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Life cycle inventories of long-distance transport of crude oil

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Report

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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

This document is based on the previous update of the life cycle inventory data for long-distance transport of crude oil (Meili et al. 2018). That study analysed the long-distance crude oil transport from the perspective of production regions relevant for Switzerland and Europe. A general overview of the former project is given in a separate report (Jungbluth et al. 2018a).

The approach for the modelling of the life cycle inventory analysis has been simplified in later projects by developing an archetype model for the crude oil and natural gas extraction (Meili & Jungbluth 2019).

The goal of the report at hand is to describe the data as they are investigated for an update for the reference year 2019.

The report 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. 2021a), the transport of crude oil to European refineries (Meili et al. 2021b) and the transport of natural gas to the European end user (Bussa et al. 2021).

After finalization, data shall be published in UVEK 2021 provided by FOEN. Additionally, the updated life cycle inventory data will be published for free on http://esu-services.ch/data/public-lci-reports.

In this update also crude oil extracted in countries that are less relevant for the Swiss or European market were included, if the Swiss or European market is supplied with a relevant share of natural gas from these countries.

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

For information on updated data for the most important transport routes, see the following chapters.

The life cycle inventory analysis for the transport of crude oil from different countries of origin to a theoretical European 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.

In this study, imports to Europe and Switzerland are only modelled from a Swiss and European perspective. Thus, imports are classified according to their relevance for the delivery of refinery products to the European and Swiss market. The data might therefore not be accurate in view of the average global or other regional production.

To simplify future modelling, aggregated datasets for crude oil import mix to Switzerland and Europe 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, the latest international trade data is used in the model (Avenergy_Suisse 2020; BP 2020).[1]

In 2019, 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. 2021a).

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	%
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	**2739**	**100.0%**

To the EU-28 countries, in 2019, crude oil is imported from the countries listed in Tab. 2.2.[1] Only for the countries highlighted in green, extraction data is modelled and updated for the reference year 2019 (Meili et al. 2021a). For the updated of the extraction data for crude oil and natural gas, 16 countries of origin were selected based on their relative share of imports to the European and Swiss market. All selected countries have a share higher than 1.5% on either the natural gas or crude oil supply to Europe or Switzerland.

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 and share of crude oil imported to the EU-28 countries in 2019, by country of origin, Countries for which updated extraction data is modelled are highlighted in green.[1]

	Origin of crude oil transported to European Union	**Crude oil imported**	**Share for import mix in 2019**
		million tons	%
1	Russian Federation	135.70	24.1%
2	Norway	55.43	9.9%
3	Iraq	46.68	8.3%
4	Nigeria	43.26	7.7%
5	Kazakhstan	40.89	7.3%
6	Saudi Arabia	40.27	7.2%
7	United States	39.71	7.1%
8	Libyan Arab Jamahiriya	34.54	6.1%
9	United Kingdom	26.32	4.7%
10	Azerbaijan	22.88	4.1%
11	Algeria	19.04	3.4%
12	Mexico	9.72	1.7%
13	Angola	7.31	1.3%
14	Kuwait	5.39	1.0%
15	Other African Countries	5.09	0.9%
16	Egypt	4.83	0.9%
17	Venezuela	4.75	0.8%
18	Brazil	4.57	0.8%
19	Canada	4.37	0.8%
20	Other FSU countries	3.07	0.5%
21	Cameroon	1.76	0.3%
22	Denmark	1.76	0.3%
23	Colombia	1.23	0.2%
24	Other European countries	1.22	0.2%
25	Gabon	0.82	0.1%
26	Tunisia	0.55	0.1%
27	Congo	0.39	0.1%
28	Congo (DR)	0.26	0.0%
29	Yemen	0.20	0.0%
30	Argentina	0.13	0.0%
31	Other Latin America countries	0.11	0.0%
32	Ukraine	0.08	0.0%
33	Syria	0.01	0.0%
41	**Total**	**562.32**	**100.0%**

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) a generic transport distances to a refinery of about 100km is considered.

3.4 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. 2021a, 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., Norway and Qatar), 200km offshore pipeline are assumed.

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).

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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.

3.4.1 Azerbaijan

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

3.4.2 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).

3.4.3 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.

