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Life cycle inventories of long-distance transport of crude oil

BFE, BAFU, Erdöl-Vereinigung

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Life cycle inventories of long-distance transport of crude oil

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
NER	Net Energy Return
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 Overview

This document describes the update of data from version v2.0 of the ecoinvent database (Jungbluth 2007). The German report has been 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 citied 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. Therefore, the content of this document does not reflect the LCI data of ecoinvent v3.

The life cycle inventory analysis for the transport of crude oil from different countries of origin to the refineries in Europe and Switzerland is modelled in this report. The investigation starts at the oil field in a foreign country and ends with the delivery of crude oil to the Swiss or the average European refinery.

Since the first edition of these data the import to Europe was modelled from a Swiss perspective only. Thus, imports were classified according to their relevance for the delivery of refinery products to the Swiss market. The data were thus not accurate in view of the average European production.

For this edition the transport to the European refinery is newly modelled according to the definition of the datasets for long-distance transports and refineries as an average for the supply situation to Europe. The inventories on long distance transports are then used as an input to model the life cycle inventory of oil refinery products produced in Switzerland and Europe (Jungbluth et al. 2018).

As the market situation changed (Meili & Jungbluth 2018), new suppliers for crude oil entered the market and therefore new transport routes were investigated for crude oil imported to Switzerland and Europe from Iraq and Saudi Arabia. Furthermore, the existing datasets for Russia, Nigeria, Kazakhstan, Norway, Mexico and the USA have been updated according to latest available information.

To simplify future modelling, aggregated datasets for crude oil import mix to Switzerland and to Europe are newly generated. All newly investigated and updated datasets for production, at long distance transport are listed in Tab. 1.1.

Tab. 1.1 Newly investigated (blue), updated (green) datasets from former study, used to model crude oil import situation in 2016

Name of dataset	Origin	Destination
crude oil, production RU, at long distance transport	Russia	Switzerland
crude oil, production NG, at long distance transport	Nigeria	
crude oil, production KZ, at long distance transport	Kazakhstan	
crude oil, production NO, at long distance transport	Norway	
crude oil, production IQ, at long distance transport	Iraq	
crude oil, production MX, at long distance transport	Mexico	
crude oil, production SA, at long distance transport	Saudi Arabia	
crude oil, production US, at long distance transport	USA	
crude oil, import mix, at long distance transport	GLO	
crude oil, production RU, at long distance transport	Russia	Europe
crude oil, production NG, at long distance transport	Nigeria	
crude oil, production KZ, at long distance transport	Kazakhstan	
crude oil, production NO, at long distance transport	Norway	
crude oil, production IQ, at long distance transport	Iraq	
crude oil, production MX, at long distance transport	Mexico	
crude oil, production SA, at long distance transport	Saudi Arabia	
crude oil, production US, at long distance transport	USA	
crude oil, import mix, at long distance transport	GLO	

In recent years, oil losses in Europe have continued to decline. It is assumed, that this is a global trend. Therefore, amount of spilled crude oil in pipelines is updated according to latest data (CONCAWE 2017).

For the infrastructure, the formerly consulted literature information on data for pipelines, relevant for the environment (specific energy demand, emissions air and water, maintenance, energy carrier of pipeline driving systems etc.) is assumed to be still valid (c.f. Jungbluth 2007) and no update was commissioned for this.

2 Market situation

In 2016, crude oil is imported predominantly directly or indirectly[1] to Switzerland from eight different countries as shown later in this chapter, in Tab. 2.3 (Erdöl-Vereinigung 2017).

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

2.1 Swiss refinery

Since 2015 there is only one refinery running in Switzerland. As shown in Tab. 2.1, in 2016 crude oil was directly imported to Switzerland mainly from Nigeria, the USA, Mexico and Kazakhstan (Erdöl-Vereinigung 2017).

Tab. 2.1 Tons of crude oil imported to Switzerland 2016 (Erdöl-Vereinigung 2017)

Origin	Tons of crude oil	Percentage
Nigeria	1'013'197	35%
USA	493'632	17%
Mexico	481'927	17%
Kazakhstan	465'145	16%
Russia	225'596	8%
Iraq	135'121	5%
Libyen	60'882	2%
Total	**2'875'500**	**100%**

Datasets for crude oil production, at long distance transport were already existing for Russia, Nigeria, Kazakhstan, Mexico and the USA. They have been updated according to latest available information. For Iraq a new dataset is created.

All of the imported crude oil is transported through the Pipeline Oléoduc du Jura Neuchâtelois from the port in Marseilles to the refinery (Erdöl-Vereinigung 2017). The length of the Pipeline is estimated with 600 km.[2]

2.2 European refineries delivering to Switzerland

Most crude oil consumed in Switzerland enters the borders in processed, refined form as an oil product like heavy, light or heating oil, etc. The crude oil for imports of mineral oil products to Switzerland is mostly refined in Germany, Belgium, France and the Netherlands as presented in Tab. 2.2 (Erdöl-Vereinigung 2017).

Tab. 2.2 Tons of refinery products imported to Switzerland 2016 (Erdöl-Vereinigung 2017)

Origin	Tons of products	% of all products
Germany	4'184'383	54%
Belgium	1'092'065	14%
France	940'530	12%
Italy	786'609	10%
Netherlands	668'782	9%
other EU-countries	85'881	1%
other non-EU-countries	19'658	0%
Total	**7'777'908**	**100%**

Each of these countries imports different shares of crude oil from different origins, depending on different access to import hubs, capabilities, purchase and selling prices, etc. For example, Northern Europe mainly refines light crude oil, Eastern Europe mainly heavy crude oil. However, most of these refinery products are there to meet the European demand and will therefore afterwards be distributed

[2] Distance measured on www.maps.google.com, online 05.10.2017

across Europe. As information about refinery technologies to distinct between different refinery locations is scarce and therefore the modelling of different refineries would increase work load and complexity the model is simplified.

Such a detailed investigation of these indirect imports of crude oil was not commissioned for this project.

2.3 Countries of origin modelled for this study

As explained before, in 2016, crude oil is imported according to these modelling assumptions predominantly directly (see Tab. 2.1) or indirectly[3] (see Tab. 2.2 and Tab. 3.1) to Switzerland from eight different countries as shown in Tab. 2.3 (Erdöl-Vereinigung 2017). The crude oil extraction was modelled for these most important countries from the Swiss perspective (Meili & Jungbluth 2018).

Tab. 2.3 Crude oil directly and indirectly (refined from Europe) imported to Switzerland in 2016 according to the modelling in this study (blue = new, green = updated in this study)

Imports of crude oil from	direct to Switzerland	indirect via Europe
Russia	7.8%	**32%**
Nigeria	**35.2%**	6%
Kazakhstan	**16.2%**	7%
Norway		**12%**
Iraq	4.7%	**8%**
Mexico	**16.8%**	3%
Saudi-Arabia		**8%**
USA	**17.2%**	
Azerbaijan		4%
Libya	2.1%	2%
Algeria		3%
Egypt		1%
Other countries		14%
Total	100%	100%
Imports to Switzerland in 2016 [tons]	**2'875'500**	**7'777'908**
Type of good	**Crude oil**	**Products**

The market situation might change quite rapidly in the future. In a certain year Switzerland might also import crude oil from Norway or Saudi-Arabia and at the same time, the share of crude oil from the US also might increase on the European market. To be prepared for such a change, new datasets are generated for crude oil, at long distance transport from Norway or Saudi-Arabia to Switzerland and from US to the European market. These datasets are created with small additional effort.

3 Transport routes

It is assumed that all crude oil directly imported to Switzerland enters the European mainland through the seaport in Marseille (FR).

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

Crude oil imported for the European average refinery is assumed to be transported to refineries located in the North, East and South of Europe. For this it is assumed that crude oil from Norway, Mexico and the US enters the European mainland via Rotterdam in the North. Rotterdam figures as an approximation, as the port lies in-between Le Havre in France and Hamburg in Germany. Crude oil imported from Russia enters Europe on the mainland via pipelines and is assumed to be refined mainly in Eastern European refineries. Crude oil from Nigeria, Kazakhstan, Iraq and Saudi-Arabia is assumed to be shipped to Marseille mainly for refineries in the South of Europe.

In former studies, the idea was to model transport to an European refinery which delivers its products exclusively to Switzerland (Jungbluth 2007; Stolz & Frischknecht 2017).

In this study however, the overall European average is modelled to have datasets in KBOB/ecoinvent databases representing the correct crude oil import mix for the refineries in Europe. Therefore, several distances estimated here might deviate from these former studies.

3.1 Transport from extraction site to seaport in Europe

If not stated differently, all distances for transport in pipelines and on open sea, stated in the following chapters are taken from online maps[4, 5], and/or from former studies (Jungbluth 2007; Stolz & Frischknecht 2017).

