

ライフサイクルアセスメント  
生命週期評估  
전 과정 평가  
வாழ்க்கை வட்டப் பகுப்பாய்வு  
ارزیابی چرخه عمر  
Evaluarea Ciclului de Viață  
Posuzování Životního Cyklu  
Bizi zikloaren analisi  
Olelusringi hindamine  
Lífsferilsgreining  
Levenscyclusanalyse  
Ljyscyklusvurdering

Updated LCI for the supply of oil and gas  
considering all methane releases

Niels Jungbluth, Christoph Meili, Maresa Bussa  
ESU-services Ltd., Schaffhausen, Switzerland



Presentation for  
Forum for Sustainability through Life Cycle Innovation e.V.  
14. September 2022

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We assist you



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Updates 2018-22 on behalf of the Swiss Federal Offices for the Environment and Energy, the Swiss Gas & Oil Associations and ecoinvent

# **EXTRACTION OF CRUDE OIL AND NATURAL GAS**

## Project outline

- Full update of data for crude oil and natural gas extraction and transportation
- Reference year 2019
- Documentation of harmonized Life Cycle Inventories in SimaPro and EcoSpold v1 format
- Global data sources used where possible  
→ consistency, simplification of data collection
- Basis for update of LCI databases used by Swiss authorities (UVEK/KBOB) and ecoinvent v3.9

## Extraction: Updates 2022

- 27 countries: on- and offshore extraction of crude oil and natural gas
- Focus on most relevant specific data sources
- Country and resource specific data for flaring and methane emissions
- Updated resource, water and energy uses and direct emissions (mainly reported by IOGP)
- Adjusted energy content for allocation
- Fire suppression agents: Halon 1211 replaced by HFC-23

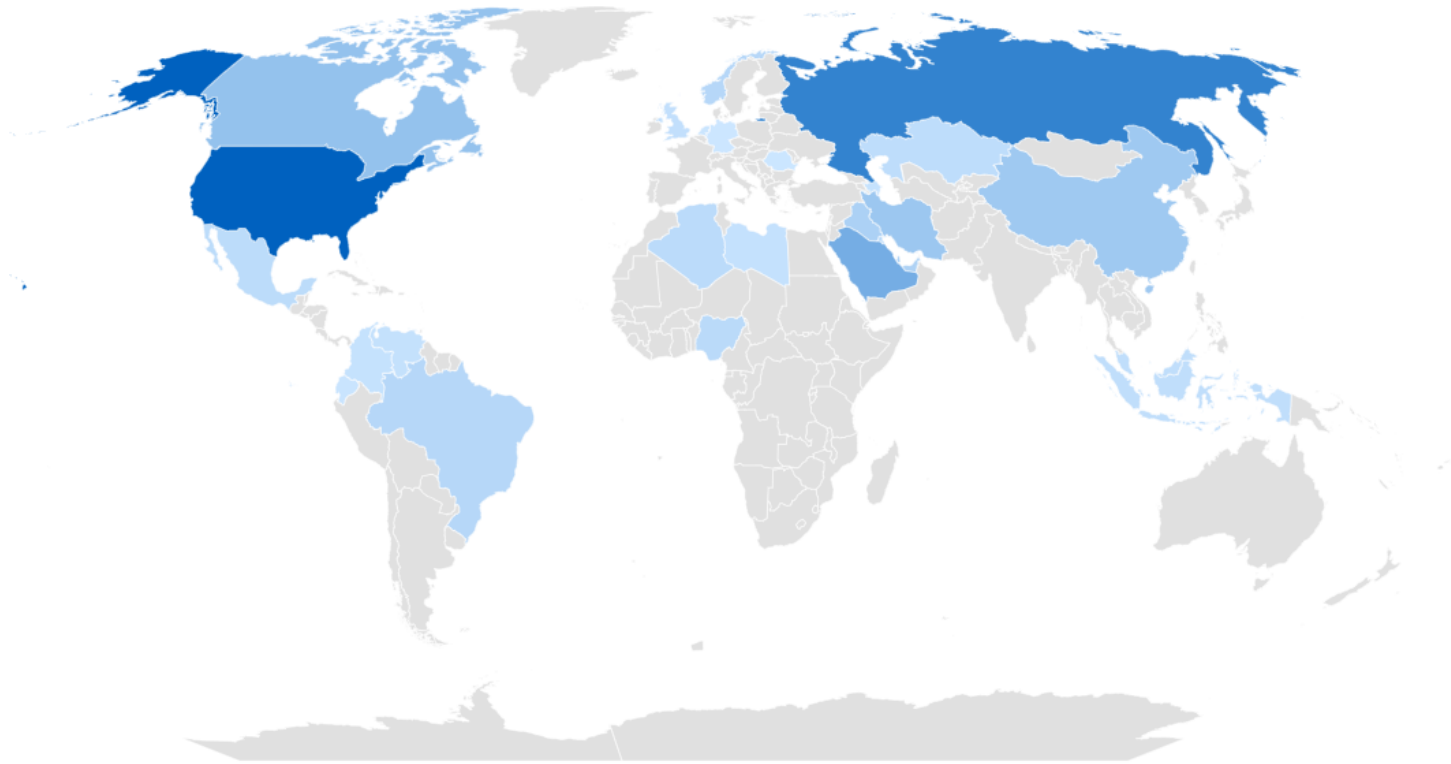
## Selection criteria for 27 countries of extraction to be analysed