3.5.1 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.

3.5.3 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.

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.

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

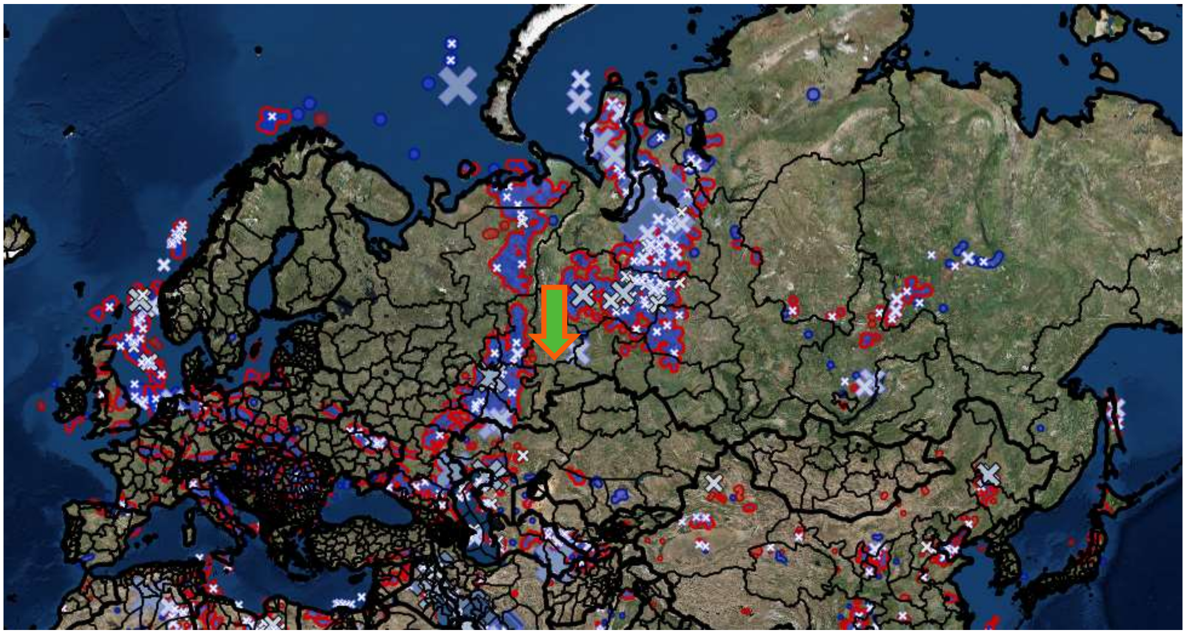

Fig. 3.1 Crude oil production in Russia and Europe according to Harvard World Map[10], Arrow in orange and green showing Yekaterinburg as assumption for average origin of crude oil imported from Russia to Europe

3.6 Transport from seaport to refineries

3.6.1 From seaport in Marseille to Switzerland

Crude oil directly imported to the Swiss refinery in Cressier is transported through the Pipeline Olé-oduc 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[14].

3.6.2 From seaport to European refinery

Most refineries in Europe are situated close to seaports as visible in Fig. 3.3. Therefore, for most countries, distances for transport of crude oil, onshore to refineries are assumed to be on average about 100km in onshore pipelines. Exceptions are, e.g., transport from Kazakhstan, Russia and Azer-baijan to Europe. There, transport is assumed to be done completely in onshore pipelines which there-fore are considerably longer. This is accounted for in Tab. 3.3 by including a longer distance "port of destination to refinery". For countries with smaller production rates like the Netherlands, Germany, and the United Kingdom, it is assumed that the whole production is refined locally. Therefore, the distance for transport in a local onshore pipeline is set to a generic value of 10km.

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.