For countries that produce a smaller share offshore (Nigeria, Kazakhstan, Mexico, Saudi-Arabia and USA), a generic value of 20km offshore pipeline is assumed. For Norway, where 100% of crude oil is produced offshore, 200km offshore pipeline are assumed. An overview on modelled transport routes is given in Tab. 3.2.

3.1.1 Russia

There are various transport routes for Russian crude oils. In addition to the mainland route by pipeline, crude oil can reach Rotterdam in summer via the Baltic Sea or (all year round) via Odessa through the Black Sea to the Mediterranean Sea. In a former study, for the North Sea region, the pure mainland route is adopted (2000 km pipeline from the refinery to transhipment in Europe), for the Mediterranean region 200 km pipeline and 1,000 km tankers are used from the refinery. These were own assumptions and estimates (Jungbluth 2007).

In a later study, it is stated that crude oil produced in Russia and Central Asia is transported via onshore pipelines to Novorossiysk on the Black Sea and then transported by oil tankers to Fos-sur-Mer near Marseille (Stolz & Frischknecht 2017). In the same study, for transport to Rotterdam, 260km in onshore pipelines and 5200km in tankers and for transport to Marseille, 5740km by pipeline and 1000km by tanker is modelled (Stolz & Frischknecht 2017).

Both mentioned sources seem to underestimate the distance from the Black Sea to Marseille (FR). According to online maps[6, 7] the distance is about 3400km, and therefore more than 3 times longer.

According to the Harvard World Map[8] (see Fig. 3.1) for crude oil production, largest production fields in Russia seem to be on the same degree of longitude as Yekaterinburg and further east. For this study, therefore, it is assumed that oil with destination Europe and Switzerland is produced on average in Yekaterinburg.

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4 Distances for pipeline transport are taken from: www.maps.google.com, online 05.10.2017
5 Distances for oceanic transport are taken from www.searates.com, online 05.10.2017
6 Distances for pipeline transport are taken from: www.maps.google.com, online 05.10.2017
7 Distances for oceanic transport are taken from www.searates.com, online 05.10.2017
8 http://worldmap.harvard.edu/maps/6176, online 18.01.2018

For the average European refinery mix it is now assumed that crude oil from Russia is mainly refined in Eastern European refineries. As approximation for the destination, the Czech Republic is assumed. This leads to a total of 3600km by pipeline transport onshore. For the transport to Switzerland, the route via the Black Sea to Marseille with 2600km by onshore pipeline and 3400km by ship is modelled.

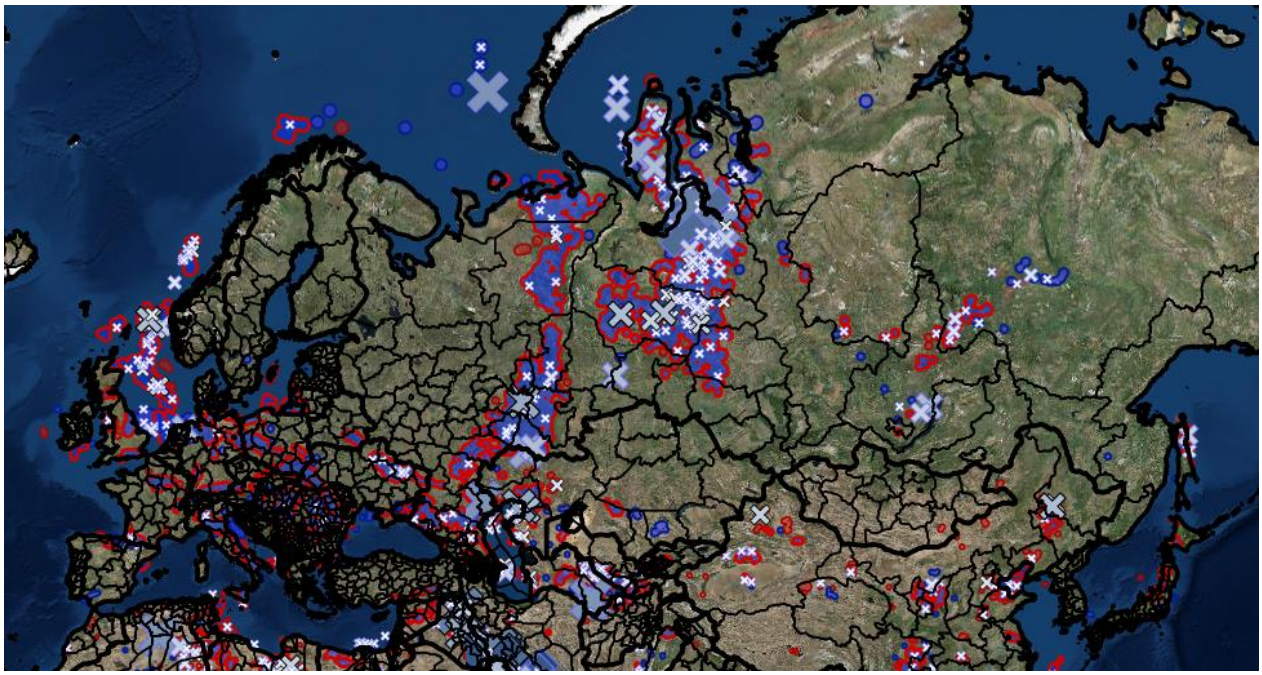

Fig. 3.1 Crude oil production in Europe according to Harvard World Map[8]

3.1.2 Nigeria

Nigerian oil tankers ship oil along the west-coast of Africa and reach the Mediterranean Sea via Gibraltar. Transports with 20km offshore pipeline are newly estimated in this study. The distances of 140km in onshore pipelines and 8000km by tanker from port Onne (in Nigeria) to Marseille are taken from a former study (Stolz & Frischknecht 2017).

3.2 Average European refineries

Only the average European refinery and thus the average supply of crude oil to this refinery is modelled. The modelled crude oil mix is equivalent to the European average mix (see Tab. 3.1)[3].

Tab. 3.1 Origin and share of crude oil imported to Europe 2016

Origin	Tons of crude oil	Percentage
Russia	176'495'741	32%
Norway	66'740'224	12%
Iraq	45'066'281	8%
Saudi-Arabia	43'902'207	8%
Kazachstan	39'633'937	7%
Nigeria	31'097'397	6%
Azarbaidschan	24'002'090	4%
Algerien	16'019'871	3%
Iran	15'687'279	3%
Angola	14'523'205	3%
Mexiko	13'968'884	3%
Libyen	13'248'267	2%
Kuwait	7'815'923	1%
Ägypten	6'707'282	1%
others	39'412'209	7%
Total	**554'320'796**	**100%**

To model this situation, datasets for crude oil production, at long distance transport, existing datasets for Russia, Norway, Nigeria, Kazakhstan and Mexico have been updated according to latest available information and new datasets for Iraq and Saudi-Arabia are created.

Datasets for crude oil production, at long distance transport were already existing for Russia, Norway, Nigeria, Kazakhstan and Mexico. They have been updated according to latest available information. For Iraq and Saudi-Arabia new datasets are created.

3.2.1 Kazakhstan

Crude oil from Kazakhstan (and Azerbaijan) is transported via pipeline to the Black Sea and then with oil tankers to the Mediterranean Sea. A 20km offshore pipeline transport is estimated to cover offshore production in Kazakhstan. The distance of 1940km in onshore pipelines is taken from a former study (Stolz & Frischknecht 2017). However, sea transport with 1000km seems to be underestimated there. Therefore, in this study the estimate is higher based on online maps[4,5]. Distance to Marseille is modelled with 3’700 km.

3.2.2 Norway

Crude oils from the North Sea are transported through offshore pipelines with an estimated length of 200km to the Norwegian mainland for reloading to oil tankers. The oil tankers then travel to Rotterdam. If crude oil from Norway would be refined in Switzerland it is assumed, that it would be transported by tanker from port Bergen to Marseille with a measured distance of 4’700 km.

3.2.3 Iraq

According to the “project of common interest- interactive map” of the European commission, crude oil is transported through an onshore pipeline from Bagdad to the port Ceyhan in the south-east of Turkey (European Commission 2017). At port Ceyhan the crude oil is reloaded to oil tankers and shipped to Europe. The pipeline has a length of 970km. Port for export of crude oil is assumed to be in the south east of Turkey, in Ceyhan. Distance to Marseille is 2’900 km.

This pipeline is capable to transport about 82 Mt of crude oil per year[9].

The total import of crude oil to Europe in 2016 was 45Mt of crude oil (cf. Tab. 3.1).

Therefore, it is assumed that the total demand of Europe and Switzerland is covered through this pipeline.

For other countries in the East, South and West, direct shipping from the South-East-cost of Iraq seems more realistic.