- Gas and oil supply mixes for Europe, North America, the global region and Switzerland are analyzed
- Selection byecoinvent: Countries with share higher than 2% for import mix of natural gas or crude oil to above mentioned regions
- Additionally: Countries with high extraction rates in Latin America (CO, EC, VE)



## Total of 27 extracting countries covered

Origin	share of global production
Unit	% OE
United Arab Emirates	3.0%
Azerbaijan	0.7%
Brazil	2.2%
Canada	5.4%
China	4.3%
Colombia	0.7%
Germany	0.1%
Algeria	1.7%
Ecuador	0.4%
United Kingdom	1.1%
Indonesia	1.2%
Iraq	3.1%
Iran	4.7%
Kuwait	2.0%
Kazakhstan	1.4%
Libyan Arab Jamahiriya	0.8%
Mexico	1.6%
Malaysia	1.2%
Nigeria	1.8%
Netherlands	0.3%
Norway	2.2%
Qatar	2.9%
Romania	0.1%
Russian Federation	14.5%
Saudi Arabia	8.4%
United States	19.4%
Venezuela	0.9%



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Share of global production (% OE)   
0.1% 19.4%

➤ Selection covers 86% of global energy production from crude oil and natural gas

## Sources of natural gas emissions

- Release of unburned natural gas to the atmosphere, due to production and processing of crude oil & natural gas.
- In industry: Unwanted release of natural gas in technical process chain, e.g. due to insufficient flaring, accidents or leakage.
- However, it may also occur due to forced changes in geological structures (e.g. due to fracking).

➤ Satellite measurements show that emissions are more diffuse and less connected to the flaring rate than expected by industry