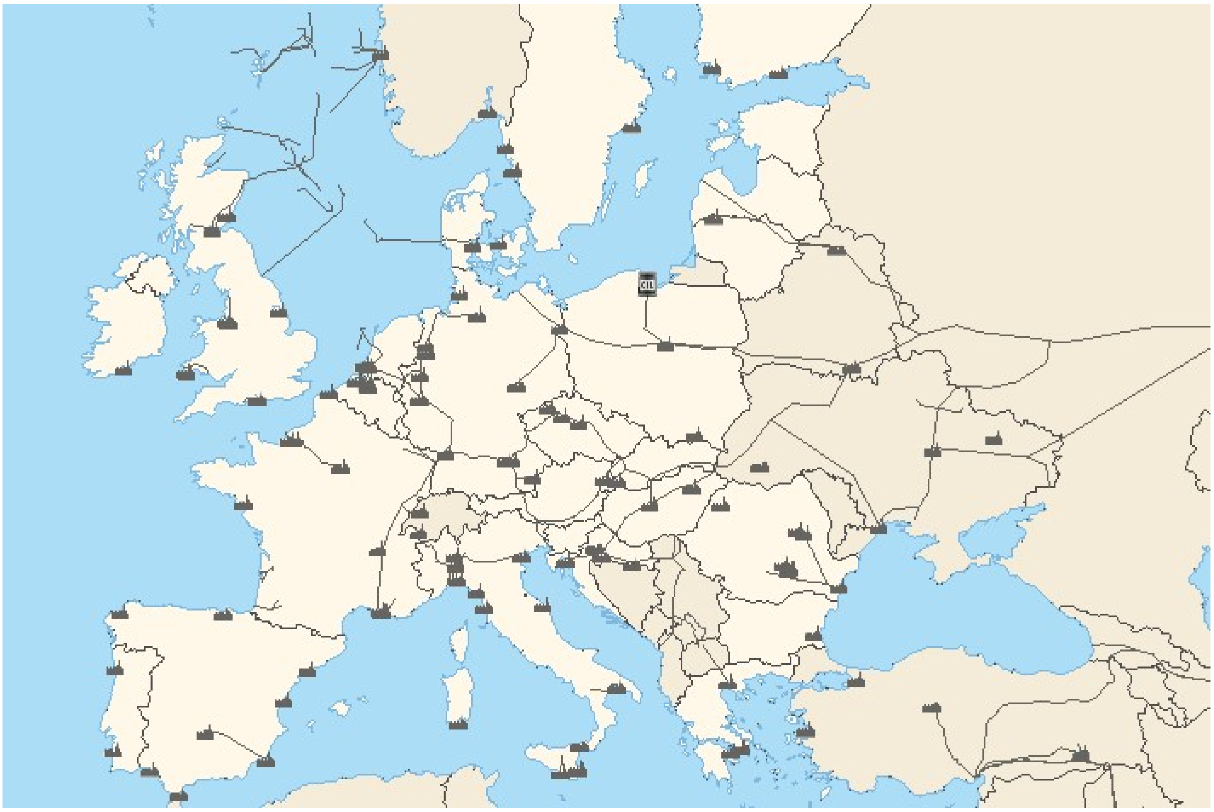

Fig. 3.3 Location of European refineries - Interactive map of the European commission (European Commission 2017)

3.7 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) and Europe (Tab. 3.3). 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.

The import mixes are derived from global, regional and national statistics (Avenergy_Suisse 2020; BP 2020).[1] As only extraction data for some of the countries were modelled, the shares of these countries (c.f. Tab. 2.1 and Tab. 2.2) 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].

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. 3.2 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 import 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

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 import mix in 2019	Distance offshore pipeline origin	Distance onshore pipeline origin	Distance destination port to refinery	Distance shipping
		%	km	km	km	km
Azerbaijan	Ceyhan	4.4%	200	1'800	100	6'300
Algeria	Algiers	3.7%	-	100	100	3'300
United Kingdom	Southhampton	5.1%	200	100	-	500
Iraq	Basrah	9.1%	-	970	100	2'900
Kazakhstan	Novorossiysk	8.0%	20	3'400	1'300	-
Libyan Arab Jamahiriya	Sirtica Terminal	6.7%	20	100	100	5'100
Mexico	Veracruz	1.9%	200	240	100	10'000
Nigeria	Lagos	8.4%	200	140	100	7'800
Norway	Bergen	10.8%	200	200	-	1'100
Russian Federation	St. Petersburg	26.4%	-	3'500	300	-
Saudi Arabia	Ju' aimah	7.8%	20	1'300	100	12'000
United States	Houston	7.7%	20	1'120	100	9'700

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 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**

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

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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 contains Meta-information about the newly modelled and updated processes. Tab. 6.2, Tab. 6.3 and 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.