3.2.4 Mexico

Mexico is one of the largest oil producers in the world (2.1 million barrels per day in 2016), and the third-largest in the Americas after the United States and Canada.[10] About 76 percent of production comes from offshore fields.[11] 200 km pipeline offshore and 100 onshore are assumed for transports to the harbour. Port for export of crude oil is assumed to be in Altamira. Distance to Marseille (for destination Switzerland) is 10'300 km and distance to discharge ports Rotterdam, Anvers, Wilhelms-haven (North Sea) is 10'000 km.

3.2.5 Saudi Arabia

Saudi-Arabia transfers its pre-treated crude oil from Abqaiq in the West to East (the Red Sea), via the pipeline Abqaiq-Yanbu with a total length of 1300 km. At the port of Yanbu, the crude oil is reloaded to tankers and shipped through the Suez Canal to Europe. The port for export of crude oil is assumed to be in Yanbu. Distance to Marseille is 4'100 km.

3.2.6 United States of America

In 2016, the United States imported about 50% more crude oil than it exported[12]. To have an accurate model of the transport emissions of the crude oil sold to Europe or Switzerland, the trading flows would have to be analysed in detail.

The former study suggests 1140km onshore and 150km offshore pipelines to the port in Houston (Jungbluth 2007). In that study the transport of onshore crude oil production in the USA, the two states with the highest production volumes were considered[13]. The location of the oil fields in Texas and North Dakota has been identified using maps from the U. S. Energy Information Administration. According to a newer study, distance to Marseille (for destination Switzerland) is 10'100 km and distance to discharge ports Rotterdam, Anvers, Wilhelmshaven (North Sea) is 9'700 km (Stolz & Frischknecht 2017). According to ArcGIS-data from 2016[14] (see Fig. 3.2), these assumptions for the length of onshore pipelines seem to be plausible also as technology changed in recent years and a higher amount of crude oil is produced with fracking.

9 https://en.wikipedia.org/wiki/Kirkuk%E2%80%93Ceyhan_Oil_Pipeline, online 01.10.2018
10 https://www.export.gov/article?id=Mexico-Upstream-Oil-and-Gas, online 02.10.2017
11 http://oilprice.com/Energy/Crude-Oil/Can-Mexico-Reverse-Its-Steep-Output-Decline.html, online 02.10.2017
12 Imports and Exports 2016: https://www.eia.gov/tools/faqs/faq.php?id=727&t=6, online 13.11.2017
13 https://www.eia.gov/dnav/pet/pet_crd_crpdn_adc_mbbl_a.htm, online 18.01.2018
14 Drilling Maps: https://www.arcgis.com/home/item.html?id=a03b2e1da77c4c93b7cad628c0f268be, online 13.11.2017

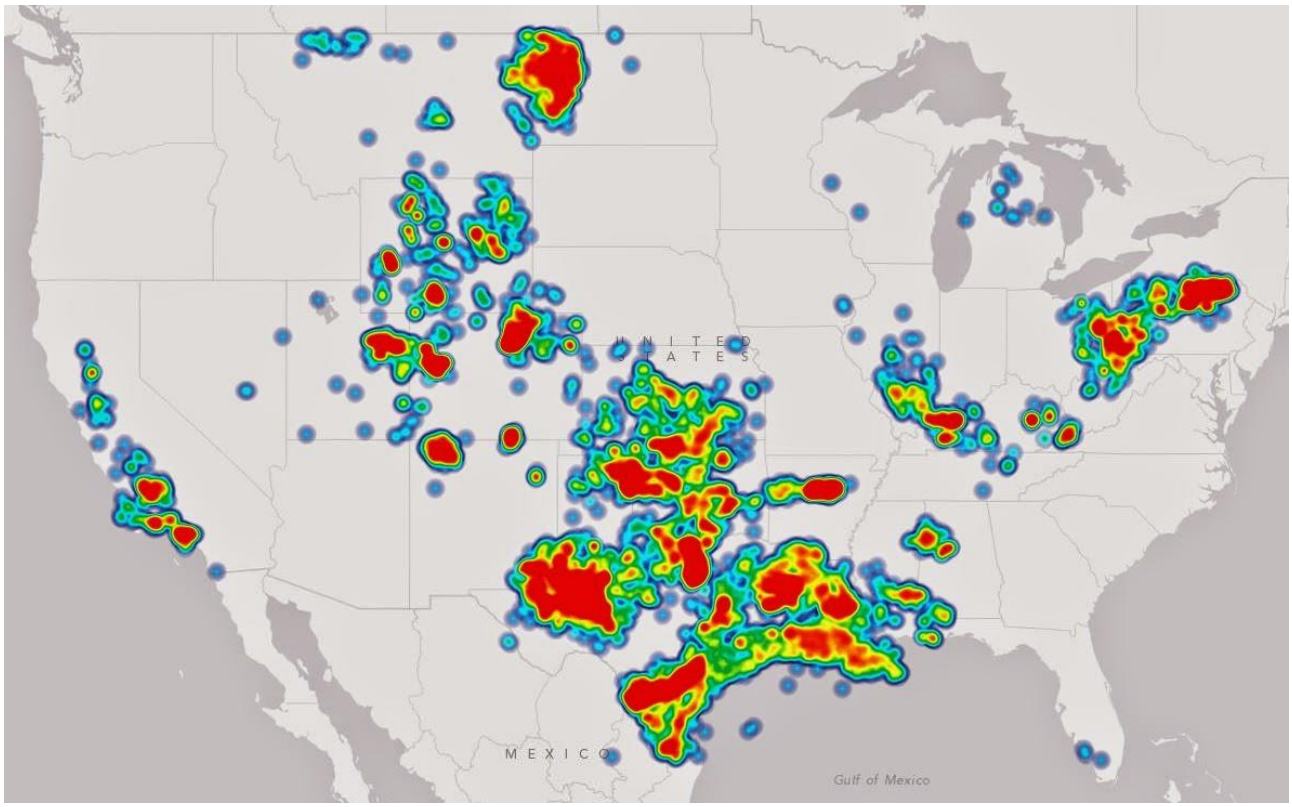

Fig. 3.2 Map of oil & natural gas drilling in the US, 2016, red and yellow colour means high and blue and green colour means lower intensities, according to ArcGIS-data from 2016[14]

3.3 Transport from seaport to refineries

3.3.1 From seaport in Marseille to Switzerland

As mentioned in chapter 2.1, crude oil directly imported to the Swiss refinery in Cressier is transported through the Pipeline Oléoduc du Jura Neuchâtelois from the port Fos-sur-Mer close to Marseille in France (Erdöl-Vereinigung 2017). The length of the Pipeline is measured with 600 km[15].

3.3.2 From seaport to European refinery

Most refineries in Europe are situated close to seaports as visible in Fig. 3.3. Therefore, distances for transport of crude oil, onshore to refineries are assumed to be on average about 100km in onshore pipelines.

[15] Distance measured on www.maps.google.com, online 05.10.2017

Fig. 3.3 Location of European refineries - Interactive map of the European commission (European Commission 2017)

3.4 Summary for the distances and means of transport

The following tables give an overview on the distances described in the chapters above, which are used to model the life cycle inventory of long distance transports of crude oil to Switzerland (Tab. 3.2) and Europe (Tab. 3.3). Where available and plausible, values were kept in line with the latest studies (Jungbluth 2007; Stolz & Frischknecht 2017).

With the proportions of different modes of transport, the distances covered and the amounts of crude oil and products (see Tab. 2.3), theoretical transports per tonne of crude oil from the production country to Switzerland/Europe are calculated. These values are presented as global average to Marseilles and Rotterdam in Tab. 3.2.

Tab. 3.2 Overview of transport distances used for modelling of long-distance transports to Switzerland

Origin	Port of origin	Port of destination	Destination	Distance offshore pipeline origin	Distance onshore origin	Distance sea	Distance destination port to refinery	Total distance pipeline onshore	Share of total import (by weight)
				km	km	km	km	km	km
Russia	Novorossiysk	Marseilles	Cressier (CH)	-	2'600	3'400	600	3'200	8%
Nigeria	Onne	Marseilles	Cressier (CH)	20	140	8'000	600	740	35%
Kazakhstan	Poti	Marseilles	Cressier (CH)	20	1'940	3'700	600	2'540	16%
Norway	Oslo	Marseilles	Cressier (CH)	200	200	4'700	600	800	0%
Iraq	Ceyhan	Marseilles	Cressier (CH)	-	970	2'900	600	1'570	5%
Mexico	Altamira	Marseilles	Cressier (CH)	20	240	10'200	600	840	17%
Saudi-Arabia	Yanbu	Marseilles	Cressier (CH)	20	1'300	4'100	600	1'900	0%
USA	Houston	Marseilles	Cressier (CH)	150	1'120	10'100	600	1'720	17%
Global average	**weighted average**	**Marseilles**	**Cressier (CH)**	**40**	**863**	**7'421**	**600**	**1'463**	**98%**