# Flaring, venting and fugitive emissions

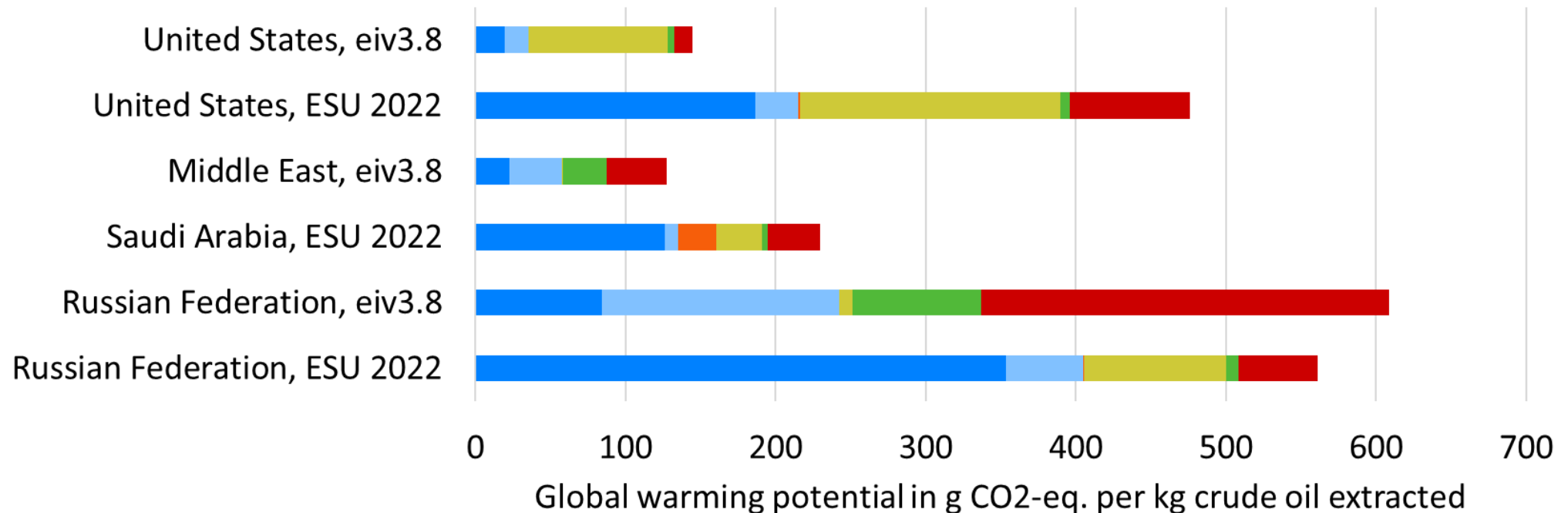
- Country-specific satellite data are available for all emission sources
- Flaring for oil and gas combined (Worldbank 2022 & Skytruth 2020)
- Venting and fugitive emissions (IEA 2022) distinguished for
  - oil & gas
  - on- & offshore
  - up- & downstream
  - conventional & unconventional

## Methane emission: consulted and used sources of information (Examples for biggest extracting countries)

Source	Crippa et al. 2019, data from EDGAR, up- & downstream (2012)	IOGP 2020, upstream only (2019)	UNFCCC 2020, up- & downstream (2018)	UNFCCC 2020, up- & downstream (2018); Production: BP (2018)	IEA 2022, up- & downstream (2019); Production: BP (2019)	<b>IEA 2022, upstream (2019); Production: BP (2019)</b>
Unit	kg/kgOE	kg/kgOE	kg/kgOE	kg/kgOE	kg/kgOE	kg/kgOE
<b>Russian Federation</b>	8.76E-03	1.12E-03	6.37E-03	6.16E-03	1.26E-02	1.11E-02
<b>Saudi Arabia</b>	4.45E-03	1.00E-04	n.a.	n.a.	4.33E-03	4.03E-03
<b>United States</b>	8.26E-03	1.25E-03	1.37E-02	5.58E-03	9.13E-03	7.40E-03
<b>Global</b>	1.01E-02	6.01E-04	7.93E-03	4.15E-03	1.06E-02	8.86E-03

