+5	0	1.22E+6	0%	89%	0%	11%	1	1.50	(3,4,5,3,3,na); IOGP 2016
emission air, low population density	Methane, bromotrifluoro-, Halon 1301	-	air	low population density	-	kg	3.84E+2	1.74E+3	0	89%	89%	11%	11%	1	1.50	(3,4,1,3,3,na); assuming 20% halon compared to Jungbluth 2007
	Methane, trifluoro-, HFC-23	-	air	low population density	-	kg	1.54E+3	6.94E+3	0	89%	89%	11%	11%	1	1.50	(3,4,1,3,3,na); assuming 80% HFC-23 compared to Jungbluth 2007
	Methane, fossil	-	air	low population density	-	kg	0	0	0	89%	89%	11%	11%	1	1.50	(3,4,5,3,3,na); considered in venting
	NMVOC, non-methane volatile organic compounds, unspecified origin	-	air	low population density	-	kg	0	0	0	89%	89%	11%	11%	1	1.50	(3,4,5,3,3,na); Generic data
	Transformation, from forest, unspecified	-	resource	land	-	m2	0	0	0	0%	89%	0%	11%	1	2.00	(3,4,5,3,3,na); included in production well and productin plant
	Transformation, to dump site	-	resource	land	-	m2	0	0	0	0%	89%	0%	11%	1	2.00	(3,4,5,3,3,na); included in production well and productin plant

Tab. 12.10 Life Cycle Inventory of Crude Oil Production, off- and onshore, in the USA 2016, part1