Tab. 3.3 Overview of transport distances used for modelling of long-distance transports to Europe

Origin	Port of origin	Port of destination	Destination	Distance offshore pipeline origin	Distance onshore origin	Distance sea	Distance destination port to refinery	Total distance pipeline onshore	Share of total import (by weight)
Russia	Yekaterinburg	Czech Republic	Eastern Europe	-	3'600	-	-	3'600	32%
Nigeria	Onne	Marseilles	Southern Europe	20	140	8'000	100	240	6%
Kazakhstan	Poti	Marseilles	Southern Europe	20	1'940	3'700	100	2'040	7%
Norway	Oslo	Rotterdam	Northern Europe	200	200	1'050	100	300	12%
Iraq	Ceyhan	Marseilles	Southern Europe	-	970	2'900	100	1'070	8%
Mexico	Altamira	Rotterdam	Northern Europe	20	240	10'000	100	340	3%
Saudi-Arabia	Yanbu	Marseilles	Southern Europe	20	1'300	4'100	100	1'400	8%
USA	Houston	Rotterdam	Northern Europe	150	1'120	9'700	100	1'220	0%
Global average	**weighted average**	**Europe**	**Europe**	**38**	**2'001**	**2'197**	**58**	**2'058**	**75%**

4 Evaporation Losses for storage and handling

According to information in the former study, for long-distance transport of crude oil, globally a VOC loss of 18 g/t is indicated for storage and handling (Veldt et al. 1992).

According to newer information, this value seems to be too low. According to this source, in 2005, 2.4 billion tons of crude oil was moved by ship, which was roughly 62 % of all crude oil produced. From storage and loading operations roughly 3.2 billion cubic meters of air/hydrocarbon vapours (VOC) are generated per year, equivalent to 5.2 million cubic meters of liquid crude oil if recovered[16]. This is equivalent to 1.4 kg/t (and not g/t) total losses. Out of this only half is VOC and the other half is inert gases. The provider of this information stated in a personal communication that the numbers are based on educated assumptions, derived from the volume of crude transported via sea-vessels and crude vapour pressure.

[16] John Zink Company 2013
www.platts.com/IM.Platts.Content/ProductsServices/ConferenceandEvents/2012/pc379/presentations/d2_4_Marco_Puglisi.pdf, online 17.01.2018

The average of former and current numbers combined with information about vapour composition is taken for the model in this study (see Tab. 4.1). Evaporation losses for storage and handling of oil products are inventoried as a lump sum independent of the transportation distance as they occur mainly during reloading and not during travel.

As these losses are less relevant in the impact assessment for long-distance transport, no further investigations are done regarding this subject.

Tab. 4.1 Composition of vapours from crude oil according to former and current source for modelling (background colour: blue)

	Veldt et al. 1992		John Zink Company 2013		This study
	losses %weight	kg VOC/kg crude oil	losses %weight	kg VOC/kg crude oil	kg VOC/kg crude oil
Total	100	1.80E-05	100	1.38E-03	
Air/inert	0		51.7	7.11E-04	not considered
Methane	9 (0.5-25)	1.62E-06	0.1	1.38E-06	**1.50E-06**
Ethane	2.5 (1-6)	4.50E-07	0.2	2.75E-06	**1.60E-06**
Propane	16±7	2.88E-06	8.7	1.20E-04	**6.13E-05**
Butane	21±7	3.78E-06	18.1	2.49E-04	**1.26E-04**
Pentane	30±5	5.40E-06	13.5	1.86E-04	**9.56E-05**
Hexane	10 (5-13)	1.80E-06	7.7	1.06E-04	**5.39E-05**
C7 +	7.5±2	1.35E-06		0.00E+00	**1.35E-06**
Benzene	2.5	4.50E-07		0.00E+00	**4.50E-07**
Toluene	1.5	2.70E-07		0.00E+00	**2.70E-07**
NMVOC total		**1.80E-05**		**6.65E-04**	**3.42E-04**

5 Pipeline transports

No updates have been commissioned for datasets on pipeline transports.

5.1 Pipeline technology and transport losses

In recent years, crude oil losses due to operational spillages in Europe have continued to decline from 3ppm in 1994 to 0.5ppm in 2015 (CONCAWE 2017; Jungbluth 2007). It is assumed, that this is a global trend. Therefore, amount of spilled crude oil and related emissions to soil and water (offshore) are updated in the datasets presented in Tab. 5.1 and Tab. 5.2. The dataset for pipeline onshore for Europe is also used to model pipelines in non-European countries. This is done due to assumed small overall relevance and lack of specific ecoinvent datasets.

Tab. 5.1 Unit process raw data for transport of crude oil in an onshore pipeline

	Name	Location	InfrastructureProcess	Unit	*transport, crude oil pipeline, onshore*	UncertaintyType	StandardDeviation95%	GeneralComment
	Location				*RER*			
	InfrastructureProcess				*0*			
	Unit				*tkm*			
technosphere	electricity, medium voltage, production ENTSO, at grid	ENTSO	0	kWh	2.00E-2	1	1.80	Range in literature and older data
	pipeline, crude oil, onshore	RER	1	km	9.46E-9	1	3.47	(1,1,5,1,1,na); Performance of European pipelines
emission air, high population density	Heat, waste	-	-	MJ	7.20E-2	1	1.80	(3,3,5,1,1,na); Literature
emission soil, unspecified	Oils, unspecified	-	-	kg	2.67E-6	1	1.77	(1,1,1,1,1,na); 0.5ppm losses due to operational spills reported in Concawe 2017

Tab. 5.2 Unit process raw data for transport of crude oil in an offshore pipeline

	Name	Location	InfrastructureProcess	Unit	*transport, crude oil pipeline, offshore*	Uncertainty Standard Deviation 95%		GeneralComment
	Location				*OCE*			
	InfrastructureProcess				*0*			
	Unit				*tkm*			
technosphere	diesel, burned in diesel-electric generating set	GLO	0	MJ	4.50E-1	1	1.80	Range in literature and older data
	pipeline, crude oil, offshore	OCE	1	km	9.46E-9	1	3.45	(1,1,5,1,1,na); Performance of European pipelines
emission water, ocean	Oils, unspecified	-	-	kg	2.67E-6	1	2.47	(3,3,1,3,5,na); Literature for onshore pipelines, 0.5ppm losses due to operational spills reported in Concawe 2017
	BOD5, Biological Oxygen Demand	-	-	kg	8.40E-6	1	2.70	(3,3,5,3,5,na); Extrapolation for sum parameter
	COD, Chemical Oxygen Demand	-	-	kg	8.40E-6	1	2.70	(3,3,5,3,5,na); Extrapolation for sum parameter
	DOC, Dissolved Organic Carbon	-	-	kg	2.31E-6	1	2.70	(3,3,5,3,5,na); Extrapolation for sum parameter
	TOC, Total Organic Carbon	-	-	kg	2.31E-6	1	2.70	(3,3,5,3,5,na); Extrapolation for sum parameter
	AOX, Adsorbable Organic Halogen as Cl	-	-	kg	2.75E-11	1	2.70	(3,3,5,3,5,na); Extrapolation for sum parameter
	Nitrogen	-	-	kg	2.06E-9	1	2.70	(3,3,5,3,5,na); Extrapolation for sum parameter
	Sulfur	-	-	kg	7.14E-9	1	2.70	(3,3,5,3,5,na); Extrapolation for sum parameter

5.2 Pipeline infrastructure

For the infrastructure, the formerly consulted literature information on data for pipelines in Tab. 5.3 & Tab. 5.4 , relevant for the environment (specific energy demand, emissions air and water, maintenance, energy carrier of pipeline driving systems etc.) is considered to be still valid (c.f. Jungbluth 2007). No update was commissioned.