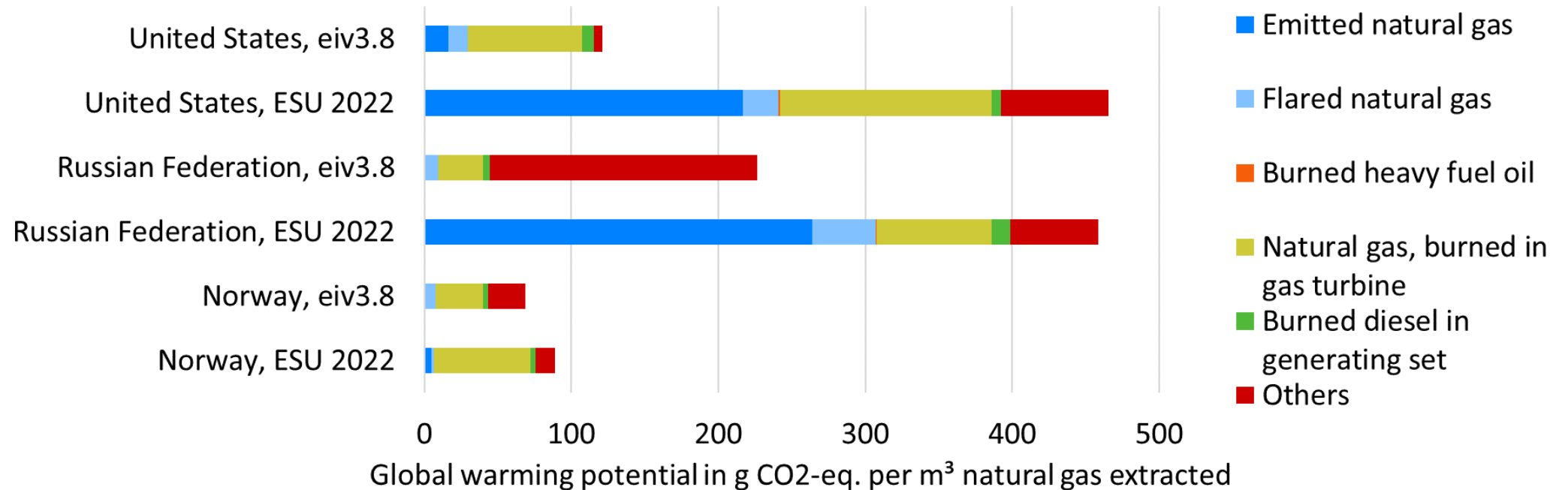
- Methane emissions reported by IOGP “industry data” are order of magnitude lower than calculated from national and global emissions in relation to national and global production data

## Crude oil from important extracting countries 2019: GWP 100a in ecoinvent v3.8 compared to our study



- Emitted natural gas
- Flared natural gas
- Burned heavy fuel oil
- Natural gas, burned in gas turbine
- Burned diesel in generating set
- Others

## Natural gas from selected extracting countries 2019: GWP 100a in ecoinvent v3.8 compared to our study



## Extraction: Global warming potential

- Wide variety of emissions depending on origin
- Main differences due to methane emissions and flaring
- GWP due to direct methane emissions about 9-times higher than reported in ecoinvent v3.8
- Global average about 2.5-times higher than reported in ecoinvent v3.8

## Extraction: Results environmental impacts

- Wide variety of environmental impacts depending on origin
- Main differences in overall impact according to ecological scarcity method due to global warming potential and main air pollutants
- Both depend mainly on flaring and natural gas emissions (e.g. venting, fugitive)