	Name	Location	Category	SubCategory	InfrastructureProcess	Unit	combined gas and oil production	combined gas and oil production offshore	combined gas and oil production onshore	crude oil, at production offshore	crude oil, at production onshore	natural gas, at production offshore	natural gas, at production onshore	UncertaintyType	StandardDeviation95%	GeneralComment
	Location						US	US	US	US	US	US	US			
	InfrastructureProcess						0	0	0	0	0	0	0			
	Unit						a	a	a	kg	kg	Nm3	Nm3			
	crude oil, at production offshore	US	-	-	0	kg	1.02E+11	1.02E+11		100%						
	crude oil, at production onshore	US	-	-	0	kg	4.54E+11		4.54E+11		100%					
	natural gas, at production offshore	US	-	-	0	Nm3	1.65E+10	1.65E+10				100%				
	natural gas, at production onshore	US	-	-	0	Nm3	7.35E+10		7.35E+10				100%			
resource, in ground	Oil, crude	-	resource	in ground	-	kg	5.56E+11	1.02E+11	4.54E+11	100%	100%			1	1.05	(1,1,1,1,1,na); Enerdata 2016
	Oil, crude	-	resource	in ground	-	kg	1.90E+7	4.98E+6	2.21E+7	100%	100%			1	1.11	(1,1,3,1,1,na); including losses due to oil spills
	Gas, natural/m3	-	resource	in ground	-	Nm3	9.00E+10	1.65E+10	7.35E+10			100%	100%	1	1.05	(1,1,1,1,1,na); Enerdata 2016
	Gas, natural/m3	-	resource	in ground	-	Nm3	0	0	0			100%	100%	1	1.13	(2,2,3,1,1,na); considered in venting
water resource	Water, unspecified natural origin, US	-	resource	in water	-	m3	1.63E+8	0	1.63E+8	100%	100%	0%	0%	1	1.16	(3,4,2,3,1,na); IOGP 2016
	Water, salt, ocean	-	resource	in water	-	m3	3.68E+7	3.68E+7	0	100%	100%	0%	0%	1	1.16	(3,4,2,3,1,na); IOGP 2016
	Water, fossil	-	resource	in water	-	m3	3.60E+8	9.60E+7	2.64E+8	100%	100%	0%	0%	1	1.16	(3,4,2,3,1,na); IOGP 2016
water emission	Water, US	-	water	river	-	m3	4.27E+8	0	4.27E+8	100%	100%	0%	0%	1	1.50	(3,4,2,3,1,na); calculation
	Water, US	-	water	ocean	-	m3	1.33E+8	1.33E+8	0	100%	100%	0%	0%	1	1.50	(3,4,2,3,1,na); calculation
	Water, US	-	water	fossil-	-	m3	0	0	0	100%	100%	0%	0%	1	1.50	(3,4,2,3,1,na); calculation
	discharge, produced water, offshore	OCE	-	-	0	kg	1.33E+11	1.33E+11	0	100%	100%	0%	0%	1	1.26	(3,4,2,3,3,na); ANL 2009
	discharge, produced water, onshore	GLO	-	-	0	kg	4.27E+11	0	4.27E+11	100%	100%	0%	0%	1	1.26	(3,4,2,3,3,na); Produced water society 2012; for 21 states, 283MtOE
technosphere	chemicals inorganic, at plant	GLO	-	-	0	kg	2.45E+8	6.42E+7	2.85E+8	88%	88%	12%	12%	1	1.60	(3,4,5,3,3,na); Generic value from Jungbluth 2007 calculated for 15% instead of 3% enhanced oil recovery.
	chemicals organic, at plant	GLO	-	-	0	kg	1.87E+8	4.90E+7	2.18E+8	88%	88%	12%	12%	1	1.60	(3,4,5,3,3,na); Generic value from Jungbluth 2007 calculated for 15% instead of 3% enhanced oil recovery.
	transport, lorry >16t, fleet average	RER	-	-	0	tkm	3.73E+8	9.80E+7	4.35E+8	88%	88%	12%	12%	1	2.34	(3,5,5,3,3,na); Standard distance for chemical transport 100km
	transport, freight, rail	RER	-	-	0	tkm	2.59E+8	6.79E+7	3.02E+8	88%	88%	12%	12%	1	2.34	(3,5,5,3,3,na); Standard distance for chemical transport 600km
	well for exploration and production, onshore	GLO	-	-	1	m	4.46E+7	0	5.46E+7	0%	88%	0%	12%	1	3.06	(2,3,3,1,3,na); EIA 2016
	well for exploration and production, offshore	OCE	-	-	1	m	7.89E+4	4.30E+5	0	88%	0%	12%	0%	1	3.06	(2,3,3,1,3,na); Literature, lifetime 15a, length 2.4km
	pipeline, crude oil, onshore	RER	-	-	1	km	3.07E+3	8.06E+2	3.58E+3	0%	88%	0%	12%	1	3.30	(3,4,5,3,3,na); Generic data
	production plant crude oil, onshore	GLO	-	-	1	unit	5.23E+1	0	6.40E+1	0%	88%	0%	12%	1	3.30	(3,4,5,3,3,na); Wernet 2016, Ecoinvent v3.4, approximated with data for Nigeria, Jungbluth 2007
	platform, crude oil, offshore	OCE	-	-	1	unit	8.84E-1	4.81E+0	0	88%	0%	12%	0%	1	3.30	(3,4,5,3,3,na); Generic data
energy	diesel, burned in diesel-electric generating set	GLO	-	-	0	MJ	1.15E+10	3.03E+9	1.35E+10	88%	88%	12%	12%	1	2.06	(2,3,2,1,3,na); Mean of 3 data sources
	electricity, low voltage, at grid	US	-	-	0	kWh	1.40E+10	3.68E+9	1.64E+10	88%	88%	12%	12%	1	2.06	(2,3,2,1,3,na); Mean of 3 data sources
	heavy fuel oil, burned in industrial furnace 1MW, non-modulating	RER	-	-	0	MJ	4.98E+9	1.31E+9	5.81E+9	88%	88%	12%	12%	1	2.06	(2,3,2,1,3,na); Mean of 3 data sources
	sweet gas, burned in gas turbine, production	NO	-	-	0	MJ	1.17E+12	3.07E+11	1.37E+12	88%	88%	12%	12%	1	2.06	(2,3,2,1,3,na); Mean of 3 data sources
	natural gas, vented	GLO	-	-	0	Nm3	6.45E+9	1.69E+9	7.52E+9	88%	88%	12%	12%	1	10.08	(2,3,1,1,3,na); Generic value according to IEA 2017
	natural gas, sweet, burned in production flare	GLO	-	-	0	Nm3	3.30E+9	8.67E+8	3.85E+9	88%	88%	12%	12%	1	1.21	(1,1,1,1,3,na); World Bank 2017

Life Cycle Inventory of Crude Oil Production, off- and onshore, in the USA 2016, part 2