Name	crude oil, import mix, at long distance transport	crude oil, import mix, at long distance transport
Location	CH	RER
Unit	kg	kg
IncludedProcesses	Transportation of crude oil from exploration sites to refineries in CH-region. Includes transport service requirements and emissions from oil handling and evaporation.	Transportation of crude oil from exploration sites to refineries in RER-region. Includes transport service requirements and emissions from oil handling and evaporation.
LocalName	Rohöl, Produktion CH, ab Ferntransport	Rohöl, Produktion RER, 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 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.
Category	oil	oil
SubCategory	transport	transport
LocalCategory	Erdöl	Erdöl
LocalSubCategory	Bereitstellung	Bereitstellung
StartDate	2019	2019
EndDate	2020	2020
DataValidForEntirePeriod	1	1
OtherPeriodText	Transport modes investigated for 2019.	Transport modes investigated for 2019.
Text	Calculations include production and transport of crude oil from 7 countries.	Calculations include production and transport of crude oil from 12 countries.
Text	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.	514 million tons of directly imported crude oil to the European region in 2019.
SamplingProcedure	Literature. Online calculators for distances.	Literature. Online calculators for distances.
Extrapolations	none	none
UncertaintyAdjustments	none	none

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

CH	Name	Location	Unit	crude oil, import mix, at long distance transport	UncertaintyType	StandardDeviation95%	GeneralComment
	Location			CH			
	Unit			kg			
	crude oil, import mix, at long distance transport	CH	kg	1.00E+0			
extraction mix from:	crude oil, at production	AZ	kg	0.1%	1	1.21	(1,1,1,3,3,BU:1.05); Transported crude oil +losses
	crude oil, at production	DZ	kg	3.3%	1	1.21	(1,1,1,3,3,BU:1.05); Transported crude oil +losses
	crude oil, at production	KZ	kg	28.7%	1	1.21	(1,1,1,1,3,BU:1.05); Transported crude oil +losses
	crude oil, at production	LY	kg	22.3%	1	1.21	(1,1,1,3,3,BU:1.05); Transported crude oil +losses
	crude oil, at production	NG	kg	34.2%	1	1.21	(1,1,1,3,3,BU:1.05); Transported crude oil +losses
	crude oil, at production	RU	kg	1.1%	1	1.21	(1,1,1,1,3,BU:1.05); Transported crude oil +losses
	crude oil, at production	US	kg	10.5%	1	1.21	(1,1,1,1,3,BU:1.05); Transported crude oil +losses
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. 6.3 Unit process raw data for produced crude oil transported to refineries in Europe.

RER	Name	Location	Unit	crude oil, import mix, at long distance transport	UncertaintyType	StandardDeviation95%	GeneralComment
	Location			RER			
	Unit			kg			
	crude oil, import mix, at long distance transport	RER	kg	1.00E+0			
extraction mix from:	crude oil, at production	AZ	kg	4.4%	1	1.21	(1,1,1,3,3,BU:1.05); Transported crude oil +losses
	crude oil, at production	DZ	kg	3.7%	1	1.21	(1,1,1,3,3,BU:1.05); Transported crude oil +losses
	crude oil, at production	GB	kg	5.1%	1	1.21	(1,1,1,3,3,BU:1.05); Transported crude oil +losses
	crude oil, at production	IQ	kg	9.1%	1	1.21	(1,1,1,1,3,BU:1.05); Transported crude oil +losses
	crude oil, at production	KZ	kg	8.0%	1	1.21	(1,1,1,1,3,BU:1.05); Transported crude oil +losses
	crude oil, at production	LY	kg	6.7%	1	1.21	(1,1,1,3,3,BU:1.05); Transported crude oil +losses
	crude oil, at production	MX	kg	1.9%	1	1.21	(1,1,1,1,3,BU:1.05); Transported crude oil +losses
	crude oil, at production	NG	kg	8.4%	1	1.21	(1,1,1,3,3,BU:1.05); Transported crude oil +losses
	crude oil, at production	NO	kg	10.8%	1	1.21	(1,1,1,3,3,BU:1.05); Transported crude oil +losses
	crude oil, at production	RU	kg	26.4%	1	1.21	(1,1,1,1,3,BU:1.05); Transported crude oil +losses
	crude oil, at production	SA	kg	7.8%	1	1.21	(1,1,1,1,3,BU:1.05); Transported crude oil +losses
	crude oil, at production	US	kg	7.7%	1	1.21	(1,1,1,1,3,BU:1.05); Transported crude oil +losses
transport	transport, transoceanic tanker	OCE	tkm	3.70E+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	6.88E-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	1.85E+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

