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Life cycle inventories of long-distance transport of crude oil

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Report

Christoph Meili; Niels Jungbluth; Maresa Bussa
ESU-services Ltd.
Rheinstrasse 20
CH-8200 Schaffhausen
Tel. +41 44 940 61 32
info@esu-services.ch
www.esu-services.ch

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Abbreviations

a	year (annum)
API	American Petroleum Institute
AZ	Azerbaijan
bbl	Barrel
bcm	billion cubic meters
BOD5	Biochemical oxygen demand for 5 days of microbial degradation
BTU	British Thermal Unit (1 BTU = 1055 J)
BTX	Benzene, Toluene, and Xylenes
Bq	Becquerel
CH_4	Methane
CHP	Combined Heat and Power
CIS	Commonwealth of Independent States
CMC	Carboxymethyl Cellulose
CO	Carbon monoxide
CO_2	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	Denitrification method (general)
DM	Dry matter
DoE	Department of Energy, US
dwt	Dead weight tons
DZ	Algeria
E5/10/15/85•	Petrol with 5%/10%/15%/85% ethanol
EOR	Enhanced Oil Recovery
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	Hydrocarbons
HEC	Hydroxyethyl cellulose
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
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
NER	Net Energy Return
NG	Nigeria
NGL	Natural Gas Liquids
NL	Netherlands
Nm^3	Normal-cubic metre (for gases)
NMVOC	Non-Methane-Volatile Organic Compounds
NO	Norway
NOAA	National Oceanic and Atmospheric Administration
NOX	Nitrogen oxides
NR	Not Reported
Ns	not specified
OBM	Oil Based Mud,
OE	Oil equivalent
OECD	Organisation for Economic Cooperation and Development
PAH	Polycyclic Aromatic Hydrocarbons
PC	Personal Communication
PM	Particulate Matter
Rn	Radon
RODP	Relative Ozone Depletion Potential
RU	Russia
SA	Saudi-Arabia
SEPL	South European Pipeline
SPCA	State Pollution Control Authority
TDS	Total Dissolved Solids
toe	Ton Oil Equivalent
TSP	Total Suspended Particulates
TSS	Total Suspended Solids
UCTE	Union for the Co-ordination of Transmission of Electricity
ULCC	Ultra Large Crude Carrier
UNEP	United Nations Environment Programme
US (A)	United States of America
UVEK	Federal Department for Environment, Transport, Energy and Communications
Works)	
VLCC	Very Large Crude Carrier
VOC	Volatile Organic Compounds
WEC	World Energy Council

1 Introduction

The goal of this study is to report the data as submitted to ecoinvent for the implementation in their database release version 3.9. Changes made by the commissioner to implement the data in the ecoinvent v3-database are not described in this report but in a separate report (Moreno Ruiz et al. 2022). The content of this document therefore does not fully reflect the LCI data as provided with ecoinvent v3.9.

This document is based on the previous update of the life cycle inventory data for long-distance transport of crude oil (Meili et al. 2021a). This former version has been elaborated in a project for updating and harmonizing the life cycle inventories in the UVEK database (UVEK 2018) for the extraction of crude oil and natural gas (Meili et al. 2021b). That study analysed the long-distance crude oil transport from the perspective of production regions relevant for Switzerland and Europe.

For this report, additionally the perspective of production regions relevant for the Northern American and the global situation are analysed for the reference year 2019.

Also the reports for the oil and gas extraction (Meili et al. 2022) and the transport of natural gas to the end user (Bussa et al. 2022) were updated in view of an integration in ecoinvent v3 in the same project.

The life cycle inventory analysis for the transport of crude oil from different countries of origin to a theoretical Global, a theoretical European, a theoretical Northern American and the actual Swiss refinery 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 a refinery at a specific country or region.

To simplify future modelling, aggregated datasets for crude oil import mix to the analysed countries or regions are generated.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

To represent the market situation in 2019, international trade data is used in the model (Avenergy_Suisse 2020; BP 2020).[1]

2.1 Switzerland

In 2019, no crude oil is extracted in or exported from Switzerland. Crude oil is only imported to Switzerland from the countries listed in Tab. 2.1. For all these countries extraction data is modelled and updated for the reference year 2019. Typical properties of crude oil are provided as well in this part of the project (Meili et al. 2022).

Tab. 2.1 Amount and share of crude oil imported to Switzerland in 2019, by country of origin (Avenergy_Suisse 2020).

	Origin of crude oil transported to Switzerland	crude oil imported	Share for import mix in 2019
		thousand tons	Mass fraction (%)
1	Nigeria	935	34.2%
2	Kazakhstan	786	28.7%
3	Libyan Arab Jamahiriya	610	22.3%
4	United States	288	10.5%
5	Algeria	89	3.3%
6	Russian Federation	29	1.1%
7	Azerbaijan	2	0.1%
	Total	**2’739**	**100.0%**

2.2 EU-28

Some of the EU-28 countries extracted and exported crude oil in 2019. Additionally, the EU-28 countries imported crude oil from different countries (BP 2020). To build a market mix, the locally extracted and imported crude oil is added up and the exported crude oil is subtracted. Tab. 2.2 shows the amount of crude oil extracted in and exported from EU-28 countries for which specific extraction data is modelled and updated for the reference year 2019 (Meili et al. 2022). Also shown is the amount of crude oil imported from outside of the EU-28, for countries of which specific extraction data is modelled and updated for the reference year 2019 (Meili et al. 2022). In total about 80% of the crude oil refined in EU-28 countries is imported. The modelled countries cover about 93% of the market mix of the EU-28 countries.

[1] https://ec.europa.eu/energy/sites/ener/files/documents/3_2019_crude_oil_imports_extra_eu_country_of_origin.zip, online: 16.12.2020

Tab. 2.2 Amount of crude oil extracted in, imported to and exported from EU-28 countries (BP 2020). Only amounts for countries for which extraction data is modelled in the LCI for 2019 are shown and summed up in "Total covered" (Meili et al. 2022).

Origin of crude oil refined in the European Union	Extracted in EU	Import to EU	Export from EU	Market (refined in EU)	Share (refined in EU)
	kg	kg	kg	kg	%
United Arab Emirates	0	1.64E+08	0	1.64E+08	0.03%
Azerbaijan	0	1.77E+10	0	1.77E+10	2.90%
Brazil	0	5.99E+09	0	5.99E+09	0.98%
Canada	0	3.74E+09	0	3.74E+09	0.61%
China	0	0	0	0	0.00%
Colombia	0	1.85E+09	0	1.85E+09	0.30%
Germany	3.18E+09	0	5.40E+08	2.65E+09	0.43%
Algeria	0	2.24E+10	0	2.24E+10	3.67%
Ecuador	0	1.13E+09	0	1.13E+09	0.19%
United Kingdom	5.18E+10	0	8.78E+09	4.30E+10	7.05%
Indonesia	0	8.82E+03	0	8.82E+03	0.00%
Iraq	0	5.54E+10	0	5.54E+10	9.08%
Iran	0	2.29E+09	0	2.29E+09	0.38%
Kuwait	0	4.87E+09	0	4.87E+09	0.80%
Kazakhstan	0	4.24E+10	0	4.24E+10	6.95%
Libyan Arab Jamahiriya	0	2.01E+10	0	2.01E+10	3.30%
Mexico	0	1.05E+10	0	1.05E+10	1.72%
Malaysia	0	6.89E+03	0	6.89E+03	0.00%
Nigeria	0	6.51E+10	0	6.51E+10	10.68%
Netherlands	1.12E+09	0	1.89E+08	9.27E+08	0.15%
Norway	7.84E+10	0	1.33E+10	6.51E+10	10.67%
Qatar	0	1.12E+09	0	1.12E+09	0.18%
Romania	3.57E+09	0	6.04E+08	2.96E+09	0.49%
Russian Federation	0	1.53E+11	0	1.53E+11	25.09%
Saudi Arabia	0	3.99E+10	0	3.99E+10	6.54%
United States	0	4.58E+10	0	4.58E+10	7.50%
Venezuela	0	1.85E+09	0	1.85E+09	0.30%
Total covered	**1.38E+11**	**4.95E+11**	**2.34E+10**	**6.10E+11**	
Total according to statistics	**1.58E+11**	**5.23E+11**	**2.67E+10**	**6.54E+11**	
Share for LCI (%)	**87%**	**95%**	**87%**	**93%**	**100%**