	Name	Location	Category	SubCategory	InfrastructureProcess	Unit	combined gas and oil production	combined gas and oil production offshore	combined gas and oil production onshore	crude oil, at production offshore	crude oil, at production onshore	natural gas, at production offshore	natural gas, at production onshore	UncertaintyType	StandardDeviation95%	GeneralComment
	Location						US	US	US	US	US	US	US			
	InfrastructureProcess						0	0	0	0	0	0	0			
	Unit						a	a	a	kg	kg	Nm3	Nm3			
	low active radioactive waste	CH	-	-	0	m3	8.84E+4	2.32E+4	1.03E+5	88%	88%	12%	12%	1	1.60	(3,4,5,3,3,na); Generic assumption
	disposal, municipal solid waste, 22.9% water, to municipal incineration	CH	-	-	0	kg	4.42E+7	1.16E+7	5.16E+7	88%	88%	12%	12%	1	1.34	(3,4,4,3,3,na); Generic assumption
emission water, river	Oils, unspecified	-	water	river	-	kg	1.18E+6	0	1.45E+6	0%	88%	0%	12%	1	1.59	(3,4,2,3,3,na); IOGP 2016
	BOD5, Biological Oxygen Demand	-	water	river	-	kg	3.73E+6	0	4.56E+6	0%	88%	0%	12%	1	1.54	(3,4,2,3,1,na); Extrapolation for sum parameter
	COD, Chemical Oxygen Demand	-	water	river	-	kg	3.73E+6	0	4.56E+6	0%	88%	0%	12%	1	1.54	(3,4,2,3,1,na); Extrapolation for sum parameter
	DOC, Dissolved Organic Carbon	-	water	river	-	kg	1.02E+6	0	1.25E+6	0%	88%	0%	12%	1	1.54	(3,4,2,3,1,na); Extrapolation for sum parameter
	TOC, Total Organic Carbon	-	water	river	-	kg	1.02E+6	0	1.25E+6	0%	88%	0%	12%	1	1.54	(3,4,2,3,1,na); Extrapolation for sum parameter
	AOX, Adsorbable Organic Halogen as Cl	-	water	river	-	kg	1.22E+1	0	1.49E+1	0%	88%	0%	12%	1	1.54	(3,4,2,3,1,na); Extrapolation for sum parameter
	Nitrogen	-	water	river	-	kg	9.14E+2	0	1.12E+3	0%	88%	0%	12%	1	1.54	(3,4,2,3,1,na); Extrapolation for sum parameter
	Sulfur	-	water	river	-	kg	3.17E+3	0	3.88E+3	0%	88%	0%	12%	1	1.54	(3,4,2,3,1,na); Extrapolation for sum parameter
emission water, ocean	Oils, unspecified	-	water	ocean	-	kg	9.15E+5	4.98E+6	0	88%	0%	12%	0%	1	1.59	(3,4,1,3,3,na); IOGP 2016 plus breakdown of 5 biggest, non-war-related oil spills
	BOD5, Biological Oxygen Demand	-	water	ocean	-	kg	4.29E+6	2.33E+7	0	88%	0%	12%	0%	1	1.53	(3,4,1,3,1,na); Extrapolation for sum parameter
	COD, Chemical Oxygen Demand	-	water	ocean	-	kg	4.29E+6	2.33E+7	0	88%	0%	12%	0%	1	1.53	(3,4,1,3,1,na); Extrapolation for sum parameter
	DOC, Dissolved Organic Carbon	-	water	ocean	-	kg	4.29E+6	2.33E+7	0	88%	0%	12%	0%	1	1.53	(3,4,1,3,1,na); Extrapolation for sum parameter
	TOC, Total Organic Carbon	-	water	ocean	-	kg	4.29E+6	2.33E+7	0	88%	0%	12%	0%	1	1.53	(3,4,1,3,1,na); Extrapolation for sum parameter
	AOX, Adsorbable Organic Halogen as Cl	-	water	ocean	-	kg	4.29E+6	2.33E+7	0	88%	0%	12%	0%	1	1.53	(3,4,1,3,1,na); Extrapolation for sum parameter
	Nitrogen	-	water	ocean	-	kg	4.29E+6	2.33E+7	0	88%	0%	12%	0%	1	1.53	(3,4,1,3,1,na); Extrapolation for sum parameter
	Sulfur	-	water	ocean	-	kg	4.29E+6	2.33E+7	0	88%	0%	12%	0%	1	1.53	(3,4,1,3,1,na); Extrapolation for sum parameter
emission to soil	Oils, unspecified	-	soil	unspecified	-	kg	3.20E+6	0	3.92E+6	0%	88%	0%	12%	1	1.85	(3,4,5,3,3,na); IOGP 2016
emission air, low population density	Methane, bromotrifluoro-, Halon 1301	-	air	low population density	-	kg	2.48E+2	1.35E+3	0	88%	88%	12%	12%	1	1.59	(3,4,1,3,3,na); assuming 20% halon compared to Jungbluth 2007
	Methane, trifluoro-, HFC-23	-	air	low population density	-	kg	9.93E+2	5.40E+3	0	88%	88%	12%	12%	1	1.59	(3,4,1,3,3,na); assuming 80% HFC-23 compared to Jungbluth 2007

Tab. 12.11 Life Cycle Inventory for production mixes of countries with onshore and offshore production