7 Life cycle impact assessment

No detailed impact assessment or impact related interpretation is commissioned. Therefore, the following subchapters only show a brief overview of environmental impacts for top-level processes.

7.1 Ecological scarcity method

Tab. 7.1 shows results in ecological scarcity points 2013 per kg crude oil, for import mixes at long distance transport to Switzerland and Europe, which have been investigated in this study, in comparison to the mixes named UVEK 2018, including data for oil and gas production for the reference year 2016 (UVEK 2018;Jungbluth et al. 2018a) [18].

The newly modelled import mix to Switzerland shows a higher overall impact than the one for Europe, mainly due to higher impacts in the categories "global warming potential" and "main air pollutants including particulate matter". Main reasons for the impacts in these categories are direct methane emissions and flaring on the extraction sites.

Compared to the former datasets, for the import mix to Switzerland the impact increased, mainly due to a higher share of crude oil imported from countries with high natural gas emissions at extraction. For the import mix to Europe, in the reference year, a smaller amount of crude oil is imported from countries with high natural gas emissions at extraction sites (e.g., Libya).

[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.

Tab. 7.1 Ecological scarcity 2013-points per kg crude oil transported to refineries for the updated supply mixes for the Swiss and European market in 2019 (this study), in comparison to UVEK 2018, including data for oil and gas production for the reference year 2016 (UVEK 2018;Jungbluth et al. 2018a).

	Europe, this study	Europe, UVEK 2018	Switzerland, this study	Switzerland, UVEK 2018
Total	**933**	**974**	**1190**	**1020**
Water resources	19.29	16.52	17.27	15.45
Energy resources	177.46	177.25	182.74	180.45
Mineral resources	17.60	22.04	15.30	23.34
Land use	2.33	2.65	2.04	2.52
Global warming	283.28	255.41	454.73	295.21
Ozone layer depletion	0.36	0.23	0.42	0.21
Main air pollutants and PM	162.33	196.46	252.93	231.36
Carcinogenic substances into air	8.80	8.40	8.20	8.58
Heavy metals into air	8.43	8.72	8.65	9.51
Water pollutants	53.60	45.82	61.96	47.32
POP into water	88.43	90.20	76.29	92.41
Heavy metals into water	96.66	136.12	96.18	100.25
Pesticides into soil	0.09	0.22	0.09	0.22
Heavy metals into soil	0.30	0.35	0.30	0.37
Radioactive substances into air	0.00	0.00	0.00	0.00
Radioactive substances into water	0.29	0.29	0.26	0.28
Noise	3.04	2.76	2.69	2.71
Non radioactive waste to deposit	1.05	0.95	1.01	0.84
Radioactive waste to deposit	9.27	9.20	8.62	8.83

Fig. 7.1 shows the most relevant activities of the crude oil supply chain and their share of the ecological scarcity 2013-points for newly modelled mixes which have been investigated in this study.

Most of the environmental impacts are caused by resource consumption and emissions of the extraction process. Main reason for differences for the import mixes is the mixture of crude oil from different origins, respectively the higher country-specific natural gas emission rates and their related global warming potential and direct release of air pollutants.

Switzerland has higher impacts caused by ship transport, as Europe can import more crude oil directly through onshore pipelines from Russia.