2.3 North America

All Northern American countries extracted and exported crude oil in 2019 (BP 2020). Additionally, they imported crude oil from different other countries (BP 2020). To build a market mix, the locally extracted and imported crude oil is added up and the exported crude oil is subtracted. Tab. 2.3 shows the amount of crude oil extracted in and exported from Northern American countries. Also shown is the amount of crude oil imported from outside of the Northern American countries of which specific extraction data is modelled and updated for the reference year 2019 (Meili et al. 2022). The modelled countries cover about 99% of the market mix of the Northern American countries.

Tab. 2.3 Amount of crude oil extracted in, imported to and exported from Northern American countries (BP 2020). Only amounts for countries for which extraction data is modelled in the LCI for 2019 are shown and summed up in "Total covered" (Meili et al. 2022).

Origin of crude oil refined in Northern America	Extracted in Northern America	Import to Northern America	Export from Northern America	Market (refined in Northern America)	Share (refined in Northern America)
	kg	kg	kg	kg	%
United Arab Emirates	0	1.40E+08	0	1.40E+08	0.01%
Azerbaijan	0	5.04E+08	0	5.04E+08	0.05%
Brazil	0	1.91E+10	0	1.91E+10	1.76%
Canada	2.75E+11	1.90E+11	1.97E+11	2.68E+11	24.64%
China	0	0	0	0	0.00%
Colombia	0	5.92E+09	0	5.92E+09	0.55%
Germany	0	1.46E+08	0	1.46E+08	0.01%
Algeria	0	1.80E+09	0	1.80E+09	0.17%
Ecuador	0	3.61E+09	0	3.61E+09	0.33%
United Kingdom	0	2.37E+09	0	2.37E+09	0.22%
Indonesia	0	5.48E+08	0	5.48E+08	0.05%
Iraq	0	1.65E+10	0	1.65E+10	1.52%
Iran	0	0	0	0	0.00%
Kuwait	0	2.23E+09	0	2.23E+09	0.21%
Kazakhstan	0	1.21E+09	0	1.21E+09	0.11%
Libyan Arab Jamahiriya	0	1.62E+09	0	1.62E+09	0.15%
Mexico	9.49E+10	2.99E+10	5.81E+10	6.66E+10	6.14%
Malaysia	0	4.28E+08	0	4.28E+08	0.04%
Nigeria	0	1.51E+10	0	1.51E+10	1.39%
Netherlands	0	5.11E+07	0	5.11E+07	0.00%
Norway	0	3.59E+09	0	3.59E+09	0.33%
Qatar	0	0	0	0	0.00%
Romania	0	1.63E+08	0	1.63E+08	0.02%
Russian Federation	0	7.47E+09	0	7.47E+09	0.69%
Saudi Arabia	0	3.00E+10	0	3.00E+10	2.76%
United States	7.47E+11	2.43E+10	1.38E+11	6.33E+11	58.32%
Venezuela	0	5.92E+09	0	5.92E+09	0.55%
Total covered	**1.12E+12**	**3.62E+11**	**3.93E+11**	**1.09E+12**	
Total according to statistics	**1.12E+12**	**3.71E+11**	**3.93E+11**	**1.09E+12**	
Share for LCI (%)	**100%**	**98%**	**100%**	**99%**	**100%**

2.4 Global market

To simplify the modelling of a global market mix, it is assumed, that the globally refined crude oil in 2019 is equal to the extracted crude oil in the same period (BP 2020). For long-distance transportation the amount of imported crude oil to the global region is considered (BP 2020). Tab. 2.4 shows the amount of crude oil extracted in and globally imported from countries for which specific extraction data is modelled and updated for the reference year 2019 (Meili et al. 2022). The modelled countries cover about 91% of the globally extracted crude oil.

Tab. 2.4 Amount of crude oil extracted in and imported to global region (BP 2020). Only amounts for countries for which extraction data is modelled in the LCI for 2019 are shown and summed up in "Total covered" (Meili et al. 2022).

Origin of crude oil refined globally	Extracted globally	Imported globally	Market (refined globally)	Share (refined globally)
	kg	kg	kg	%
United Arab Emirates	1.80E+11	1.39E+11	1.80E+11	4.44%
Azerbaijan	3.81E+10	2.38E+10	3.81E+10	0.94%
Brazil	1.51E+11	6.95E+10	1.51E+11	3.71%
Canada	2.75E+11	1.97E+11	2.75E+11	6.77%
China	1.91E+11	4.38E+08	1.91E+11	4.70%
Colombia	4.67E+10	2.15E+10	4.67E+10	1.15%
Germany	3.18E+09	5.40E+08	3.18E+09	0.08%
Algeria	6.43E+10	3.54E+10	6.43E+10	1.58%
Ecuador	2.85E+10	1.31E+10	2.85E+10	0.70%
United Kingdom	5.18E+10	8.78E+09	5.18E+10	1.28%
Indonesia	3.82E+10	1.33E+10	3.82E+10	0.94%
Iraq	2.34E+11	2.01E+11	2.34E+11	5.77%
Iran	1.61E+11	6.66E+10	1.61E+11	3.96%
Kuwait	1.44E+11	9.92E+10	1.44E+11	3.55%
Kazakhstan	9.14E+10	5.70E+10	9.14E+10	2.25%
Libyan Arab Jamahiriya	5.78E+10	3.18E+10	5.78E+10	1.42%
Mexico	9.49E+10	5.81E+10	9.49E+10	2.34%
Malaysia	2.98E+10	1.04E+10	2.98E+10	0.73%
Nigeria	1.01E+11	2.19E+11	1.01E+11	2.50%
Netherlands	1.12E+09	1.89E+08	1.12E+09	0.03%
Norway	7.84E+10	1.33E+10	7.84E+10	1.93%
Qatar	7.85E+10	3.25E+10	7.85E+10	1.93%
Romania	3.57E+09	6.04E+08	3.57E+09	0.09%
Russian Federation	5.68E+11	2.86E+11	5.68E+11	13.99%
Saudi Arabia	5.57E+11	3.58E+11	5.57E+11	13.70%
United States	7.47E+11	1.38E+11	7.47E+11	18.38%
Venezuela	4.66E+10	2.15E+10	4.66E+10	1.15%
Total covered	**4.06E+12**	**2.12E+12**	**4.06E+12**	
Total according to statistics	**4.48E+12**	**2.24E+12**	**4.48E+12**	
Share for LCI (%)	**91%**	**95%**	**91%**	**100%**

3 Transport routes

3.1 Import to Switzerland

No changes were made compared to a former study (Meili et al. 2018). According to the refinery in Cressier, all crude oil that is directly imported to Switzerland enters the European mainland through the seaport in Marseille (FR)[2]. The length of the Pipeline is measured with 600 km[3].