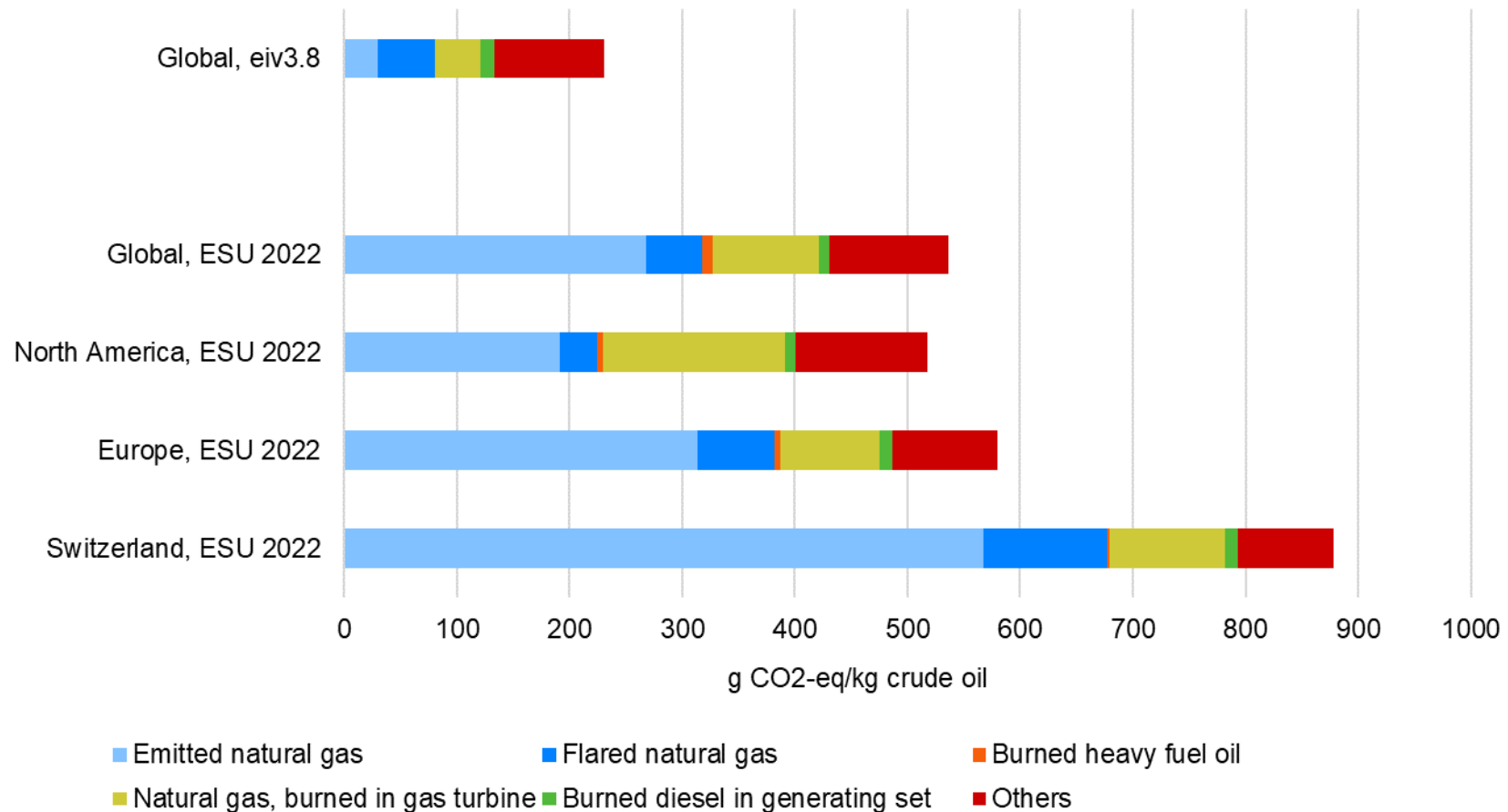
Last update 2022 for 2019

# TRANSPORT AND MIX OF CRUDE OIL FOR REFINERIES

## Crude oil transport: Updates

- Supply mixes for Europe, Northern America, Switzerland and global situation
- Same port of origin and destination independent of journey
- Extrapolation from shares of analysed countries to model 100% of the mix
- No updates for infrastructure and direct emissions
- One dataset for modelling average supply to refinery (easier to handle updates)

# Crude oil mix transported to refinery: Results GWP 100a



➤ Updated LCI about factor 2.3 higher GWP than in ecoinvent v3.8

## Crude oil transported to refinery: Results

- New datasets show higher GWP due to higher methane emissions in crude oil mix
- Transport itself has small relevance (~2% of GWP)
- Regional import mixes show large variety depending on the origin of crude oil. E.g. Switzerland imported a higher share of crude oil from Libya, where methane emissions were highest compared to other countries.