	Name	Location	InfrastructureProcess	Unit	*crude oil, at production*	*natural gas, at production*	*crude oil, at production*	*natural gas, at production*	*crude oil, at production*	*crude oil, at production*	*natural gas, at production*	UncertaintyType	StandardDeviation95%	GeneralComment
	Location				*SA*	*SA*	*MX*	*MX*	*KZ*	*US*	*US*			
	InfrastructureProcess				*0*	*0*	*0*	*0*	*0*	*0*	*0*			
	Unit				*kg*	*Nm3*	*kg*	*Nm3*	*kg*	*kg*	*Nm3*			
technosphere	crude oil, at production offshore	SA	0	kg	22%							1	1.05	(2,3,1,1,3,5); Share Offshore 2016
	crude oil, at production onshore	SA	0	kg	78%							1	1.05	(2,3,1,1,3,5); Share Onshore 2016
	natural gas, at production offshore	SA	0	Nm3		22%						1	1.05	(2,3,1,1,3,5); Share Offshore 2016
	natural gas, at production onshore	SA	0	Nm3		78%						1	1.05	(2,3,1,1,3,5); Share Onshore 2016
	crude oil, at production offshore	MX	0	kg			75%					1	1.05	(2,3,1,1,3,5); Share Offshore 2016
	crude oil, at production onshore	MX	0	kg			25%					1	1.05	(2,3,1,1,3,3); Share Onshore 2016
	natural gas, at production offshore	MX	0	Nm3				75%				1	1.05	(2,3,1,1,3,3); Share Offshore 2016
	natural gas, at production onshore	MX	0	Nm3				25%				1	1.05	(2,3,1,1,3,3); Share Onshore 2016
	crude oil, at production onshore	KZ	0	kg					76%			1	1.05	(2,3,1,1,3,3); Share Onshore 2016
	crude oil, at production offshore	KZ	0	kg					24%			1	1.05	(2,3,1,1,3,3); Share Offshore 2016
	crude oil, at production offshore	US	0	kg						18%		1	1.05	(2,3,1,1,3,3); Share Offshore 2016
	crude oil, at production onshore	US	0	kg						82%		1	1.05	(2,3,1,1,3,3); Share Onshore 2016
	natural gas, at production offshore	US	0	Nm3							18%	1	1.05	(2,3,1,1,3,3); Share Offshore 2016
	natural gas, at production onshore	US	0	Nm3							82%	1	1.05	(2,3,1,1,3,3); Share Onshore 2016

13 Data quality

The modules for oil production are complete in terms of environmental impacts. However, the variation between different oil fields can be extremely high. A part of the data was just available for single oil fields, for regional averages or for globally operating companies. Thus, it was difficult to establish good estimates on a country level.

To model the market situation, top down data for the reference year 2016 are used. These data can be considered as reliable.

For other relevant inputs and outputs like energy consumption, flaring and venting literature sources show a high variability. A part of the reported information is also only available for smaller (single fields) or larger regions (regional or global data and reports of multi-national oil companies). Thus, the estimates in this study for single countries are not very certain.

The demand for production chemicals is extrapolated based on studies in the North Sea. As enhanced oil recovery is getting more important every day, this value will increase in the future.

The quantities of production water and the proportion of water discharged into surface waters are also partly based on assumptions. The composition of the production waters is estimated based on several measurements and is subject to great fluctuations, which can hardly be estimated.

For data expected to be of lower relevance according to evaluations with the ecological scarcity method 2013, generic data and data for regions, investigated in former reports were used as approximations (e.g. Jungbluth 2007; Stolz & Frischknecht 2017). This data includes e.g. LCI for infrastructure, content of trace elements in spilled oil, composition of chemicals used for EOR and disposal routes for several types of wastes.

For the part of the data which is quite old there seems to be not much interest to investigate these issues further. This also shows that they might not be so relevant from an environmental point of view.

Thus, in summary the data for single countries are a combination of different data sources and it was quite difficult to establish such inventories for single countries due to the difficulties also mentioned at the beginning:

- Environmental impacts of oil extraction depend to a substantial extent on local conditions at the single field (e.g. depth of the oil resource, oil per well, age of field, formation water, on- or offshore, etc.) and less on general technical issues such as energy efficiency or management of oil spills. Thus, they can be quite different per oil field or country.
- Environmental reports of single companies are less detailed than ten years ago, they are often established for global operation and the system boundaries do not match the stages investigated in this study. This makes it more difficult than before to use this type of information for establishing a life cycle inventory.
- Summarizing information for for flaring and venting was available from global estimates. Information by companies representing about one quarter of global oil production was available in regional figures for the energy use, emissions of oil and use of water.
- Some inventories for crude oil and natural gas extraction in other countries investigated in former versions have not been updated. These inventories are not yet harmonized on important assumptions such as energy use, venting and emissions of ozone depleting substances. It would be recommended to update these inventories as well and not to use the currently available LCI anymore as they underestimate the impacts considerable.

All the issues mentioned before might sound as if the data have not been improved with this update. But, due to more information available, uncertainties are also known better, which leads to this more differentiated picture. Altough the amount of data considered has been increased considerable, the uncertainty for some issues is still high or even increased. The present data is an improvement compared to the former version because:

- Assumptions are harmonized, and cross checked between different countries. Thus, the former bias e.g. due to lack of information is avoided.
- Information for several single aspects was revised and checked again. Therefore, several new data sources were consulted.
- With the increased amount of information used for this study, possible uncertainites and variations of data are now known better.
- Data for additional countries relevant for the European and Swiss supply situation were newly investigated.
- Several background data sets (e.g. composition of vented gas and produced water) are revised and updated with current data.
- Estimates for the most important aspects like venting, flaring, energy use, emission of oil and use of water are each based on one consistent source of data.