3.2 Import to Europe

Crude oil imported for the European average refinery is assumed to be shipped to the European mainland via Rotterdam. Crude oil, which is directly imported onshore, e.g., from Russia, Kazakhstan and Azerbaijan enters Europe on the mainland via pipelines and is assumed to be refined mainly in Eastern European refineries. In this model, for these exceptions, a refinery in Bratislava, Slovakia is assumed for distance calculations.

For crude oil processed directly in the country of origin (e.g., DE, GB, NL) and oil transported by ship, a generic transport distances to a refinery of about 100km is considered.

3.3 Import to North America

Crude oil imported to Northern America is assumed to be shipped to Houston. For crude oil processed directly in the country of origin (CA, MX, US) and oil transported by ship, a generic transport distance to a refinery of about 100km is considered.

3.4 Import to global market

For the countries for which extraction of crude oil is modelled, the weighted transport distance for export to specific countries or global regions is calculated based on global statistics (BP 2020). For each country one single harbour, which is close to local oil fields is chosen as port of origin. For countries that do not extract crude oil, harbours close to refineries are selected. Independent of current trade statistics and local circumstances for each country only one harbour is selected and modelled as origin and destination port.

3.5 Transport from extraction site to port of destination

All distances for transport in pipelines and on open sea are taken from online maps[4,5] and/or from former studies (Jungbluth 2007; Meili et al. 2018; Stolz & Frischknecht 2017).

For countries that produce between 10% and 50% offshore (e.g., Kazakhstan, Saudi-Arabia, and USA, c.f. Meili et al. 2021b, Tab. 4.1), a generic value of 20km offshore pipeline is assumed. For countries where more than 50% of crude oil is produced offshore (e.g., Nigeria, Norway and Qatar), 200km offshore pipeline are assumed.

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[2] https://www.srf.ch/news/wirtschaft/was-kommt-nach-dem-erdoel-cressier-die-letzte-erdoel-raffinerie-der-schweiz online 16.12.2020

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

[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 and https://sea-distances.org/, online 23.10.2019.

For countries, where long distances for pipeline use are assumed, an individual distance for onshore transportation from typical extraction sites to a selected harbour is assessed. The selected harbours do reflect an average origin estimated for the importing region and do not necessarily reflect the harbour from which the highest amount of crude oil is exported. For countries, for which a shorter transport by pipeline is assumed, a generic distance of 100km is used.

To make the model globally consistent, compared to former studies one single harbour per country was selected to be used independent of the destination (Meili et al. 2018). Therefore, e.g., Port of Origin for Russia is St. Petersburg. Port of origin for Kazakhstan is newly assumed to be in Novorossiysk, as this is the nearest port on the black sea, which has a high global export capacity (European Commission 2015).

Some exceptional cases are described in the following subchapters.

An overview on modelled transport distances and assumed ports of origin is given for long distance transports of crude oil to Switzerland (Tab. 3.2) and Europe (Tab. 3.3).

3.5.1 Azerbaijan

Transport through the Baku–Tbilisi–Ceyhan pipeline to the port of Ceyhan in Turkey is assumed for main exports[6].

3.5.2 Iraq

To be consistent with a global transport model, the average port of origin is assumed to be directly in Iraq, in Basrah. This option is chosen although it is more likely that most crude oil is transported to Europe and Switzerland via an onshore pipeline from Bagdad to the port Ceyhan in the south-east of Turkey (European Commission 2017).

3.5.3 Kazakhstan

Crude oil from Kazakhstan is transported via onshore pipeline to the Black Sea. Port of Novorossiysk is assumed to be the main port of origin (European Commission 2015). A 20km offshore pipeline transport is estimated to cover offshore production. For Import to EU-28, no transport by ship is assumed. For this case, the whole transport is done in onshore pipelines.

3.6.1 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 in Bergen.

3.6.3 Russia

There are various transport routes for Russian crude oils. In addition to the mainland route through the Druzhba 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.

[6] https://www.azerbaijans.com/content_1030_en.html, online 13.03.2021

[7] https://en.wikipedia.org/wiki/Kirkuk%E2%80%93Ceyhan_Oil_Pipeline, online 01.10.2018

[8] https://www.export.gov/article?id=Mexico-Upstream-Oil-and-Gas, online 02.10.2017

[9] http://oilprice.com/Energy/Crude-Oil/Can-Mexico-Reverse-Its-Steep-Output-Decline.html, online 02.10.2017

Main crude oil production in Russia with destination Europe is produced in the Ural and western Siberian region (European Commission 2015). According to the Harvard World Map[10] (see Fig. 3.1), many large production fields lie in the west and east of Yekaterinburg. Based on this map, it is assumed that oil with destination Europe and Switzerland is produced on average in Yekaterinburg.

For the average European refinery mix it is 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 3800km by pipeline transport onshore. For the transport to Switzerland, to stay consistent with a global transport model, the route with shipping from St. Petersburg to Marseille is modelled. This option is chosen although it is more likely that most crude oil is transported to Switzerland via the Black sea.

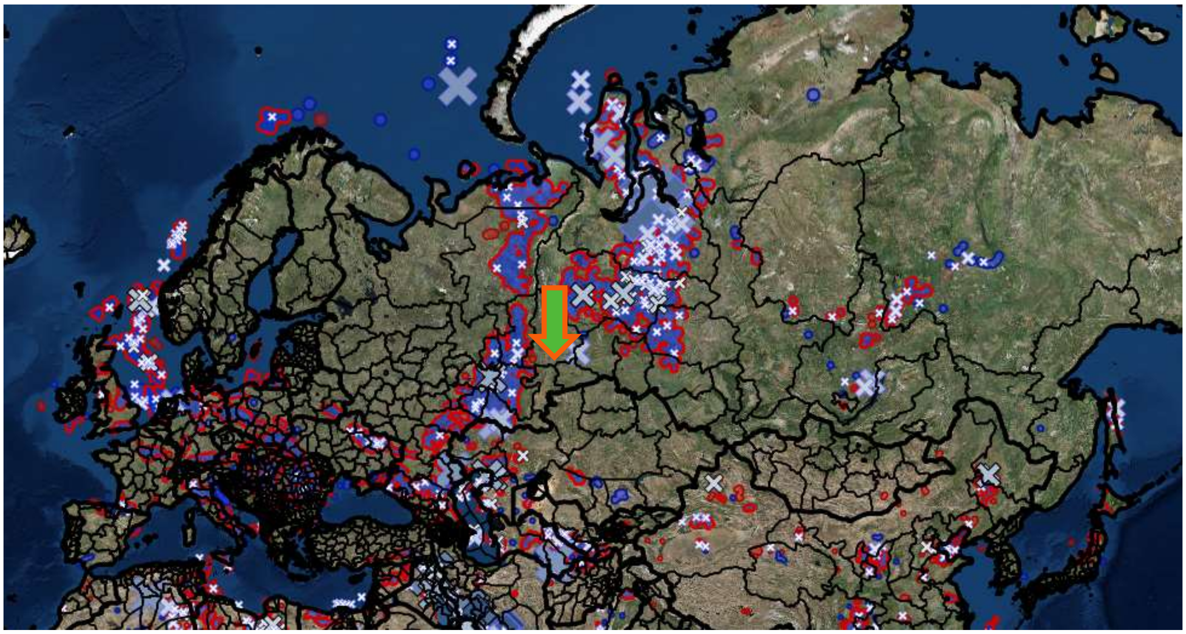

Fig. 3.1 Crude oil production in Russia and Europe according to Harvard World Map.[10] Arrow in orange and green showing Yekaterinburg as assumption for average origin of crude oil imported from Russia to Europe

3.8 Summary for the distances and means of transport

The following tables give an overview on the data which are used to model a theoretical life cycle inventory of long-distance transports of crude oil to Switzerland (Tab. 3.2), Europe (Tab. 3.3), Northern America (Tab. 3.4) and the global market (Tab. 3.5). Included are the shares of crude oil transported from the modelled countries of extraction (see chapter 2) and the assumed transport distances by mean of transport.