Tab. 5.3 Unit process raw data for pipeline construction, offshore

	Name	Location	Infrastruct	Unit	*pipeline, crude oil, offshore*	Uncertaint	Standard Deviation 95%	GeneralComment
	Location				*OCE*			
	InfrastructureProcess				*1*			
	Unit				*km*			
product	pipeline, crude oil, offshore	OCE	1	km	1.00E+0			
resource, land	Transformation, from seabed, unspecified	-	-	m2	1.10E+2	1	2.29	(3,3,5,1,3,na); Calculation for gas pipeline
	Transformation, to industrial area, benthos	-	-	m2	1.10E+2	1	2.29	(3,3,5,1,3,na); Calculation for gas pipeline
	Occupation, industrial area, benthos	-	-	m2a	3.30E+3	1	1.84	(3,3,5,1,3,na); Calculation for 30a use
resource, in water	Water, unspecified natural origin, GLO	-	-	m3	1.87E+2	1	1.51	(2,3,5,1,1,na); Environmental report
technosphere	diesel, burned in building machine	GLO	0	MJ	3.34E+6	1	1.51	(2,3,5,1,1,na); Environmental report
	drawing of pipes, steel	RER	0	kg	4.00E+5	1	1.53	(3,3,5,3,1,na); Estimation
	concrete, sole plate and foundation, at plant	CH	0	m3	4.91E+1	1	1.53	(3,3,5,3,1,na); Literature
	sand, at mine	CH	0	kg	1.75E+5	1	1.53	(3,3,5,3,1,na); Literature
	steel, low-alloyed, at plant	RER	0	kg	4.00E+4	1	1.53	(3,3,5,3,1,na); Literature
	reinforcing steel, at plant	RER	0	kg	3.60E+5	1	1.53	(3,3,5,3,1,na); Literature
	aluminium, production mix, cast alloy, at plant	RER	0	kg	3.32E+3	1	10.80	(5,5,5,1,1,na); Estimation for aluminium anode, basic uncertainity estimated = 10
	cast iron, at plant	RER	0	kg	4.20E+0	1	10.80	(5,5,5,1,1,na); Estimation for aluminium anode, basic uncertainity estimated = 10
	MG-silicon, at plant	NO	0	kg	5.25E+0	1	10.80	(5,5,5,1,1,na); Estimation for aluminium anode, basic uncertainity estimated = 10
	copper, at regional storage	RER	0	kg	2.10E-1	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	1.75E+2	1	10.80	(5,5,5,1,1,na); Estimation for aluminium anode, basic uncertainity estimated = 10
	bitumen, at refinery	RER	0	kg	9.00E+4	1	1.53	(3,3,5,3,1,na); Literature
	disposal, concrete, 5% water, to inert material landfill	CH	0	kg	1.08E+5	1	1.53	(3,3,5,3,1,na); Literature
	disposal, bitumen, 1.4% water, to sanitary landfill	CH	0	kg	9.00E+4	1	1.53	(3,3,5,3,1,na); Literature
	disposal, municipal solid waste, 22.9% water, to municipal incineration	CH	0	kg	4.84E+3	1	1.51	(2,3,5,1,1,na); Environmental report
	disposal, hazardous waste, 25% water, to hazardous waste incineration	CH	0	kg	3.53E+3	1	1.51	(2,3,5,1,1,na); Environmental report
	treatment, sewage, from residence, to wastewater treatment, class 2	CH	0	m3	1.87E+2	1	1.51	(2,3,5,1,1,na); Environmental report
	transport, lorry >16t, fleet average	RER	0	tkm	7.77E+4	1	2.38	(4,5,5,5,3,na); Standard distance 100km
	transport, freight, rail	RER	0	tkm	4.01E+5	1	2.38	(4,5,5,5,3,na); Standard distance 600km
emission water, ocean	Aluminium	-	-	kg	2.82E+3	1	10.80	(5,5,5,1,1,na); Estimation 85% utilisation of anode
	Iron	-	-	kg	3.57E+0	1	10.80	(5,5,5,1,1,na); Estimation 85% utilisation of anode
	Silicon	-	-	kg	4.46E+0	1	10.80	(5,5,5,1,1,na); Estimation 85% utilisation of anode
	Copper	-	-	kg	1.79E-1	1	10.80	(5,5,5,1,1,na); Estimation 85% utilisation of anode
	Zinc	-	-	kg	1.49E+2	1	10.80	(5,5,5,1,1,na); Estimation 85% utilisation of anode
	Titanium	-	-	kg	5.99E-1	1	10.80	(5,5,5,1,1,na); Estimation 85% utilisation of anode
	weight			kg	5.12E+5			

Tab. 5.4 Unit process raw data for pipeline construction, onshore

	Name	Location	InfrastructureProcess	Unit	*pipeline, crude oil, onshore*	Uncertainty	StandardDeviation95%	GeneralComment
	Location				*RER*			
	InfrastructureProcess				*1*			
	Unit				*km*			
product	pipeline, crude oil, onshore	RER	1	km	1.00E+0			
resource, land	Transformation, from forest, unspecified	-	-	m2	2.00E+3	1	2.52	(3,3,5,1,3,na); Calculation for gas pipeline
	Transformation, to heterogeneous, agricultural	-	-	m2	2.00E+3	1	1.89	(3,3,5,1,3,na); Calculation for gas pipeline
	Occupation, construction site	-	-	m2a	3.33E+3	1	2.08	(3,3,5,1,3,na); Occupation during construction
resource, in water	Water, unspecified natural origin, GLO	-	-	m3	8.05E+2	1	1.79	(2,3,5,1,1,na); Environmental report
technosphere	diesel, burned in building machine	GLO	0	MJ	2.60E+6	1	1.79	(2,3,5,1,1,na); Environmental report
	drawing of pipes, steel	RER	0	kg	1.40E+5	1	1.80	(3,3,5,3,1,na); Estimation
	sand, at mine	CH	0	kg	6.60E+5	1	1.80	(3,3,5,3,1,na); Literature
	steel, low-alloyed, at plant	RER	0	kg	1.50E+4	1	1.80	(3,3,5,3,1,na); Literature
	reinforcing steel, at plant	RER	0	kg	1.25E+5	1	1.80	(3,3,5,3,1,na); Literature
	disposal, municipal solid waste, 22.9% water, to municipal incineration	CH	0	kg	1.26E+3	1	1.79	(2,3,5,1,1,na); Environmental report
	disposal, hazardous waste, 25% water, to hazardous waste incineration	CH	0	kg	1.13E+3	1	1.79	(2,3,5,1,1,na); Environmental report
	treatment, sewage, from residence, to wastewater treatment, class 2	CH	0	m3	8.05E+2	1	1.79	(2,3,5,1,1,na); Environmental report
	transport, lorry >16t, fleet average	RER	0	tkm	8.00E+4	1	2.61	(4,5,5,5,3,na); Standard distance 100km
	transport, freight, rail	RER	0	tkm	4.80E+5	1	2.61	(4,5,5,5,3,na); Standard distance 600km

6 Summary of life cycle inventory data

In this chapter 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 (unit process in SimaPro). 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. 6.1 contains Meta-information about the newly modelled and updated processes. Tab. 6.2 & Tab. 6.3 show the full life cycle inventory data for the newly modelled and updated processes.

Tab. 6.1 Meta information (X-Process) for the investigated life cycle inventories, part 1.

ReferenceFunction	Name	crude oil, production RU, at long distance transport	crude oil, production NG, at long distance transport	crude oil, production KZ, at long distance transport	crude oil, production NO, at long distance transport	crude oil, production IQ, at long distance transport
Geography	Location	CH	CH	CH	CH	CH
ReferenceFunction	Unit	kg	kg	kg	kg	kg
	IncludedProcesses	Transportation of crude oil from exploration site to refinery in Switzerland. Includes transport service requirements and emissions from oil handling and evaporation.	Transportation of crude oil from exploration site to refinery in Switzerland. Includes transport service requirements and emissions from oil handling and evaporation.	Transportation of crude oil from exploration site to refinery in Switzerland. Includes transport service requirements and emissions from oil handling and evaporation.	Transportation of crude oil from exploration site to refinery in Switzerland. Includes transport service requirements and emissions from oil handling and evaporation.	Transportation of crude oil from exploration site to refinery in Switzerland. Includes transport service requirements and emissions from oil handling and evaporation.
	LocalName	Rohöl, Produktion RU ab Ferntransport	Rohöl, Produktion NG, ab Ferntransport	Rohöl, Produktion KZ, ab Ferntransport	Rohöl, Produktion NO, ab Ferntransport	Rohöl, Produktion IQ, ab Ferntransport
	Synonyms					
	GeneralComment	Calculation for transport distances assuming transport by pipeline offshore and onshore as well as sea transport in tanker. Sites and modes of transportation based on the supply situation in 2016.	Calculation for transport distances assuming transport by pipeline offshore and onshore as well as sea transport in tanker. Sites and modes of transportation based on the supply situation in 2016.	Calculation for transport distances assuming transport by pipeline offshore and onshore as well as sea transport in tanker. Sites and modes of transportation based on the supply situation in 2016.	Calculation for transport distances assuming transport by pipeline offshore and onshore as well as sea transport in tanker. Sites and modes of transportation based on the supply situation in 2016.	Calculation for transport distances assuming transport by pipeline offshore and onshore as well as sea transport in tanker. Sites and modes of transportation based on the supply situation in 2016.
	Category	oil	oil	oil	oil	oil
	SubCategory	transport	transport	transport	transport	transport
	LocalCategory	Erdöl	Erdöl	Erdöl	Erdöl	Erdöl
	LocalSubCategory	Bereitstellung	Bereitstellung	Bereitstellung	Bereitstellung	Bereitstellung
TimePeriod	StartDate	2016	1992	2016	2016	2016
	EndDate	2016	2016	2016	2016	2016
	DataValidForEntirePeriod	1	1	1	1	1
	OtherPeriodText	Transport modes investigated for 2016	Transport modes investigated for 2016	Transport modes investigated for 2016	Transport modes investigated for 2016	Transport modes investigated for 2016
Geography	Text	Calculations based on assumptions for supply to Swiss refineries.	Calculations based on assumptions for supply to Swiss refineries.	Calculations based on assumptions for supply to Swiss refineries.	Calculations based on assumptions for supply to Swiss refineries.	Calculations based on assumptions for supply to Swiss refineries.
Technology	Text	Operation of crude oil pipelines by electricity.	Operation of crude oil pipelines by electricity.	Operation of crude oil pipelines by electricity.	Operation of crude oil pipelines by electricity.	Operation of crude oil pipelines by electricity.
	ProductionVolume	225k tons of directly imported crude oil in CH in 2016	1million tons of directly imported crude oil in CH in 2016	465k tons of directly imported crude oil in CH in 2016	Not known	130k tons of directly imported crude oil in CH in 2016
	SamplingProcedure	Literature. Online calculators for distances.	Literature. Online calculators for distances.	Literature. Online calculators for distances.	Literature. Online calculators for distances.	Literature. Online calculators for distances.
	Extrapolations	none	none	none	none	none
	UncertaintyAdjustments	none	none	none	none	none