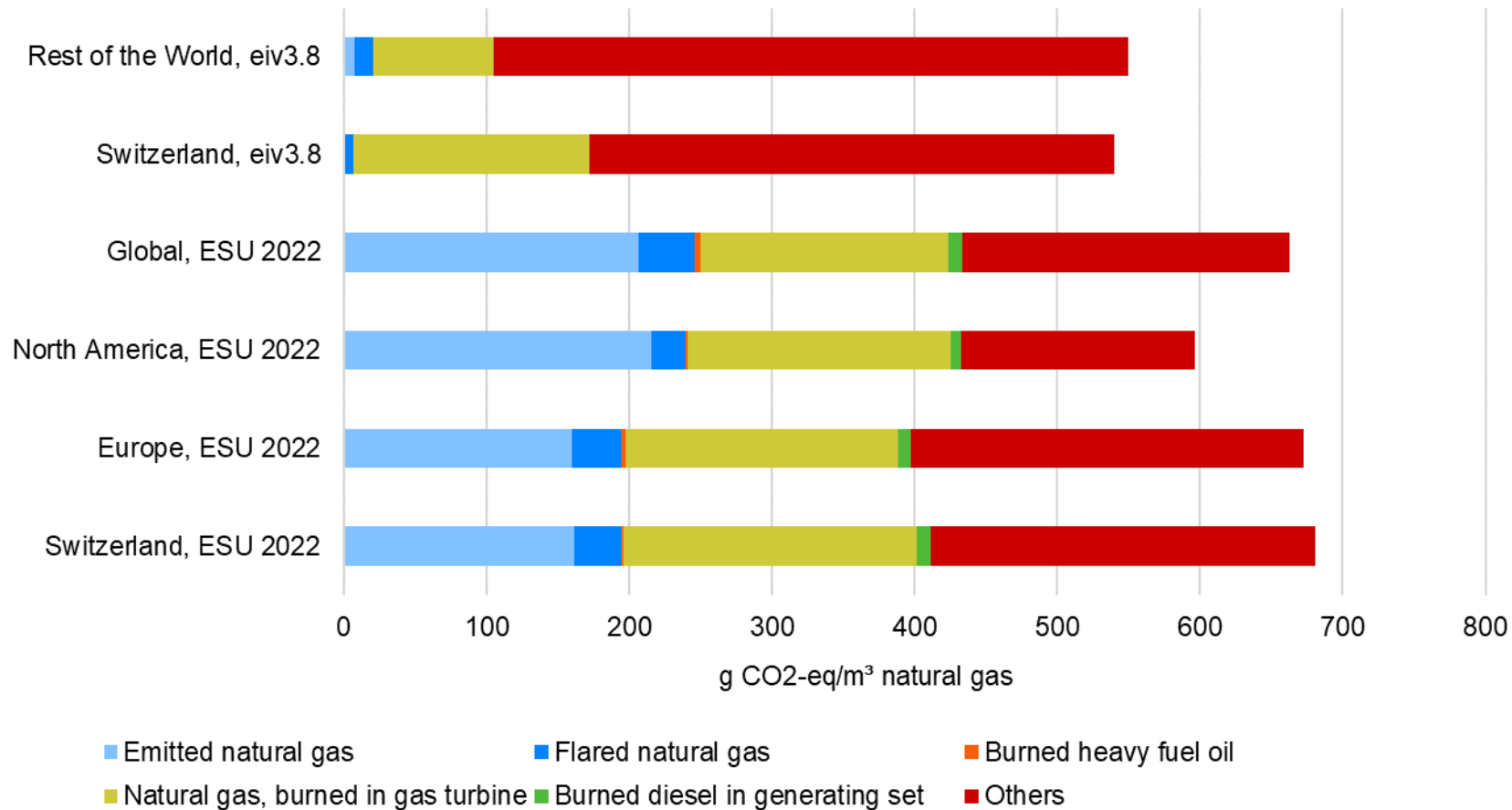
Last update 2022 for 2019

# **TRANSPORT, MIX AND DISTRIBUTION OF NATURAL GAS TO END CONSUMERS**

## Natural gas transport: Updates in LCI

- Low pressure Supply mixes for GLO, RNA, RER and 12 specific countries with one dataset per importing country (mix and transports) instead of old detailed model
- Energy demand and leakage rates of pipeline transport, regional and local distribution
- Offshore pipeline from RU (North Stream 1)
- Fire suppression agents: Halon 1211 replaced by HFC-23
- Energy demand and emissions of liquefaction and evaporation
- Fuel consumption and emissions of LNG carriers