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[10] http://worldmap.harvard.edu/maps/6176, online 18.01.2018

[11] Imports and Exports 2016: https://www.eia.gov/tools/faqs/faq.php?id=727&t=6, online 13.11.2017

[12] https://www.eia.gov/dnav/pet/pet_crd_crpdn_adc_mbbl_a.htm, online 18.01.2018

[13] Drilling Maps: https://www.arcgis.com/home/item.html?id=a03b2e1da77c4c93b7cad628c0f268be, online 13.11.2017

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

The import mixes are derived from global, regional and national statistics (Avenergy_Suisse 2020; BP 2020). As only extraction data for some of the countries were modelled, the shares of these countries (c.f. Tab. 2.1 to Tab. 2.4) are extrapolated to match 100% of the import mix

Where available and plausible, values for transport distances were kept in line with the latest studies (Jungbluth 2007; Meili et al. 2018; Stolz & Frischknecht 2017). Other distances for transport in pipelines and on open sea are taken from online maps[15,16].

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

Origin of crude oil transported to CH-region	Port of Origin	Share for market mix in 2019	Distance offshore pipeline origin	Distance onshore pipeline origin	Distance destination port to refinery	Distance shipping
		%	km	km	km	km
Azerbaijan	Ceyhan	0.1%	200	1'800	600	3'000
Algeria	Algiers	3.3%	-	100	600	800
Kazakhstan	Novorossiysk	28.7%	20	3'400	600	3'400
Libyan Arab Jamahiriya	Sirtica Terminal	22.3%	20	100	600	1'900
Nigeria	Lagos	34.2%	200	140	600	7'100
Russian Federation	St. Petersburg	1.1%	-	3'500	600	6'000
United States	Houston	10.5%	20	1'120	600	10'100
Total	-	100.0%	-	-	-	-

15 Distances for pipeline transport are taken from: www.maps.google.com, online 05.10.2017.

16 Distances for oceanic transport are taken from www.searates.com, online 05.10.2017 and https://sea-distances.org/, online 23.10.2019.

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

Origin of crude oil transported to RER-region	Port of Origin	Share for market mix in 2019	Distance offshore pipeline origin	Distance onshore pipeline origin	Distance destination port to refinery	Distance shipping
		%	km	km	km	km
Azerbaijan	Ceyhan	2.9%	200	1'800	100	6'300
Brazil	Santos	1.0%	20	100	100	10'100
Canada	Quebec	0.6%	20	100	100	9'700
Colombia	Tumaco	0.3%	20	100	100	9'800
Germany	Hamburg	0.4%	20	100	-	-
Algeria	Algiers	3.7%	-	100	100	3'300
Ecuador	Port of Manta	0.2%	20	100	100	10'100
United Kingdom	Southampton	7.1%	200	100	-	500
Iraq	Basrah	9.1%	-	970	100	2'900
Iran	Bahregan Sar Oilfield	0.4%	20	100	100	12'100
Kuwait	Port of Kuwait	0.8%	20	100	100	12'200
Kazakhstan	Novorossiysk	7.0%	20	3'400	1'300	-
Libyan Arab Jamahiriya	Sirtica Terminal	3.3%	20	100	100	5'100
Mexico	Veracruz	1.7%	200	240	100	10'000
Nigeria	Lagos	10.7%	200	140	100	7'800
Netherlands	Rotterdam	0.2%	20	100	-	-
Norway	Bergen	10.7%	200	200	-	1'100
Qatar	Halul Island	0.2%	200	100	100	11'700
Romania	Constanța	0.5%	20	100	-	-
Russian Federation	St. Petersburg	25.1%	-	3'500	300	-
Saudi Arabia	Ju' aimah	6.5%	20	1'300	100	12'000
United States	Houston	7.5%	20	1'120	100	9'700
Venezuela	Jose Petroterminal	0.3%	20	100	100	7'800
Total	-	100.0%	-	-	-	-

Tab. 3.4 Overview of transport distances and export shares used for modelling of long-distance transports to North American market.

Origin of crude oil transported to RNA-region	Port of Origin	Share for market mix in 2019	Distance offshore pipeline origin	Distance onshore pipeline origin	Distance destination port to refinery	Distance shipping
		%	km	km	km	km
Brazil	Santos	1.8%	20	100	100	10'300
Canada	Quebec	24.6%	20	100	100	6'100
Colombia	Tumaco	0.5%	20	100	100	3'800
Algeria	Algiers	0.2%	-	100	100	9'600
Ecuador	Port of Manta	0.3%	20	100	100	4'000
United Kingdom	Southampton	0.2%	200	100	100	9'300
Indonesia	Port of Tanjung Priok	0.1%	20	100	100	22'200
Iraq	Basrah	1.5%	-	970	100	19'000
Kuwait	Port of Kuwait	0.2%	20	100	100	18'500
Kazakhstan	Novorossiysk	0.1%	20	3'400	100	13'100
Libyan Arab Jamahiriya	Sirtica Terminal	0.1%	20	100	100	11'400
Mexico	Veracruz	6.1%	200	240	100	1'300
Nigeria	Lagos	1.4%	200	140	100	11'100
Norway	Bergen	0.3%	200	200	100	9'200
Russian Federation	St. Petersburg	0.7%	-	3'500	100	11'000
Saudi Arabia	Ju' aimah	2.8%	20	1'300	100	19'000
United States	Houston	58.3%	20	1'120	100	-
Venezuela	Jose Petroterminal	0.5%	20	100	100	3'900
Total	-	100.0%	-	-	-	-

Tab. 3.5 Overview of transport distances and export shares used for modelling of long-distance transports to the global market.