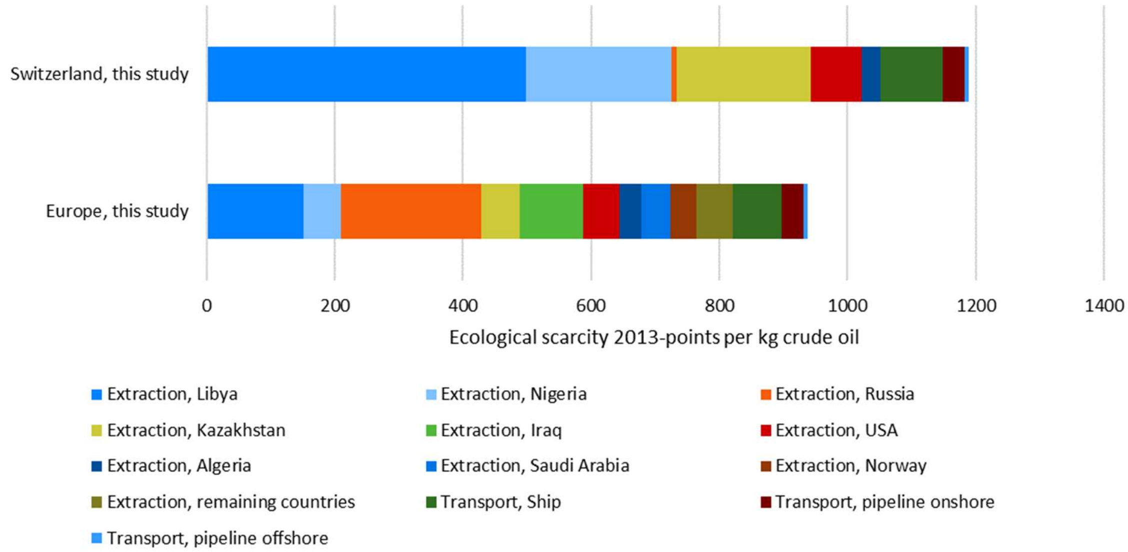

Fig. 7.1 Most relevant activities in terms of Ecological scarcity 2013-points for the Swiss and European crude oil supply mix to refineries in 2019.

7.2 Global warming potential

Tab. 7.2 shows the global warming potential over 100 years in kg-CO_2-eq. for import mixes at long distance transport to Switzerland and Europe, which have been investigated in this study, in comparison to the mixes named UVEK 2018, including data for oil and gas production for the reference year 2016 (UVEK 2018;Jungbluth et al. 2018a).[18]

For the import mix to Switzerland the impact increased, mainly due to a higher share of crude oil imported from countries with high natural gas emissions at extraction. For the import mix to Europe, a smaller amount of crude oil is imported from countries with high natural gas emissions at extraction sites. Nevertheless, also the impact of the import mix to Europe increased, mainly due to the country-specific methane emission data used to model extraction.

Tab. 7.2 Global warming potential in g CO_2-eq per kg crude oil transported to refineries for the updated supply mixes for the Swiss and European market in 2019 (this study), in comparison to UVEK 2018, including data for oil and gas production for the reference year 2016 (UVEK 2018;Jungbluth et al. 2018a).

	Europe, this study	Europe, UVEK 2018	Switzerland, this study	Switzerland, UVEK 2018
IPCC GWP 100a	675	593	1103	680

Fig. 7.2 shows the most relevant activities of the crude oil supply chain and their share of the global warming potential over 100 years in kg-CO_2-eq. for import mixes at long distance transport to Switzerland and Europe, which have been investigated in this study.

The import mix to Switzerland shows a higher warming potential mainly due to higher direct methane emissions on the extraction sites. Switzerland has higher impacts caused by ship transport, as Europe can import more crude oil directly through onshore pipelines from Russia.

The category "others" includes remaining direct emissions and the resource and energy consumption at the extraction sites.