## Natural gas transport to low pressure:



- Updated GWP about 20% higher than ecoinvent v3.8
- Downstream emissions more relevant and thus lower increase

## Key messages natural gas transport

1. Consumption mix plays important role
2. Differentiation between Pipeline and LNG-imports matters
3. Effect of methane from extraction less pronounced than for crude oil due to higher downstream emissions



Own update to harmonize assumptions for cumulative data in 2021

# **INFLUENCE ON PLASTICS DATA**

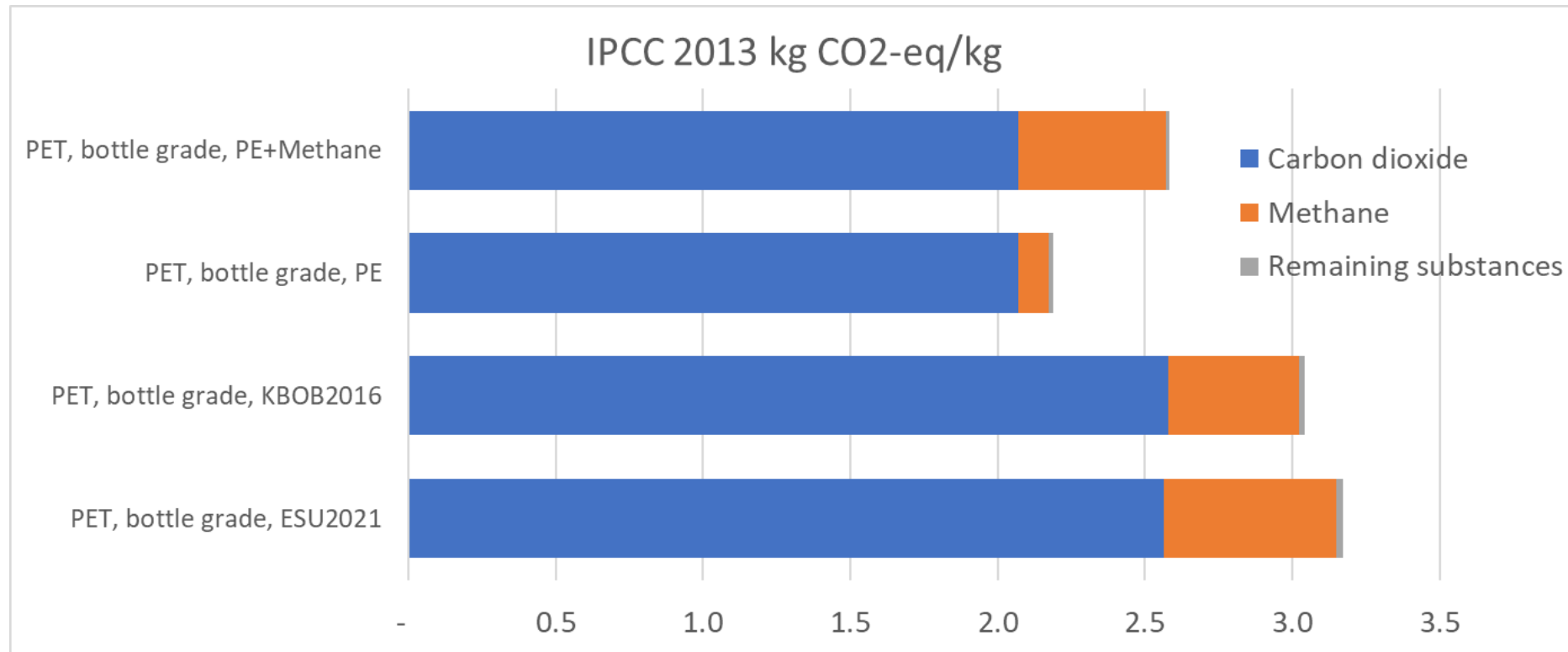
## What is the contribution for plastics?