14 Life cycle impact assessment

14.1 Crude oil production

Tab. 14.1 shows the key indicator results for the processes which have been investigated in this report.

Venting of gases is an important contributor for climate change related indicators. Direct energy uses and flaring or relevant for the climate change and cumulative energy demand.

Produced water is most dominant for emissions to water, which is accounted for in the ecological scarcity method. For Russia and Kazakhstan countriy specific data was available in a former study. These data explain the highest results for these two countries.

Extraction in Mexico and US shows high results due to a bad performance per well. This results in a high energy consumption per kg oil equivalent. The lowest environmental impacts are shown for Saudia Arabia. It can be assumed that the conditions for extraction are still good in the Middle East. However, the global warming potential in Iraq is much higher due to a higher measured flaring intensity. It might be worth to investigate the difference between these two countries in more detail. If the same amount of gas would be directly released instead of flared in Saudi Arabia this would turn the results upside down.

Tab. 14.1 Key indicator results for the updated processes investigating crude oil extracted for the Swiss and European market in 2016 (red marks highest and green lowest values per column of special interest)

technology	reference value	primary energy factor, total	primary energy factor,fossil	primary energy factor, nuklear	primary energy factor, renewable	CO2 equivalents	eco-points
		MJ-eq	MJ-eq	MJ-eq	MJ-eq	kg CO2-eq	eco-points 2013
production onshore /RU	kg OE	50.4	50.0	0.30	0.12	0.53	1'073
production /NG	kg OE	50.3	50.2	0.05	0.02	0.58	627
production offshore /KZ	kg OE	48.9	48.9	0.02	0.02	0.46	1'221
production onshore /KZ	kg OE	50.0	49.8	0.18	0.07	0.52	1'095
production /KZ	kg OE	49.8	49.6	0.14	0.06	0.50	1'125
production offshore /NO	kg OE	48.0	47.9	0.01	0.12	0.37	657
production /IQ	kg OE	50.8	50.6	0.10	0.04	0.65	805
production offshore /MX	kg OE	51.8	51.7	0.06	0.06	0.64	885
production onshore /MX	kg OE	53.1	52.8	0.20	0.12	0.73	971
production /MX	kg OE	52.1	52.0	0.09	0.07	0.66	906
production offshore /SA	kg OE	47.1	47.1	0.02	0.01	0.32	678
production onshore /SA	kg OE	47.5	47.3	0.10	0.03	0.33	623
production /SA	kg OE	47.4	47.3	0.08	0.03	0.33	635
production offshore /US	kg OE	50.2	50.0	0.12	0.03	0.51	882
production onshore /US	kg OE	53.0	52.6	0.30	0.14	0.69	1'110
production /US	kg OE	52.5	52.1	0.27	0.12	0.66	1'068
production offshore /GB	kg OE	48.2	48.1	0.02	0.02	0.15	819
production offshore /NL	kg OE	46.6	46.5	0.03	0.02	0.06	654
production onshore /NL	kg OE	46.3	46.2	0.02	0.01	0.04	189
production onshore RAF	kg OE	49.9	49.5	0.32	0.11	0.38	543
production onshore RME	kg OE	47.2	47.2	0.02	0.03	0.14	375

In Tab. 14.2, results for crude oil extraction, modelled in this study, are compared with the results in the former version of available production data (Jungbluth 2007; KBOB v2.2: 2016).

Tab. 14.2 LCIA-comparison of updated and former datasets for crude oil production

technology	reference value	primary energy factor, total		eco-points		CO2 equivalents	
		MJ-eq		eco-points		CO2 equivalents	
production onshore /RU	kg OE	51.6	50.4	1611	1073	0.38	0.53
production /NG	kg OE	53.2	50.3	836	627	0.81	0.58
production offshore /KZ	kg OE	49.7	48.9	980	1221	0.18	0.46
production onshore /KZ	kg OE	50.6	50.0	1463	1095	0.29	0.52
production offshore /NO	kg OE	47.0	48.0	374	657	0.08	0.37
Source		KBOB v2.2: 2016	This study	KBOB v2.2: 2016	This study	KBOB v2.2: 2016	This study

Some findings are:

- In Russia lower air pollution results due to reduced flaring, but higher venting relevant for GWP
- In Kazakhstan a higher GWP due to new estimate for venting.
- In Norway, a higher GWP and PM results due to increased flaring and venting.