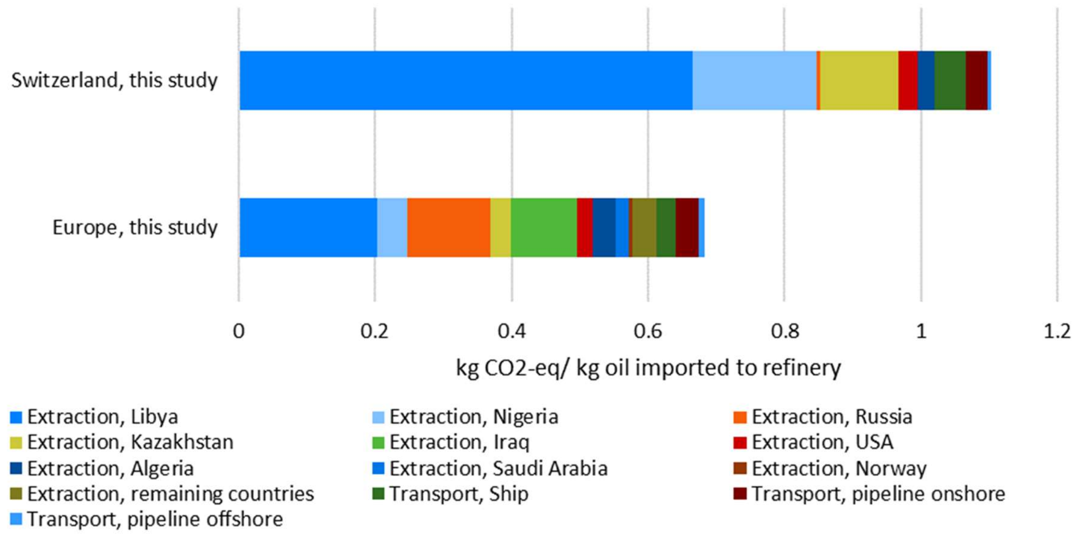

Fig. 7.2 Most relevant activities in terms of global warming potential in kg CO_2-eq. for the Swiss and European crude oil supply mix in 2019.

7.3 Primary energy factors

Tab. 7.3 shows primary energy factors in MJ for the newly modelled import mixes at long distance transport to Switzerland and Europe, which have been investigated in this study, in comparison to the mixes named UVEK 2018, including data for oil and gas production for the reference year 2016 (UVEK 2018;Jungbluth et al. 2018a).[18]

The total result is dominated by fossil energy carriers extracted. Nuclear and renewable energy carriers mainly occur in the electricity mixes, while the small value for land transformation is caused by using vegetable methyl ethers in the diesel mix and lubricating oils (estimated with diesel) used in the drilling fluids.

Tab. 7.3 Primary energy factors in MJ per kg per kg crude oil transported to refineries for the updated supply mixes for the Swiss and European market in 2019 (this study), in comparison to UVEK 2018, including data for oil and gas production for the reference year 2016 (UVEK 2018;Jungbluth et al. 2018a).

	Europe, this study	Europe, UVEK 2018	Switzerland, this study	Switzerland, UVEK 2018
Total	5.14E+01	5.13E+01	5.30E+01	5.23E+01
Non renewable, fossil	5.10E+01	5.09E+01	5.26E+01	5.19E+01
Non-renewable, nuclear	2.98E-01	2.93E-01	2.79E-01	2.78E-01
Renewable, biomass	2.34E-02	3.02E-02	2.25E-02	3.09E-02
Renewable, wind, solar, geothermal	1.27E-02	1.14E-02	1.20E-02	1.19E-02
Renewable, water	7.11E-02	7.09E-02	5.17E-02	5.50E-02
Non-renewable, land transformation	5.44E-04	1.20E-03	5.42E-04	1.21E-03

Fig. 7.3 shows the cumulative energy demand in MJ per kg crude oil imported to Swiss and European refineries, which have been investigated in this study.

The energy content (lower heating value, LHV) of the newly modelled crude oil is defined as 43.4 MJ_{LHV}/kg (BP 2020, as explained in Meili et al. 2021a). It is slightly higher than in the former model (43.24 MJ_{LHV}/kg). To account for this in the method to calculate the cumulative energy demand, the related higher heating value (HHV) of 46 $MJeq_{\_HHV}$/kg is implemented. This energy remains in the crude oil after extraction. For extraction and transportation to the refineries, about 12 (Europe) to 13% (Swiss) of the overallcumulative energy demand are used.

The import mix to Switzerland shows also a slightly higher primary energy consumption due to the higher share of ship transport. Europe can import a relevant share directly through on-shore pipelines from Russia.