Meta information (X-Process) for the investigated life cycle inventories, part 2.

ReferenceFunction	Name	crude oil, production MX, at long distance transport	crude oil, production SA, at long distance transport	crude oil, production US, at long distance transport	crude oil, production RU, at long distance transport	crude oil, production NG, at long distance transport
Geography	Location	CH	CH	CH	RER	RER
ReferenceFunction	Unit	kg	kg	kg	kg	kg
	IncludedProcesses	Transportation of crude oil from exploration site to refinery in Switzerland. Includes transport service requirements and emissions from oil handling and evaporation.	Transportation of crude oil from exploration site to refinery in Switzerland. Includes transport service requirements and emissions from oil handling and evaporation.	Transportation of crude oil from exploration site to refinery in Switzerland. Includes transport service requirements and emissions from oil handling and evaporation.	Transportation of crude oil from exploration site to refinery in Eastern Europe (CZ). Includes transport service requirements and emissions from oil handling and evaporation.	Transportation of crude oil from exploration site to refinery at seaport in Southern Europe (FR). Includes transport service requirements and emissions from oil handling and evaporation.
	LocalName	Rohöl, Produktion MX, ab Ferntransport	Rohöl, Produktion SA, ab Ferntransport	Rohöl, Produktion US, ab Ferntransport	Rohöl, Produktion RU, ab Ferntransport	Rohöl, Produktion NG, ab Ferntransport
	Synonyms					
	GeneralComment	Calculation for transport distances assuming transport by pipeline offshore and onshore as well as sea transport in tanker. Sites and modes of transportation based on the supply situation in 2016.	Calculation for transport distances assuming transport by pipeline offshore and onshore as well as sea transport in tanker. Sites and modes of transportation based on the supply situation in 2016.	Calculation for transport distances assuming transport by pipeline offshore and onshore as well as sea transport in tanker. Sites and modes of transportation based on the supply situation in 2016.	Calculation for transport distances assuming transport by pipeline offshore and onshore as well as sea transport in tanker. Sites and modes of transportation based on the supply situation in 2016.	Calculation for transport distances assuming transport by pipeline offshore and onshore as well as sea transport in tanker. Sites and modes of transportation based on the supply situation in 2016.
	Category	oil	oil	oil	oil	oil
	SubCategory	transport	transport	transport	transport	transport
	LocalCategory	Erdöl	Erdöl	Erdöl	Erdöl	Erdöl
	LocalSubCategory	Bereitstellung	Bereitstellung	Bereitstellung	Bereitstellung	Bereitstellung
TimePeriod	StartDate	2016	2016	2016	1992	1992
	EndDate	2016	2016	2016	2016	2016
	DataValidForEntirePeriod	1	1	1	1	1
	OtherPeriodText	Transport modes investigated for 2016	Transport modes investigated for 2016	Transport modes investigated for 2016	Emissions published in 1992. Transport modes investigated for 1994.	Emissions published in 1992. Transport modes investigated for 1994.
Geography	Text	Calculations based on assumptions for supply to Swiss refineries.	Calculations based on assumptions for supply to Swiss refineries.	Calculations based on assumptions for supply to Swiss refineries.	Calculations based on assumptions for supply to European refineries.	Calculations based on assumptions for supply to European refineries.
Technology	Text	Operation of crude oil pipelines by electricity.	Operation of crude oil pipelines by electricity.	Operation of crude oil pipelines by electricity.	Use of different generic transport devices (pipelines and tanker).	Use of different generic transport devices (pipelines and tanker).
	ProductionVolume	480k tons of directly imported crude oil in CH in 2016	Not known	490k tons of directly imported crude oil in CH in 2016	176 million tons of directly imported crude oil in Europe in 2016	31 million tons of directly imported crude oil in Europe in 2016
	SamplingProcedure	Literature. Online calculators for distances.	Literature. Online calculators for distances.	Literature. Online calculators for distances.	Literature, statistics and own calculations.	Literature, statistics and own calculations.
	Extrapolations	none	none	none	none	none
	UncertaintyAdjustments	none	none	none	none	none

Meta information (X-Process) for the investigated life cycle inventories, part 3.

ReferenceFunction	Name	crude oil, production KZ, at long distance transport	crude oil, production NO, at long distance transport	crude oil, production IQ, at long distance transport	crude oil, production MX, at long distance transport	crude oil, production SA, at long distance transport
Geography	Location	RER	RER	RER	RER	RER
ReferenceFunction	Unit	kg	kg	kg	kg	kg
	IncludedProcesses	Transportation of crude oil from exploration site to refinery at seaport in Southern Europe (FR). Includes transport service requirements and emissions from oil handling and evaporation.	Transportation of crude oil from exploration site to refinery at seaport in Central Europe (FR, BE, GE or NL). Includes transport service requirements and emissions from oil handling and evaporation.	Transportation of crude oil from exploration site to refinery at seaport in Southern Europe (FR). Includes transport service requirements and emissions from oil handling and evaporation.	Transportation of crude oil from exploration site to refinery at seaport in Central Europe (FR, BE, GE or NL). Includes transport service requirements and emissions from oil handling and evaporation.	Transportation of crude oil from exploration site to refinery at seaport in Southern Europe (FR). Includes transport service requirements and emissions from oil handling and evaporation.
	LocalName	Rohöl, Produktion KZ, ab Ferntransport	Rohöl, Produktion NO, ab Ferntransport	Rohöl, Produktion IQ, ab Ferntransport	Rohöl, Produktion MX, ab Ferntransport	Rohöl, Produktion SA, ab Ferntransport
	Synonyms					
	GeneralComment	Calculation for transport distances assuming transport by pipeline offshore and onshore as well as sea transport in tanker. Sites and modes of transportation based on the supply situation in 2016.	Calculation for transport distances assuming transport by pipeline offshore and onshore as well as sea transport in tanker. Sites and modes of transportation based on the supply situation in 2016.	Calculation for transport distances assuming transport by pipeline offshore and onshore as well as sea transport in tanker. Sites and modes of transportation based on the supply situation in 2016.	Calculation for transport distances assuming transport by pipeline offshore and onshore as well as sea transport in tanker. Sites and modes of transportation based on the supply situation in 2016.	Calculation for transport distances assuming transport by pipeline offshore and onshore as well as sea transport in tanker. Sites and modes of transportation based on the supply situation in 2016.
	Category	oil	oil	oil	oil	oil
	SubCategory	transport	transport	transport	transport	transport
	LocalCategory	Erdöl	Erdöl	Erdöl	Erdöl	Erdöl
	LocalSubCategory	Bereitstellung	Bereitstellung	Bereitstellung	Bereitstellung	Bereitstellung
TimePeriod	StartDate	2016	1992	2016	2016	2016
	EndDate	2016	2016	2016	2016	2016
	DataValidForEntirePeriod	1	1	1	1	1
	OtherPeriodText	Emissions published in 1992. Transport modes investigated for 1994.	Emissions published in 1992. Transport modes investigated for 1994.	Transport modes investigated for 2016	Transport modes investigated for 2016	Transport modes investigated for 2016
Geography	Text	Calculations based on assumptions for supply to European refineries.	Calculations based on assumptions for supply to European refineries.	Calculations based on assumptions for supply to European refineries.	Calculations based on assumptions for supply to European refineries.	Calculations based on assumptions for supply to European refineries.
Technology	Text	Use of different generic transport devices (pipelines and tanker).	Use of different generic transport devices (pipelines and tanker).	Operation of crude oil pipelines by electricity.	Operation of crude oil pipelines by electricity.	Operation of crude oil pipelines by electricity.
	ProductionVolume	39 million tons of directly imported crude oil in Europe in 2016	67 million tons of directly imported crude oil in Europe in 2016	45 million tons of directly imported crude oil in Europe in 2016	14 million tons of directly imported crude oil in Europe in 2016	44 million tons of directly imported crude oil in Europe in 2016
	SamplingProcedure	Literature, statistics and own calculations.	Literature, statistics and own calculations.	Literature. Online calculators for distances.	Literature. Online calculators for distances.	Literature. Online calculators for distances.
	Extrapolations	none	none	none	none	none
	UncertaintyAdjustments	none	none	none	none	none

Meta information (X-Process) for the investigated life cycle inventories, part 4.