The influence of various sources for the impacts on climate change is evaluated further in Fig. 14.1. The main impact is in most cases due to the venting emissions which are estimated with a global average value. For emissions due to flaring considerable differences can be observed in different countries. Use of energy for drilling and production is split up into the use of heavy fuel oil (HFO), natural gas and diesel. All other contributions including electricity consumption are covered in the last category.

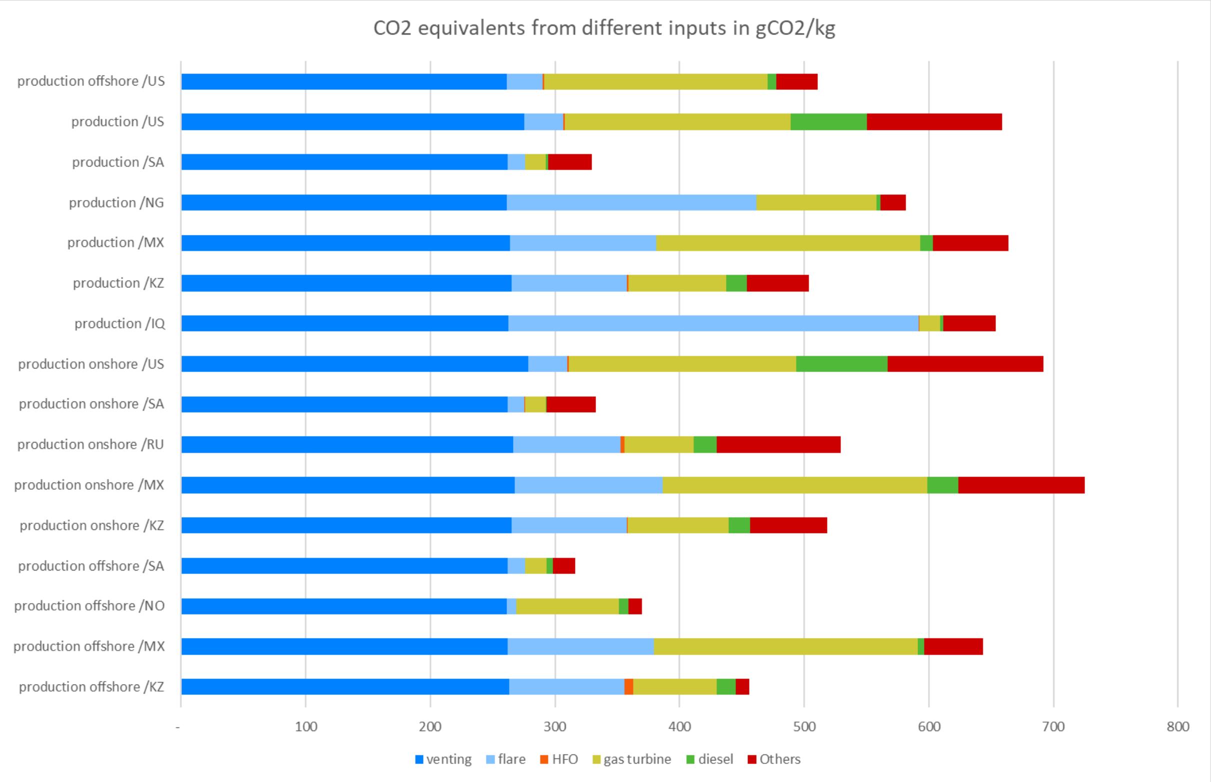

Fig. 14.1 Climate change impacts of crude oil explorations due to different source categories

14.2 Natural gas production

As crude oil production was modelled for most countries together with natural gas extraction, also the datasets for natural gas production can be analysed (see Tab. 14.3). Here only data for Norway was available in a former study (bottom line of Tab. 14.3).

Tab. 14.3 Key indicator results for the updated and obsolete processes investigating natural gas and comparison with data for other countries (red marks highest and green lowest values per column of special interest)

technology	reference value	primary energy factor, total [MJ-eq]	primary energy factor,fossil [MJ-eq]	primary energy factor, nuklear [MJ-eq]	primary energy factor, renewable [MJ-eq]	CO2 equivalents [kg CO2-eq]	eco-points [eco-points 2013]
natural gas, at production/m3/NG	m3	42.1	42.0	0.04	0.02	0.49	440
natural gas, at production offshore/m3/NO	m3	40.3	40.1	0.01	0.11	0.31	474
natural gas, at production/m3/IQ	m3	42.5	42.4	0.09	0.03	0.55	483
natural gas, at production/m3/MX	m3	43.6	43.5	0.08	0.06	0.56	646
natural gas, at production onshore/m3/SA	m3	39.7	39.6	0.08	0.03	0.28	330
natural gas, at production onshore/m3/US	m3	44.4	44.0	0.25	0.12	0.58	757

In Norway, like for the crude oil extraction, also for natural gas, the GWP for natural gas extraction is higher in this study due to a higher venting rate.