Origin of crude oil transported to GLO-region	Port of Origin	Share for market mix in 2019	Distance offshore pipeline origin	Distance onshore pipeline origin	Distance destination port to refinery	Distance shipping
		%	km	km	km	km
United Arab Emirates	Abu Dhabi	4.4%	20	100	67	6'600
Azerbaijan	Ceyhan	0.9%	200	1'800	18	1'800
Brazil	Santos	3.7%	20	100	89	13'800
Canada	Quebec	6.8%	20	100	98	6'200
China	Guangdong	4.7%	20	100	0	100
Colombia	Tumaco	1.1%	20	100	89	12'400
Germany	Hamburg	0.1%	20	100	100	14'200
Algeria	Algiers	1.6%	-	100	32	3'300
Ecuador	Port of Manta	0.7%	20	100	89	11'700
United Kingdom	Southampton	1.3%	200	100	93	13'200
Indonesia	Port of Tanjung Priok	0.9%	20	100	73	3'200
Iraq	Basrah	5.8%	-	970	61	5'200
Iran	Bahregan Sar Oilfield	4.0%	20	100	78	6'800
Kuwait	Port of Kuwait	3.5%	20	100	55	4'800
Kazakhstan	Novorossiysk	2.3%	20	3'400	18	2'000
Libyan Arab Jamahiriya	Sirtica Terminal	1.4%	20	100	32	3'200
Mexico	Veracruz	2.3%	200	240	70	4'100
Malaysia	Sungai UdangPort	0.7%	20	100	73	3'100
Nigeria	Lagos	2.5%	200	140	60	9'600
Netherlands	Rotterdam	0.0%	20	100	100	13'500
Norway	Bergen	1.9%	200	200	93	13'900
Qatar	Halul Island	1.9%	200	100	78	6'500
Romania	Constanța	0.1%	20	100	93	11'700
Russian Federation	St. Petersburg	14.0%	-	3'500	36	6'900
Saudi Arabia	Ju' aimah	13.7%	20	1'300	63	6'600
United States	Houston	18.4%	20	1'120	40	4'800
Venezuela	Jose Petroterminal	1.1%	20	100	89	12'000
Total		100.0%				

4 Evaporation Losses for storage and handling

No updates were made in this chapter compared to Meili et al. 2018.

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[17]. 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[17] 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 oil transported via sea-vessels and crude vapour pressure.

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 (numbers in bold)

	Veldt et al. 1992		John Zink Company		This study
	losses %weight	kg VOC/kg crude oil	losses %weight	kg VOC/kg crude oil	kg VOC/kg crude oil
Total	100.0	1.80E-05	100.0	1.38E-03	
Air/inert	-		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

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

5 Pipeline transports

No updates were commissioned for this chapter compared to Meili et al. 2018. However, a calculation error for oil spilled is corrected and related emission values are included and updated.

5.1 Pipeline technology and transport losses

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 assumption is taken because of an 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			
product	transport, crude oil pipeline, onshore	RER	0	tkm	1.00E+0			
technosphere	electricity, medium voltage, production ENTSO, at grid	ENTSO	0	kWh	2.00E-2	1	1.53	(3,3,5,1,1,BU:1.05); Literature
	pipeline, crude oil, onshore	RER	1	km	9.46E-9	1	3.24	(3,1,5,1,1,BU:3); Literature
emission soil, industrial	Oils, unspecified	-	-	kg	2.65E-9	1	1.51	(2,1,2,1,1,BU:1.5); 0.5ppm average losses due to operational spills, times throughput of 418Mm3 divided by traffic volume of 79m3km, as reported in Concawe 2017, p. 8 and 22
	Nitrogen	-	-	kg	2.04E-12	1	1.52	(3,na,na,3,1,BU:1.5); Extrapolation for sum parameter
	Sulfur	-	-	kg	7.08E-12	1	1.52	(3,na,na,3,1,BU:1.5); Extrapolation for sum parameter

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	UncertaintyType	StandardDeviation95%	GeneralComment
	Location				OCE			
	InfrastructureProcess				0			
	Unit				tkm			
product	transport, crude oil pipeline, offshore	OCE	0	tkm	1.00E+0			
technosphere	diesel, burned in diesel-electric generating set	GLO	0	MJ	4.50E-1	1	1.53	(3,3,5,1,1,BU:1.05); Literature
	pipeline, crude oil, offshore	OCE	1	km	9.46E-9	1	3.23	(1,1,5,1,1,BU:3); Performance of European pipelines
emission water, ocean	Oils, unspecified	-	-	kg	2.65E-9	1	2.25	(3,3,1,3,5,BU:1.5); Literature for onshore pipelines, 0.5ppm losses due to operational spills reported in Concawe 2017
	BOD5, Biological Oxygen Demand	-	-	kg	8.33E-09	1	1.52	(3,na,na,3,1,BU:1.5); Extrapolation for sum parameter
	COD, Chemical Oxygen Demand	-	-	kg	8.33E-09	1	1.52	(3,na,na,3,1,BU:1.5); Extrapolation for sum parameter
	DOC, Dissolved Organic Carbon	-	-	kg	2.29E-09	1	1.52	(3,na,na,3,1,BU:1.5); Extrapolation for sum parameter
	TOC, Total Organic Carbon	-	-	kg	2.29E-09	1	1.52	(3,na,na,3,1,BU:1.5); Extrapolation for sum parameter
	AOX, Adsorbable Organic Halogen as Cl	-	-	kg	2.72E-14	1	2.47	(3,3,5,3,5,BU:1.5); Extrapolation for sum parameter
	Nitrogen	-	-	kg	2.04E-12	1	2.47	(3,3,5,3,5,BU:1.5); Extrapolation for sum parameter
	Sulfur	-	-	kg	7.08E-12	1	2.47	(3,3,5,3,5,BU:1.5); Extrapolation for sum parameter

5.2 Pipeline infrastructure

No updates were made in this chapter compared to Meili et al. 2018.

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).

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*	UncertaintyType	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 to Tab. 6.4 show the full life cycle inventory data for the newly modelled and updated processes. Tab. 6.5 contains Meta-information about the newly modelled and updated processes.

Tab. 6.1 Unit process raw data for produced crude oil transported to refineries in Switzerland.

CH, market	Name	Location	Unit	crude oil, market mix, at long distance transport	UncertaintyType	StandardDeviation95%	GeneralComment
	Location			CH			
	Unit			kg			
	crude oil, market mix, at long distance transport	CH	kg	1.00E+0			
	crude oil, at production	AZ	kg	0.06%	1	1.21	(1,1,1,3,3,BU:1.05); Crude oil including losses in transport
	crude oil, at production	DZ	kg	3.26%	1	1.21	(1,1,1,3,3,BU:1.05); Crude oil including losses in transport
	crude oil, at production	KZ	kg	28.70%	1	1.21	(1,1,1,1,3,BU:1.05); Crude oil including losses in transport
	crude oil, at production	LY	kg	22.28%	1	1.21	(1,1,1,3,3,BU:1.05); Crude oil including losses in transport
	crude oil, at production	NG	kg	34.16%	1	1.21	(1,1,1,3,3,BU:1.05); Crude oil including losses in transport
	crude oil, at production	RU	kg	1.06%	1	1.21	(1,1,1,1,3,BU:1.05); Crude oil including losses in transport
	crude oil, at production	US	kg	10.51%	1	1.21	(1,1,1,1,3,BU:1.05); Crude oil including losses in transport
transport	transport, transoceanic tanker	OCE	tkm	4.93E+0	1	2.06	(3,2,1,3,3,BU:2); Calculation based on estimated shipping route and pipelines according to searates.com and export data for 2019.
	transport, crude oil pipeline, offshore	OCE	tkm	8.07E-2	1	1.24	(3,2,1,3,3,BU:1.05); Calculation based on estimated shipping route and pipelines according to searates.com and export data for 2019.
	transport, crude oil pipeline, onshore	RER	tkm	1.80E+0	1	1.24	(3,2,1,3,3,BU:1.05); Calculation based on estimated shipping route and pipelines according to searates.com and export data for 2019.
air, low population	Hydrocarbons, aliphatic, alkanes, unspecified	-	kg	1.35E-6	1	1.59	(3,4,4,1,1,BU:1.5); Evaporation losses for storage and handling
	Benzene	-	kg	4.50E-7	1	3.07	(3,4,4,1,1,BU:3); Evaporation losses for storage and handling
	Butane	-	kg	1.26E-4	1	1.59	(3,4,4,1,1,BU:1.5); Evaporation losses for storage and handling
	Methane, fossil	-	kg	1.50E-6	1	1.59	(3,4,4,1,1,BU:1.5); Evaporation losses for storage and handling
	Ethane	-	kg	1.60E-6	1	1.59	(3,4,4,1,1,BU:1.5); Evaporation losses for storage and handling
	Hexane	-	kg	5.39E-5	1	1.59	(3,4,4,1,1,BU:1.5); Evaporation losses for storage and handling
	Pentane	-	kg	9.56E-5	1	1.59	(3,4,4,1,1,BU:1.5); Evaporation losses for storage and handling
	Propane	-	kg	6.13E-5	1	1.59	(3,4,4,1,1,BU:1.5); Evaporation losses for storage and handling
	Toluene	-	kg	2.70E-7	1	1.59	(3,4,4,1,1,BU:1.5); Evaporation losses for storage and handling