ReferenceFunction	Name	crude oil, production US, at long distance transport	crude oil, import mix, at long distance transport	crude oil, import mix, at long distance transport
Geography	Location	RER	CH	RER
ReferenceFunction	Unit	kg	kg	kg
	IncludedProcesses	Transportation of crude oil from exploration site to refinery at seaport in Central Europe (FR, BE, GE or NL). Includes transport service requirements and emissions from oil handling and evaporation.	Transportation of crude oil from exploration sites to refinery in Switzerland. Includes transport service requirements and emissions from oil handling and evaporation.	Transportation of crude oil from exploration sites to refinery at seaport in Central Europe (FR, BE, GE or NL). Includes transport service requirements and emissions from oil handling and evaporation.
	LocalName	Rohöl, Produktion US, ab Ferntransport	Rohöl, Importmix, ab Ferntransport	Rohöl, Importmix, ab Ferntransport
	Synonyms			
	GeneralComment	Calculation for transport distances assuming transport by pipeline offshore and onshore as well as sea transport in tanker. Sites and modes of transportation based on the supply situation in 2016.	Calculation for transport distances assuming transport by pipeline offshore and onshore as well as sea transport in tanker. Sites and modes of transportation based on the supply situation in 2016.	Calculation for transport distances assuming transport by pipeline offshore and onshore as well as sea transport in tanker. Sites and modes of transportation based on the supply situation in 2016.
	Category	oil	oil	oil
	SubCategory	transport	transport	transport
	LocalCategory	Erdöl	Erdöl	Erdöl
	LocalSubCategory	Bereitstellung	Bereitstellung	Bereitstellung
TimePeriod	StartDate	2016	2016	2016
	EndDate	2016	2016	2016
	DataValidForEntirePeriod	1	1	1
	OtherPeriodText	Transport modes investigated for 2016	Transport modes investigated for 2016	Transport modes investigated for 2016
Geography	Text	Calculations based on assumptions for supply to European refineries.	Calculations based on assumptions for supply with refinery products on the Swiss market.	Calculations include the 6 most relevant import countries for Europe in 2016 plus shares for US and MX.
Technology	Text	Operation of crude oil pipelines by electricity.	Operation of crude oil pipelines by electricity.	Operation of crude oil pipelines by electricity.
	ProductionVolume	Not known	2.88 million tons of directly imported crude oil in Europe in 2016	550 million tons imported to Europe in 2016
	SamplingProcedure	Literature. Online calculators for distances.	Literature. Online calculators for distances.	Literature. Online calculators for distances.
	Extrapolations	none	none	none
	UncertaintyAdjustments	none	none	none

Tab. 6.2 Unit process raw data for produced crude oil transported to refineries in Switzerland.

	Name	Location	Unit	*crude oil, production RU, at long distance transport*	*crude oil, production NG, at long distance transport*	*crude oil, production KZ, at long distance transport*	*crude oil, production NO, at long distance transport*	*crude oil, production IQ, at long distance transport*	*crude oil, production MX, at long distance transport*	*crude oil, production SA, at long distance transport*	*crude oil, production US, at long distance transport*	*crude oil, import mix, at long distance transport*	UncertaintyType	StandardDeviation95%	GeneralComment
	Location			*CH*	*CH*	*CH*	*CH*	*CH*	*CH*	*CH*	*CH*	*CH*			
	InfrastructureProcess			*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*			
	Unit			*kg*	*kg*	*kg*	*kg*	*kg*	*kg*	*kg*	*kg*	*kg*			
technosphere	crude oil, at production onshore	RU	kg	1.00E+0	-	-	-	-	-	-	-	8.02E-2	1	1.05	(1,1,1,1,1,na); Transported crude oil +losses
	crude oil, at production	NG	kg	-	1.00E+0	-	-	-	-	-	-	3.60E-1	1	1.05	(1,1,1,1,1,na); Transported crude oil +losses
	crude oil, at production	KZ	kg	-	-	1.00E+0	-	-	-	-	-	1.65E-1	1	1.05	(1,1,1,1,1,na); Transported crude oil +losses
	crude oil, at production offshore	NO	kg		-		1.00E+0	-	-	-	-	-	1	1.05	(1,1,1,1,1,na); Transported crude oil +losses
	crude oil, at production	IQ	kg	-	-	-	-	1.00E+0	-	-	-	4.80E-2	1	1.05	(1,1,1,1,1,na); Transported crude oil +losses
	crude oil, at production	MX	kg	-	-	-	-	-	1.00E+0	-	-	1.71E-1	1	1.05	(1,1,1,1,1,na); Transported crude oil +losses
	crude oil, at production	SA	kg	-	-	-	-	-	-	1.00E+0	-	-	1	1.05	(1,1,1,1,1,na); Transported crude oil +losses
	crude oil, at production	US	kg	-	-	-	-	-	-	-	1.00E+0	1.75E-1	1	1.05	(1,1,1,1,1,na); Transported crude oil +losses
	transport, transoceanic tanker	OCE	tkm	1.00E+0	8.00E+0	3.70E+0	4.70E+0	2.90E+0	1.02E+1	4.10E+0	1.01E+1	7.42E+0	1	2.05	(4,1,1,3,1,na); Calculation 2016
	transport, crude oil pipeline, offshore	OCE	tkm	-	2.00E-2	2.00E-2	2.00E-1	-	2.00E-2	2.00E-2	1.50E-1	4.02E-2	1	1.21	(4,1,1,3,1,na); Calculation 2016
	transport, crude oil pipeline, onshore	RER	tkm	3.20E+0	7.40E-1	2.54E+0	8.00E-1	1.57E+0	8.40E-1	1.90E+0	1.72E+0	1.46E+0	1	1.21	(4,1,1,3,1,na); Calculation 2016
air, low population	Hydrocarbons, aliphatic, alkanes, unspecified	-	kg	1.35E-6	1.35E-6	1.35E-6	1.35E-6	1.35E-6	1.35E-6	1.35E-6	1.35E-6	1.35E-6	1	1.63	(3,5,4,1,1,na); Literature
	Benzene	-	kg	4.50E-7	4.50E-7	4.50E-7	4.50E-7	4.50E-7	4.50E-7	4.50E-7	4.50E-7	4.50E-7	1	3.10	(3,5,4,1,1,na); Literature
	Butane	-	kg	1.26E-4	1.26E-4	1.26E-4	1.26E-4	1.26E-4	1.26E-4	1.26E-4	1.26E-4	1.26E-4	1	1.63	(3,5,4,1,1,na); Literature
	Methane, fossil	-	kg	1.50E-6	1.50E-6	1.50E-6	1.50E-6	1.50E-6	1.50E-6	1.50E-6	1.50E-6	1.50E-6	1	1.63	(3,5,4,1,1,na); Literature
	Ethane	-	kg	1.60E-6	1.60E-6	1.60E-6	1.60E-6	1.60E-6	1.60E-6	1.60E-6	1.60E-6	1.60E-6	1	1.63	(3,5,4,1,1,na); Literature
	Hexane	-	kg	5.39E-5	5.39E-5	5.39E-5	5.39E-5	5.39E-5	5.39E-5	5.39E-5	5.39E-5	5.39E-5	1	1.63	(3,5,4,1,1,na); Literature
	Pentane	-	kg	9.56E-5	9.56E-5	9.56E-5	9.56E-5	9.56E-5	9.56E-5	9.56E-5	9.56E-5	9.56E-5	1	1.63	(3,5,4,1,1,na); Literature
	Propane	-	kg	6.13E-5	6.13E-5	6.13E-5	6.13E-5	6.13E-5	6.13E-5	6.13E-5	6.13E-5	6.13E-5	1	1.63	(3,5,4,1,1,na); Literature
	Toluene	-	kg	2.70E-7	2.70E-7	2.70E-7	2.70E-7	2.70E-7	2.70E-7	2.70E-7	2.70E-7	2.70E-7	1	1.63	(3,5,4,1,1,na); Literature
Losses	Total losses		kg	3.42E-4	3.42E-4	3.42E-4	3.42E-4	3.42E-4	3.42E-4	3.42E-4	3.42E-4	3.42E-4			

Tab. 6.3 Unit process raw data for produced crude oil transported to refineries in Europe.