The GWP for natural gas extraction in US and Mexico is higher than for other countries, mainly due to a higher amount of wells/sites needed per m3 extracted.

14.3 Comparison with literature data

The greenhouse gas emissions of crude oil production have been investigated in several models. These models also show a large variation which confirms the uncertainties behind such estimations. Fig. 14.2 shows a comparison of the results as evaluated in an EU study (ICCT 2014).

Generally, the results in this study are distinct higher than in these estimates due to the actual and more complete estimates for venting emissions.

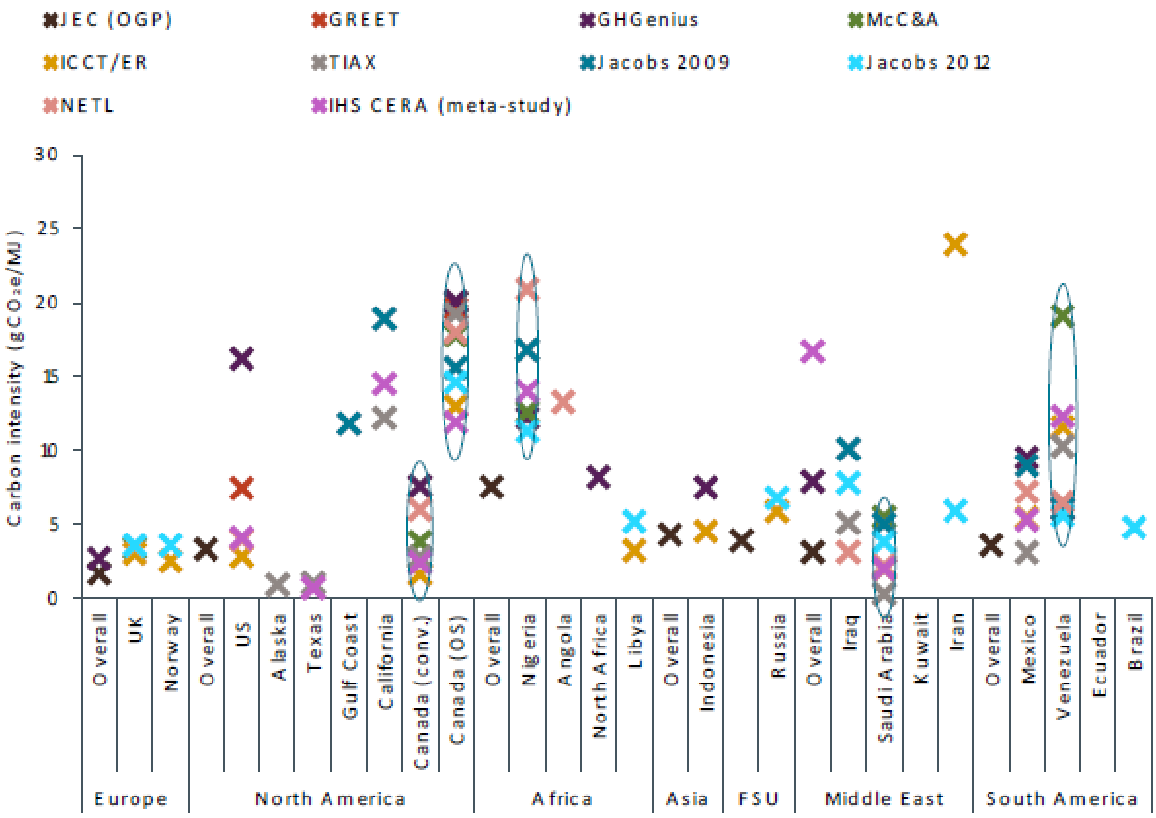

Fig. 14.2 Upstream crude oil carbon footprint emissions from literature studies (ICCT 2014)

In Tab. 14.4 values from this EU study are compared with the values calculated in this study. The EROEI is calculated as the lower heating value of crude oil divided by the calculated (CED_{fossil} – $LHV_{crude\ oil}$).

The information for the EROEI (direct model) is taken from Tab. 8.1.

Values modelled with this life cycle approach are higher than these in the EU study. This is mainly due to the inclusion of cumulative energy uses instead of only direct energy uses.

For comparison also older, not updated data are shown in Tab. 14.4 (font in light grey). There data for crude oil extraction in the Netherlands seems to be outdated and too optimistic.