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

RER, market	Name	Location	Unit	crude oil, market mix, at long distance transport	UncertaintyType	StandardDeviation95%	GeneralComment
	Location			RER			
	Unit			kg			
	crude oil, market mix, at long distance transport	RER	kg	1.00E+0			
extraction mix from:	crude oil, at production	AE	kg	0.03%	1	1.21	(1,1,1,3,3,BU:1.05); Crude oil including losses in transport
	crude oil, at production	AZ	kg	2.90%	1	1.21	(1,1,1,3,3,BU:1.05); Crude oil including losses in transport
	crude oil, at production	BR	kg	0.98%	1	1.21	(1,1,1,3,3,BU:1.05); Crude oil including losses in transport
	crude oil, at production	CA	kg	0.61%	1	1.21	(1,1,1,3,3,BU:1.05); Crude oil including losses in transport
	crude oil, at production	CN	kg	0.00%	1	1.21	(1,1,1,3,3,BU:1.05); Crude oil including losses in transport
	crude oil, at production	CO	kg	0.30%	1	1.21	(1,1,1,3,3,BU:1.05); Crude oil including losses in transport
	crude oil, at production	DE	kg	0.43%	1	1.21	(1,1,1,3,3,BU:1.05); Crude oil including losses in transport
	crude oil, at production	DZ	kg	3.67%	1	1.21	(1,1,1,3,3,BU:1.05); Crude oil including losses in transport
	crude oil, at production	EC	kg	0.19%	1	1.21	(1,1,1,3,3,BU:1.05); Crude oil including losses in transport
	crude oil, at production	GB	kg	7.06%	1	1.21	(1,1,1,3,3,BU:1.05); Crude oil including losses in transport
	crude oil, at production	ID	kg	0.00%	1	1.21	(1,1,1,3,3,BU:1.05); Crude oil including losses in transport
	crude oil, at production	IQ	kg	9.08%	1	1.21	(1,1,1,1,3,BU:1.05); Crude oil including losses in transport
	crude oil, at production	IR	kg	0.38%	1	1.21	(1,1,1,3,3,BU:1.05); Crude oil including losses in transport
	crude oil, at production	KW	kg	0.80%	1	1.21	(1,1,1,3,3,BU:1.05); Crude oil including losses in transport
	crude oil, at production	KZ	kg	6.95%	1	1.21	(1,1,1,1,3,BU:1.05); Crude oil including losses in transport
	crude oil, at production	LY	kg	3.30%	1	1.21	(1,1,1,3,3,BU:1.05); Crude oil including losses in transport
	crude oil, at production	MX	kg	1.72%	1	1.21	(1,1,1,1,3,BU:1.05); Crude oil including losses in transport
	crude oil, at production	MY	kg	0.00%	1	1.21	(1,1,1,3,3,BU:1.05); Crude oil including losses in transport
	crude oil, at production	NG	kg	10.68%	1	1.21	(1,1,1,3,3,BU:1.05); Crude oil including losses in transport
	crude oil, at production	NL	kg	0.15%	1	1.21	(1,1,1,3,3,BU:1.05); Crude oil including losses in transport
	crude oil, at production	NO	kg	10.68%	1	1.21	(1,1,1,3,3,BU:1.05); Crude oil including losses in transport
	crude oil, at production	QA	kg	0.18%	1	1.21	(1,1,1,3,3,BU:1.05); Crude oil including losses in transport
	crude oil, at production	RO	kg	0.49%	1	1.21	(1,1,1,3,3,BU:1.05); Crude oil including losses in transport
	crude oil, at production	RU	kg	25.10%	1	1.21	(1,1,1,1,3,BU:1.05); Crude oil including losses in transport
	crude oil, at production	SA	kg	6.54%	1	1.21	(1,1,1,3,3,BU:1.05); Crude oil including losses in transport
	crude oil, at production	US	kg	7.51%	1	1.21	(1,1,1,1,3,BU:1.05); Crude oil including losses in transport
	crude oil, at production	VE	kg	0.30%	1	1.21	(1,1,1,3,3,BU:1.05); Crude oil including losses in transport
transport	transport, transoceanic tanker	OCE	tkm	4.47E+0	1	2.06	(3,2,1,3,3,BU:2); Calculation based on estimated shipping route and pipelines according to searates.com and export data for 2019.
	transport, crude oil pipeline, offshore	OCE	tkm	4.50E-2	1	1.24	(3,2,1,3,3,BU:1.05); Calculation based on estimated shipping route and pipelines according to searates.com and export data for 2019.
	transport, crude oil pipeline, onshore	RER	tkm	2.05E+0	1	1.24	(3,2,1,3,3,BU:1.05); Calculation based on estimated shipping route and pipelines according to searates.com and export data for 2019.
air, low population	Hydrocarbons, aliphatic, alkanes, unspecified	-	kg	1.35E-6	1	1.59	(3,4,4,1,1,BU:1.5); Evaporation losses for storage and handling
	Benzene	-	kg	4.50E-7	1	3.07	(3,4,4,1,1,BU:3); Evaporation losses for storage and handling
	Butane	-	kg	1.26E-4	1	1.59	(3,4,4,1,1,BU:1.5); Evaporation losses for storage and handling
	Methane, fossil	-	kg	1.50E-6	1	1.59	(3,4,4,1,1,BU:1.5); Evaporation losses for storage and handling
	Ethane	-	kg	1.60E-6	1	1.59	(3,4,4,1,1,BU:1.5); Evaporation losses for storage and handling
	Hexane	-	kg	5.39E-5	1	1.59	(3,4,4,1,1,BU:1.5); Evaporation losses for storage and handling
	Pentane	-	kg	9.56E-5	1	1.59	(3,4,4,1,1,BU:1.5); Evaporation losses for storage and handling
	Propane	-	kg	6.13E-5	1	1.59	(3,4,4,1,1,BU:1.5); Evaporation losses for storage and handling
	Toluene	-	kg	2.70E-7	1	1.59	(3,4,4,1,1,BU:1.5); Evaporation losses for storage and handling