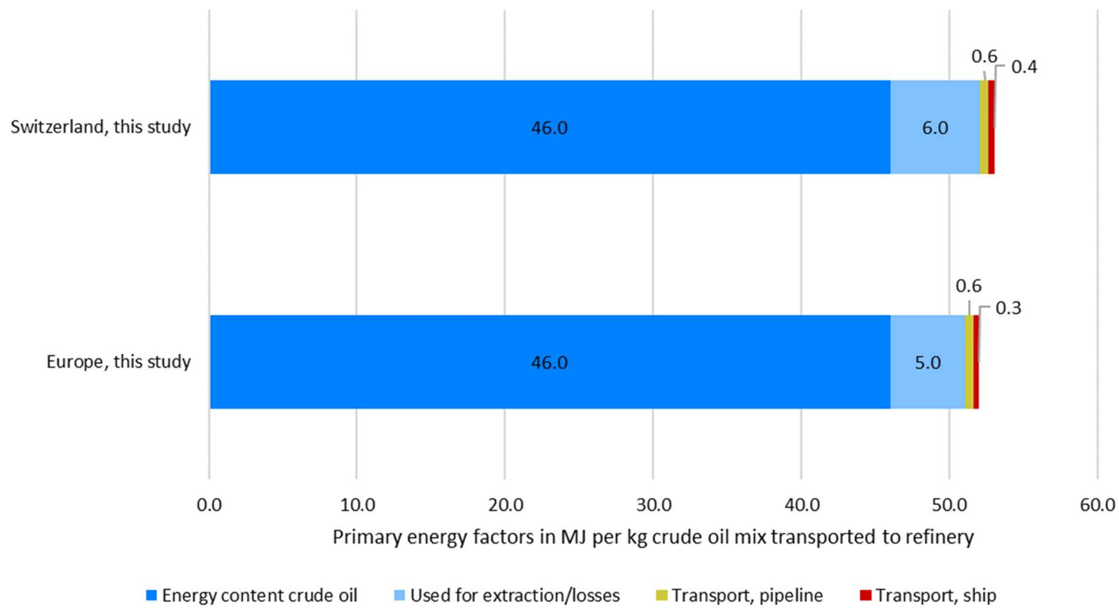

Fig. 7.3 Most relevant activities in terms of cumulative energy demand in MJ/kg for the Swiss and European crude oil supply mix in 2019.

7.4 Comparison of downstream methane emissions

For extraction (upstream), top-down estimates for methane emissions according to IEA 2020 are used in the model (c.f. Meili et al. 2021a, chapter 9.2). However, downstream emissions occur only partially in the country of origin. In the current study only emissions due to transportation are assessed. However, emissions for refining and distribution were assessed in former studies (Jungbluth et al. 2018b; Jungbluth et al. 2018c). Like this, it is possible to calculate the downstream methane emissions, bottom-up for transportation, refining, distribution and burning in a heating system. Methane emissions for modelled processes light fuel oil, burned in industrial furnace are provided for the European and the Swiss import mix in kg methane per MJ energy content in Tab. 7.4 (lower section). To only account for the downstream emissions, emissions from extraction (upstream) are subtracted.

To check for plausibility of these bottom-up assessments, Tab. 7.4 also shows the global downstream emissions of methane according to IEA 2020 (upper section). The values are set in relation to production data according to BP 2020 and divided by a lower heating value of 43.4MJ/kg crude oil (c.f. Meili et al. 2021a, chapter 5.1.2).

Despite the different system boundaries, the data can be used to compare the orders of magnitude of the downstream methane emissions with the bottom-up assessment for light fuel oil, burned in a heating system. The results for both import mixes assessed in this report are in the same order of magnitude as the IEA data. The modelled downstream emissions of the European dataset are higher, due to higher share of pipeline imports from Russia through a longer onshore pipeline.

Tab. 7.4 Comparison of methane downstream emissions per MJ oil as modelled for this study with data for 2019 (IEA 2020). Higher methane emissions are highlighted in red, lower in green.

Origin	**Methane emission factor downstream (Crude oil)**
Unit	kg/MJ crude oil
Literature	IEA 2020, upstream (2019)
Global	**1.14E-06**
LCI data available for this study	This study
Natural gas, burned in gas turbine/CH	
Natural gas, burned in gas turbine/MJ/RER	
Light fuel oil, burned in industrial furnace 1MW, non-modulating/MJ/CH	6.00E-06
Light fuel oil, burned in industrial furnace 1MW, non-modulating/MJ/RER	7.00E-06

8 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.

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).

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