Tab. 14.4 Comparison of the greenhouse gas emissions and EROEI for crude oil with data from literature

technology	CO2 equivalents	CO2-eq direct (IOGP2015)	Range EU study	EROEI (this study)	EROEI (direct model)	EROEI (in literature)	Comments
	gCO2/MJ	gCO2/MJ	gCO2/MJ	-		-	
production onshore /RU	12.2	2.3	3-7.5	11	17	24	CO2-eq higher mostly due to higher venting rate
production /NG	13.5	4.9	10-22	10	14	17	
production offshore /KZ	10.5	2.3	3-7.5	15	25	23	CO2-eq higher mostly due to higher venting rate
production onshore /KZ	12.0	2.3	3-7.5	12	19	23	CO2-eq higher mostly due to higher venting rate
production /KZ	11.7	2.3	3-7.5	12	20	23	CO2-eq higher mostly due to higher venting rate
production offshore /NO	8.6	1.3	2.5-4	22	22	22	CO2-eq higher mostly due to higher venting rate
production /IQ	15.1	1.3	3-10	9	11	11	CO2-eq higher mostly due to higher venting and flaring rate
production offshore /MX	14.9	3.0	3-10	8		20	CO2-eq higher mostly due to higher venting rate and high amount of wells needed
production onshore /MX	16.8	3.0	3-10	7		20	CO2-eq higher mostly due to higher venting rate and high amount of wells needed
production /MX	15.4	3.0	3-10	7	20	20	CO2-eq higher mostly due to higher venting rate and high amount of wells needed
production offshore /SA	7.3	1.3	1-5	35		49	CO2-eq higher mostly due to higher venting rate
production onshore /SA	7.7	1.3	1-5	30		49	CO2-eq higher mostly due to higher venting rate
production /SA	7.6	1.3	1-5	31	49	49	CO2-eq higher mostly due to higher venting rate
production offshore /US	11.8	6.3	3-17	11		8	CO2-eq higher mostly due to higher venting rate and high amount of wells needed
production onshore /US	16.0	6.3	3-17	7		8	CO2-eq higher mostly due to higher venting rate and high amount of wells needed
production /US	15.2	6.3	3-17	7	7	8	CO2-eq higher mostly due to higher venting rate and high amount of wells needed
production offshore /GB	3.4		3-4	20			Impacts seem to be heavily underestimated. Obsolete.
production offshore /NL	1.3		2-4	65			Impacts seem to be heavily underestimated. Obsolete.
production onshore /NL	0.8		2-4	102			Impacts seem to be heavily underestimated. Obsolete.
production onshore RAF	8.8			12			Replaced now by NG
production onshore RME	3.1			33			Replaced now by SA and IQ

15 Outlook

As explained at the beginning of this report and in the chapter on data quality, it was difficult to generate reliable country specific datasets for oil production. The applied technology and occurring emissions can vary largely depending on geological situation, oil type, company and national laws.

One option to overcome this situation might be to establish future LCI based on information for single companies. With this more up-to-date information sources could be used. But, it might be difficult to find then statistical data for the deliveries of these companies to certain regions like Europe or Switzerland. Furthermore, reporting of these companies might use different system boundaries compared to the data structure used here.

The IOGP published environmental key data over the last years per continent (IOGP 2017). The data are based on a survey from different oil producing companies representing about one quarter of global oil production. Using these data does allow a more consistent modelling of data per continent, but a critical evaluation of such summarized data e.g. for reported emissions due to venting is difficult. Furthermore, the data do not fit with the present structure of life cycle inventory modelling taking additional aspects like e.g. drilling metres into account.

Another possibility would be to establish a global dataset for crude oil extraction. With this it would be possible to use also more information from global statistical data sources and environmental reports of multi-national companies. But, then no short-term changes in the supply situation for Europe and Switzerland could be modelled anymore.

In theory it would also be possible to base the estimates on better assumptions concerning the technology applied in oil extraction, e.g. share of EOR. But, also here many datagaps would exist.

One other option might be better to investigate worst and best-case technologies. A data user could then check if the provider of crude oil meets the customers' demands regarding certain criteria.

Thus, finally there might be range of different options for modelling. But, in all of these it will never be possible to use all datasources together.

As mentioned in chapter 9.1 estimates for methane emissions related to fossil fuel extraction are highly uncertain. As this factor is highly relevant for the LCIA of crude oil products, it would be recommended to investigate this topic on global and national level for the next update.

As explained in chapter 9.3, due to lack of LCI data for the flame-retardant FK-5-1-12, the replaced Halon 1301 had to be modelled completely with HFC-23. Like this, the impacts on climate change due to the use of flame retardants might be overestimated. To fix this, the production of FK-5-1-12 should be modelled for ecoinvent and global amounts for each flame retardant should be gathered.

With this new update, the LCI data of natural gas supply chain are not fully harmonized anymore with the new assumptions made in this report. For avoiding a bias in the cross comparison, it is recommended to update the data on natural gas as soon as possible. Most urgent would be a harmonization concerning the estimates for venting emissions.

In the future the re-injection of CO_2 as a means of carbon capture storage (CCS) and a replacement of injected water might become more important and thus should be included in the analysis.

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