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

RNA, market	Name	Location	Unit	crude oil, market mix, at long distance transport	UncertaintyType	Standard-Deviation95%	GeneralComment
	Location			RNA			
	Unit			kg			
	crude oil, market mix, at long distance transport	RNA	kg	1.00E+0			
extraction mix from:	crude oil, at production	AE	kg	0.01%	1	1.21	(1,1,1,3,3,BU:1.05); Crude oil including losses in transport
	crude oil, at production	AZ	kg	0.05%	1	1.21	(1,1,1,3,3,BU:1.05); Crude oil including losses in transport
	crude oil, at production	BR	kg	1.76%	1	1.21	(1,1,1,3,3,BU:1.05); Crude oil including losses in transport
	crude oil, at production	CA	kg	24.64%	1	1.21	(1,1,1,3,3,BU:1.05); Crude oil including losses in transport
	crude oil, at production	CN	kg	0.00%	1	1.21	(1,1,1,3,3,BU:1.05); Crude oil including losses in transport
	crude oil, at production	CO	kg	0.55%	1	1.21	(1,1,1,3,3,BU:1.05); Crude oil including losses in transport
	crude oil, at production	DE	kg	0.01%	1	1.21	(1,1,1,3,3,BU:1.05); Crude oil including losses in transport
	crude oil, at production	DZ	kg	0.17%	1	1.21	(1,1,1,3,3,BU:1.05); Crude oil including losses in transport
	crude oil, at production	EC	kg	0.33%	1	1.21	(1,1,1,3,3,BU:1.05); Crude oil including losses in transport
	crude oil, at production	GB	kg	0.22%	1	1.21	(1,1,1,3,3,BU:1.05); Crude oil including losses in transport
	crude oil, at production	ID	kg	0.05%	1	1.21	(1,1,1,3,3,BU:1.05); Crude oil including losses in transport
	crude oil, at production	IQ	kg	1.52%	1	1.21	(1,1,1,1,3,BU:1.05); Crude oil including losses in transport
	crude oil, at production	IR	kg	0.00%	1	1.21	(1,1,1,3,3,BU:1.05); Crude oil including losses in transport
	crude oil, at production	KW	kg	0.21%	1	1.21	(1,1,1,3,3,BU:1.05); Crude oil including losses in transport
	crude oil, at production	KZ	kg	0.11%	1	1.21	(1,1,1,1,3,BU:1.05); Crude oil including losses in transport
	crude oil, at production	LY	kg	0.15%	1	1.21	(1,1,1,3,3,BU:1.05); Crude oil including losses in transport
	crude oil, at production	MX	kg	6.14%	1	1.21	(1,1,1,1,3,BU:1.05); Crude oil including losses in transport
	crude oil, at production	MY	kg	0.04%	1	1.21	(1,1,1,3,3,BU:1.05); Crude oil including losses in transport
	crude oil, at production	NG	kg	1.40%	1	1.21	(1,1,1,3,3,BU:1.05); Crude oil including losses in transport
	crude oil, at production	NL	kg	0.00%	1	1.21	(1,1,1,3,3,BU:1.05); Crude oil including losses in transport
	crude oil, at production	NO	kg	0.33%	1	1.21	(1,1,1,3,3,BU:1.05); Crude oil including losses in transport
	crude oil, at production	QA	kg	0.00%	1	1.21	(1,1,1,3,3,BU:1.05); Crude oil including losses in transport
	crude oil, at production	RO	kg	0.02%	1	1.21	(1,1,1,3,3,BU:1.05); Crude oil including losses in transport
	crude oil, at production	RU	kg	0.69%	1	1.21	(1,1,1,1,3,BU:1.05); Crude oil including losses in transport
	crude oil, at production	SA	kg	2.76%	1	1.21	(1,1,1,1,3,BU:1.05); Crude oil including losses in transport
	crude oil, at production	US	kg	58.34%	1	1.21	(1,1,1,1,3,BU:1.05); Crude oil including losses in transport
	crude oil, at production	VE	kg	0.55%	1	1.21	(1,1,1,3,3,BU:1.05); Crude oil including losses in transport
transport	transport, transoceanic tanker	OCE	tkm	7.63E+0	1	2.06	(3,2,1,3,3,BU:2); Calculation based on estimated shipping route and pipelines according to searates.com and export data for 2019.
	transport, crude oil pipeline, offshore	OCE	tkm	4.41E-2	1	1.24	(3,2,1,3,3,BU:1.05); Calculation based on estimated shipping route and pipelines according to searates.com and export data for 2019.
	transport, crude oil pipeline, onshore	RER	tkm	5.05E-1	1	1.24	(3,2,1,3,3,BU:1.05); Calculation based on estimated shipping route and pipelines according to searates.com and export data for 2019.
air, low population	Hydrocarbons, aliphatic, alkanes, unspecified	-	kg	1.35E-6	1	1.59	(3,4,4,1,1,BU:1.5); Evaporation losses for storage and handling
	Benzene	-	kg	4.50E-7	1	3.07	(3,4,4,1,1,BU:3); Evaporation losses for storage and handling
	Butane	-	kg	1.26E-4	1	1.59	(3,4,4,1,1,BU:1.5); Evaporation losses for storage and handling
	Methane, fossil	-	kg	1.50E-6	1	1.59	(3,4,4,1,1,BU:1.5); Evaporation losses for storage and handling
	Ethane	-	kg	1.60E-6	1	1.59	(3,4,4,1,1,BU:1.5); Evaporation losses for storage and handling
	Hexane	-	kg	5.39E-5	1	1.59	(3,4,4,1,1,BU:1.5); Evaporation losses for storage and handling
	Pentane	-	kg	9.56E-5	1	1.59	(3,4,4,1,1,BU:1.5); Evaporation losses for storage and handling
	Propane	-	kg	6.13E-5	1	1.59	(3,4,4,1,1,BU:1.5); Evaporation losses for storage and handling
	Toluene	-	kg	2.70E-7	1	1.59	(3,4,4,1,1,BU:1.5); Evaporation losses for storage and handling

Tab. 6.4 Unit process raw data for produced crude oil transported to refineries in global area.