	Name	Location	Unit	*crude oil, production RU, at long distance transport*	*crude oil, production NG, at long distance transport*	*crude oil, production KZ, at long distance transport*	*crude oil, production NO, at long distance transport*	*crude oil, production IQ, at long distance transport*	*crude oil, production MX, at long distance transport*	*crude oil, production SA, at long distance transport*	*crude oil, production US, at long distance transport*	*crude oil, import mix, at long distance transport*	UncertaintyType	StandardDeviation95%	GeneralComment
	Location			*RER*	*RER*	*RER*	*RER*	*RER*	*RER*	*RER*	*RER*	*RER*			
	InfrastructureProcess			*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*			
	Unit			*kg*	*kg*	*kg*	*kg*	*kg*	*kg*	*kg*	*kg*	*kg*			
technosphere	crude oil, at production onshore	RU	kg	1.00E+0	-	-	-	-	-	-	-	4.23E-1	1	1.05	(1,1,1,1,1,na); Transported crude oil +losses
	crude oil, at production	NG	kg	-	1.00E+0	-	-	-	-	-	-	7.46E-2	1	1.05	(1,1,1,1,1,na); Transported crude oil +losses
	crude oil, at production	KZ	kg	-	-	1.00E+0	-	-	-	-	-	9.51E-2	1	1.05	(1,1,1,1,1,na); Transported crude oil +losses
	crude oil, at production offshore	NO	kg	-	-		1.00E+0	-	-	-	-	1.60E-1	1	1.05	(1,1,1,1,1,na); Transported crude oil +losses
	crude oil, at production	IQ	kg	-	-	-	-	1.00E+0	-	-	-	1.08E-1	1	1.05	(1,1,1,1,1,na); Transported crude oil +losses
	crude oil, at production	MX	kg	-	-	-	-	-	1.00E+0	-	-	3.35E-2	1	1.05	(1,1,1,1,1,na); Transported crude oil +losses
	crude oil, at production	SA	kg	-	-	-	-	-	-	1.00E+0	-	1.05E-1	1	1.05	(1,1,1,1,1,na); Transported crude oil +losses
	crude oil, at production	US	kg	-	-	-	-	-	-	-	1.00E+0	-	1	1.05	(1,1,1,1,1,na); Transported crude oil +losses
	transport, transoceanic tanker	OCE	tkm	-	8.00E+0	3.70E+0	1.05E+0	2.90E+0	1.00E+1	4.10E+0	9.70E+0	2.20E+0	1	2.05	(4,1,1,3,1,na); Calculation 2016
	transport, crude oil pipeline, offshore	OCE	tkm	-	2.00E-2	2.00E-2	2.00E-1	-	2.00E-2	2.00E-2	1.50E-1	3.82E-2	1	1.21	(4,1,1,3,1,na); Calculation 2016
	transport, crude oil pipeline, onshore	RER	tkm	3.60E+0	2.40E-1	2.04E+0	3.00E-1	1.07E+0	3.40E-1	1.40E+0	1.22E+0	2.06E+0	1	1.21	(4,1,1,3,1,na); Calculation 2016
air, low population	Hydrocarbons, aliphatic, alkanes, unspecified	-	kg	1.35E-6	1.35E-6	1.35E-6	1.35E-6	1.35E-6	1.35E-6	1.35E-6	1.35E-6	1.35E-6	1	1.63	(3,5,4,1,1,na); Literature
	Benzene	-	kg	4.50E-7	4.50E-7	4.50E-7	4.50E-7	4.50E-7	4.50E-7	4.50E-7	4.50E-7	4.50E-7	1	3.10	(3,5,4,1,1,na); Literature
	Butane	-	kg	1.26E-4	1.26E-4	1.26E-4	1.26E-4	1.26E-4	1.26E-4	1.26E-4	1.26E-4	1.26E-4	1	1.63	(3,5,4,1,1,na); Literature
	Methane, fossil	-	kg	1.50E-6	1.50E-6	1.50E-6	1.50E-6	1.50E-6	1.50E-6	1.50E-6	1.50E-6	1.50E-6	1	1.63	(3,5,4,1,1,na); Literature
	Ethane	-	kg	1.60E-6	1.60E-6	1.60E-6	1.60E-6	1.60E-6	1.60E-6	1.60E-6	1.60E-6	1.60E-6	1	1.63	(3,5,4,1,1,na); Literature
	Hexane	-	kg	5.39E-5	5.39E-5	5.39E-5	5.39E-5	5.39E-5	5.39E-5	5.39E-5	5.39E-5	5.39E-5	1	1.63	(3,5,4,1,1,na); Literature
	Pentane	-	kg	9.56E-5	9.56E-5	9.56E-5	9.56E-5	9.56E-5	9.56E-5	9.56E-5	9.56E-5	9.56E-5	1	1.63	(3,5,4,1,1,na); Literature
	Propane	-	kg	6.13E-5	6.13E-5	6.13E-5	6.13E-5	6.13E-5	6.13E-5	6.13E-5	6.13E-5	6.13E-5	1	1.63	(3,5,4,1,1,na); Literature
	Toluene	-	kg	2.70E-7	2.70E-7	2.70E-7	2.70E-7	2.70E-7	2.70E-7	2.70E-7	2.70E-7	2.70E-7	1	1.63	(3,5,4,1,1,na); Literature
Losses	Total losses		kg	3.42E-4	3.42E-4	3.42E-4	3.42E-4	3.42E-4	3.42E-4	3.42E-4	3.42E-4	3.42E-4			

7 Life cycle impact assessment

Tab. 7.1 shows the key indicator results for the processes which have been investigated in this report. Crude oil at production is the most dominant contributor for most indicators. Thus, differences are mainly due to differences in crude oil extraction. Second most important are distances for transports by oceanic tanker and pipeline. Direct emissions, energy uses, and infrastructure are of minor importance.

Tab. 7.1 Key indicator results for the updated processes investigating crude oil transported to European and Swiss refineries (red marks highest and green lowest values per column of special interest)

	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
crude oil, production RU, at long distance transport/kg/CH	kg	51.4	50.7	0.56	0.20	0.58	1'175
crude oil, production NG, at long distance transport/kg/CH	kg	51.3	51.0	0.17	0.06	0.64	928
crude oil, production KZ, at long distance transport/kg/CH	kg	50.9	50.4	0.37	0.13	0.57	1'310
crude oil, production NO, at long distance transport/kg/CH	kg	48.9	48.6	0.12	0.15	0.42	862
crude oil, production IQ, at long distance transport/kg/CH	kg	51.5	51.2	0.25	0.08	0.69	941
crude oil, production MX, at long distance transport/kg/CH	kg	53.3	52.9	0.23	0.12	0.74	1'286
crude oil, production SA, at long distance transport/kg/CH	kg	48.3	48.0	0.26	0.08	0.38	822
crude oil, production US, at long distance transport/kg/CH	kg	54.0	53.3	0.48	0.19	0.75	1'474
crude oil, import mix, at long distance transport/kg/CH	kg	52.1	51.7	0.30	0.11	0.66	1'175
crude oil, production RU, at long distance transport/kg/RER	kg	51.5	50.7	0.59	0.20	0.58	1'147
crude oil, production NG, at long distance transport/kg/RER	kg	51.1	50.9	0.13	0.04	0.63	918
crude oil, production KZ, at long distance transport/kg/RER	kg	50.7	50.3	0.33	0.12	0.56	1'301
crude oil, production NO, at long distance transport/kg/RER	kg	48.4	48.2	0.05	0.13	0.39	725
crude oil, production IQ, at long distance transport/kg/RER	kg	51.4	51.1	0.21	0.07	0.69	932
crude oil, production MX, at long distance transport/kg/RER	kg	53.1	52.8	0.19	0.10	0.73	1'270
crude oil, production SA, at long distance transport/kg/RER	kg	48.2	47.9	0.22	0.07	0.38	812
crude oil, production US, at long distance transport/kg/RER	kg	53.8	53.2	0.44	0.18	0.74	1'451
crude oil, import mix, at long distance transport/kg/RER	kg	50.6	50.1	0.35	0.14	0.55	1'023

8 Outlook

To simplify updates in the future, it seems easier to create just two datasets with import mixes for Europe and Switzerland directly rather than creating datasets for each transported crude oil. This has been done in this study also to facilitate the modelling of the refinery datasets and to harmonize the approach with ecoinvent data v3.

In the future it would be recommended to exclude the datasets for long distance transport for each country from the update.

Values for NMVOC-emissions seem to be rather uncertain across the whole lifecycle of crude oil products. If this issue would gain relevance in the future, it should be investigated for crude oil transport in more detail. But, for the evaluation with the ecological scarcity method the emissions at this stage are of minor relevance in the moment.

The transport processes have not been updated in this project. Such an update would be recommended.

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