GLO, market	Name	Location	Unit	crude oil, market mix, at long distance transport	UncertaintyType	StandardDeviation95%	GeneralComment
	Location			GLO			
	Unit			kg			
	crude oil, market mix, at long distance transport	GLO	kg	1.00E+0			
extraction mix from:	crude oil, at production	AE	kg	4.44%	1	1.21	(1,1,1,3,3,BU:1.05); Crude oil including losses in transport
	crude oil, at production	AZ	kg	0.94%	1	1.21	(1,1,1,3,3,BU:1.05); Crude oil including losses in transport
	crude oil, at production	BR	kg	3.71%	1	1.21	(1,1,1,3,3,BU:1.05); Crude oil including losses in transport
	crude oil, at production	CA	kg	6.77%	1	1.21	(1,1,1,3,3,BU:1.05); Crude oil including losses in transport
	crude oil, at production	CN	kg	4.70%	1	1.21	(1,1,1,3,3,BU:1.05); Crude oil including losses in transport
	crude oil, at production	CO	kg	1.15%	1	1.21	(1,1,1,3,3,BU:1.05); Crude oil including losses in transport
	crude oil, at production	DE	kg	0.08%	1	1.21	(1,1,1,3,3,BU:1.05); Crude oil including losses in transport
	crude oil, at production	DZ	kg	1.58%	1	1.21	(1,1,1,3,3,BU:1.05); Crude oil including losses in transport
	crude oil, at production	EC	kg	0.70%	1	1.21	(1,1,1,3,3,BU:1.05); Crude oil including losses in transport
	crude oil, at production	GB	kg	1.28%	1	1.21	(1,1,1,3,3,BU:1.05); Crude oil including losses in transport
	crude oil, at production	ID	kg	0.94%	1	1.21	(1,1,1,3,3,BU:1.05); Crude oil including losses in transport
	crude oil, at production	IQ	kg	5.77%	1	1.21	(1,1,1,1,3,BU:1.05); Crude oil including losses in transport
	crude oil, at production	IR	kg	3.96%	1	1.21	(1,1,1,3,3,BU:1.05); Crude oil including losses in transport
	crude oil, at production	KW	kg	3.55%	1	1.21	(1,1,1,3,3,BU:1.05); Crude oil including losses in transport
	crude oil, at production	KZ	kg	2.25%	1	1.21	(1,1,1,1,3,BU:1.05); Crude oil including losses in transport
	crude oil, at production	LY	kg	1.42%	1	1.21	(1,1,1,3,3,BU:1.05); Crude oil including losses in transport
	crude oil, at production	MX	kg	2.34%	1	1.21	(1,1,1,1,3,BU:1.05); Crude oil including losses in transport
	crude oil, at production	MY	kg	0.73%	1	1.21	(1,1,1,3,3,BU:1.05); Crude oil including losses in transport
	crude oil, at production	NG	kg	2.50%	1	1.21	(1,1,1,3,3,BU:1.05); Crude oil including losses in transport
	crude oil, at production	NL	kg	0.03%	1	1.21	(1,1,1,3,3,BU:1.05); Crude oil including losses in transport
	crude oil, at production	NO	kg	1.93%	1	1.21	(1,1,1,3,3,BU:1.05); Crude oil including losses in transport
	crude oil, at production	QA	kg	1.93%	1	1.21	(1,1,1,3,3,BU:1.05); Crude oil including losses in transport
	crude oil, at production	RO	kg	0.09%	1	1.21	(1,1,1,3,3,BU:1.05); Crude oil including losses in transport
	crude oil, at production	RU	kg	13.99%	1	1.21	(1,1,1,1,3,BU:1.05); Crude oil including losses in transport
	crude oil, at production	SA	kg	13.71%	1	1.21	(1,1,1,1,3,BU:1.05); Crude oil including losses in transport
	crude oil, at production	US	kg	18.39%	1	1.21	(1,1,1,1,3,BU:1.05); Crude oil including losses in transport
	crude oil, at production	VE	kg	1.15%	1	1.21	(1,1,1,3,3,BU:1.05); Crude oil including losses in transport
transport	transport, transoceanic tanker	OCE	tkm	6.59E+0	1	2.06	(3,2,1,3,3,BU:2); Calculation based on estimated shipping route and pipelines according to searates.com and export data for 2019.
	transport, crude oil pipeline, offshore	OCE	tkm	4.53E-2	1	1.24	(3,2,1,3,3,BU:1.05); Calculation based on estimated shipping route and pipelines according to searates.com and export data for 2019.
	transport, crude oil pipeline, onshore	RER	tkm	1.09E+0	1	1.24	(3,2,1,3,3,BU:1.05); Calculation based on estimated shipping route and pipelines according to searates.com and export data for 2019.
air, low population	Hydrocarbons, aliphatic, alkanes, unspecified	-	kg	1.35E-6	1	1.59	(3,4,4,1,1,BU:1.5); Evaporation losses for storage and handling
	Benzene	-	kg	4.50E-7	1	3.07	(3,4,4,1,1,BU:3); Evaporation losses for storage and handling
	Butane	-	kg	1.26E-4	1	1.59	(3,4,4,1,1,BU:1.5); Evaporation losses for storage and handling
	Methane, fossil	-	kg	1.50E-6	1	1.59	(3,4,4,1,1,BU:1.5); Evaporation losses for storage and handling
	Ethane	-	kg	1.60E-6	1	1.59	(3,4,4,1,1,BU:1.5); Evaporation losses for storage and handling
	Hexane	-	kg	5.39E-5	1	1.59	(3,4,4,1,1,BU:1.5); Evaporation losses for storage and handling
	Pentane	-	kg	9.56E-5	1	1.59	(3,4,4,1,1,BU:1.5); Evaporation losses for storage and handling
	Propane	-	kg	6.13E-5	1	1.59	(3,4,4,1,1,BU:1.5); Evaporation losses for storage and handling
	Toluene	-	kg	2.70E-7	1	1.59	(3,4,4,1,1,BU:1.5); Evaporation losses for storage and handling

Tab. 6.5 Meta information (X-Process) for the investigated life cycle inventories.

ReferenceFunction	Name	crude oil, import mix, at long distance transport	crude oil, import mix, at long distance transport	crude oil, import mix, at long distance transport	crude oil, import mix, at long distance transport
Geography	Location	CH	RER	RNA	GLO
ReferenceFunction	InfrastructureProcess	0	0	0	0
ReferenceFunction	Unit	kg	kg	kg	kg
	IncludedProcesses	Transportation of crude oil from exploration sites to refineries in Swiss-region. Includes transport service requirements and emissions from oil handling and evaporation.	Transportation of crude oil from exploration sites to refineries in European-region. Includes transport service requirements and emissions from oil handling and evaporation.	Transportation of crude oil from exploration sites to refineries in North American-region. Includes transport service requirements and emissions from oil handling and evaporation.	Transportation of crude oil from exploration sites to refineries in global region. Includes transport service requirements and emissions from oil handling and evaporation.
	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 2019.	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 2019.	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 2019.	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 2019.
	InfrastructureIncluded	1	1	1	1
	Category	oil	oil	oil	oil
	SubCategory	transport	transport	transport	transport
TimePeriod	StartDate	2019	2019	2019	2019
	EndDate	2022	2022	2022	2022
	DataValidForEntirePeriod	1	1	1	1
	OtherPeriodText	Transport modes investigated for 2019.	Transport modes investigated for 2019.	Transport modes investigated for 2019.	Transport modes investigated for 2019.
Geography	Text	Calculations include production and transport of crude oil from 7 countries.	Calculations include production and transport of crude oil from 26 countries.	Calculations include production and transport of crude oil from countries.	Calculations include production and transport of crude oil from 27 countries.
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.
	ProductionVolume	2.7 million tons of directly imported crude oil to Switzerland in 2019.	610 million tons of directly imported crude oil to the European region in 2019.	1086 million tons of directly imported crude oil globally in 2019.	4062 million tons of directly imported crude oil globally in 2019.
	SamplingProcedure	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
	UncertaintyAdjustments	none	none	none	none
ecoinvent v3	ProductionVolumeNumber	2.7	610	1086	4062
	ProductionVolumeText	Megatons of oil transported in 2019	Megatons of oil transported in 2019	Megatons of oil transported in 2019	Megatons of oil transported in 2019

7 Outlook

Due to the availability of more specific national data on flaring of associated petroleum gas (APG) and unintentional methane emissions during oil production, and its high relevance for the country-specific environmental impacts of crude oil extraction, the composition of the crude oil import mix gets a higher importance.

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

It would be recommended to update the LCI for the crude oil import mix regularly to monitor the environmental impacts related to crude oil supply in Switzerland and Europe.

Some feedback to the present models indicated that data for shipping of crude oil and especially associated sulphur dioxide emissions might be outdated and not reflecting implementation of the IMO 2020 reduction in maximum sulphur content for marine fuel. Controlling this was out of the scope of this project. Such an update would be recommended, based on latest literature (e.g. Rajabi et al. 2020). It might also be part of a general update project for transport processes of sea transports.

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

[18] The fundament of this database is ecoinvent v2.2. Updates and data published on www.lc-inventories.ch as well as further studies available on www.treeze.ch are incorporated in this database UVEK LCI Data 2018.

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