- Bias for system processes needs to be avoided
- Estimation of surplus methane release based on LCI for crude oil and natural gas resource use

methane, fossil/kg = oil, crude in ground/kg \* 0.0135 kg/kg + gas, natural/m<sup>3</sup> \* 0.0089 kg/m<sup>3</sup>

- Integrated in system processes provided by Plastics Europe and imported to ESU-database 2022

## Results for plastics, example PET



ESU 2021 - Unit processes with CH<sub>4</sub>  
PE - system processes

KBOB 2016 - Unit processes without CH<sub>4</sub>  
PE+Methane - including methane

- Increase “at gate” due to methane 15-30%
- Effect of methane less pronounced due to further CO<sub>2</sub> emissions from fossil fuels
- Data for several plastics integrated in ESU database 2021

Last update published 2018

# **PRODUCTION OF OIL PRODUCTS IN REFINERIES**

## Updates: Refineries

- Petrol and diesel modelled with low-sulphur (10 ppm) only
- Update of product properties, e.g. carbon and energy content **(must be considered for datasets using products!)**
- Update for internal energy use and emissions
- Change of allocation for crude input (energy content instead of mass)

## Change of results: oil refinery

- Products with a larger heating value have higher impacts than these with a lower energy content due to allocation based now for more flows on the heating value of the products.
- Increase on renewable energy due to introduction of biogenic fuels in Europe and Switzerland used in the life cycle

## Change of results: oil refinery

Increase or decrease of indicator results compared to KBOB database	reference value	primary energy factor, total [MJ-eq]	primary energy factor, fossil [MJ-eq]	primary energy factor, nuklear [MJ-eq]	primary energy factor, renewable [MJ-eq]	CO2 equivalents [kg CO2-eq]	eco-points [eco-points 2013]
bitumen/RER	0	-3.3%	-3.9%	41.7%	68.5%	28.3%	-14.2%
diesel/CH	0	4.1%	3.7%	44.0%	66.6%	54.8%	21.5%
diesel/RER	0	0.1%	-0.3%	40.7%	72.6%	34.7%	-10.7%
heavy fuel oil/RER	0	-4.3%	-4.8%	38.2%	66.7%	27.9%	-15.1%
kerosene/CH	0	4.0%	3.6%	40.5%	64.2%	52.5%	20.8%
kerosene/RER	0	0.4%	0.0%	39.4%	72.5%	32.2%	-11.2%
light fuel oil/CH	0	3.5%	3.0%	43.2%	65.6%	51.8%	20.3%
light fuel oil/RER	0	-0.3%	-0.8%	39.9%	71.7%	31.6%	-11.7%
naphtha/CH	0	8.1%	7.3%	67.0%	82.9%	60.7%	25.6%
naphtha/RER	0	4.9%	4.3%	52.2%	77.9%	42.7%	-5.8%
petrol/CH	0	0.5%	-0.1%	46.7%	60.2%	26.1%	12.7%
petrol/RER	0	-3.8%	-4.4%	38.1%	61.7%	7.5%	-17.9%
propane/ butane/CH	0	10.7%	10.0%	61.7%	77.9%	54.4%	26.5%
propane/ butane/RER	0	6.2%	5.6%	48.3%	73.1%	30.7%	-7.5%
refinery gas/CH	0	14.7%	14.3%	57.4%	80.5%	51.8%	28.6%
refinery gas/RER	0	9.2%	8.7%	49.5%	81.8%	23.4%	-8.4%

- Products with a larger heating value show higher impacts
- Increase on renewable energy due to introduction of biogenic fuels in Europe and Switzerland used in the life cycle

# Interpretation

- Increase of eco-points for CH products and a decrease for EU products due to harmonization of assumptions
- Increase of the GWP for all products due to new data for methane emissions during crude oil extraction
- No clear trend for the fossil energy demand. Changes due to new allocation factors
- European products have slightly higher energy demand than products of the Swiss refinery. This is mainly due to the higher internal energy use



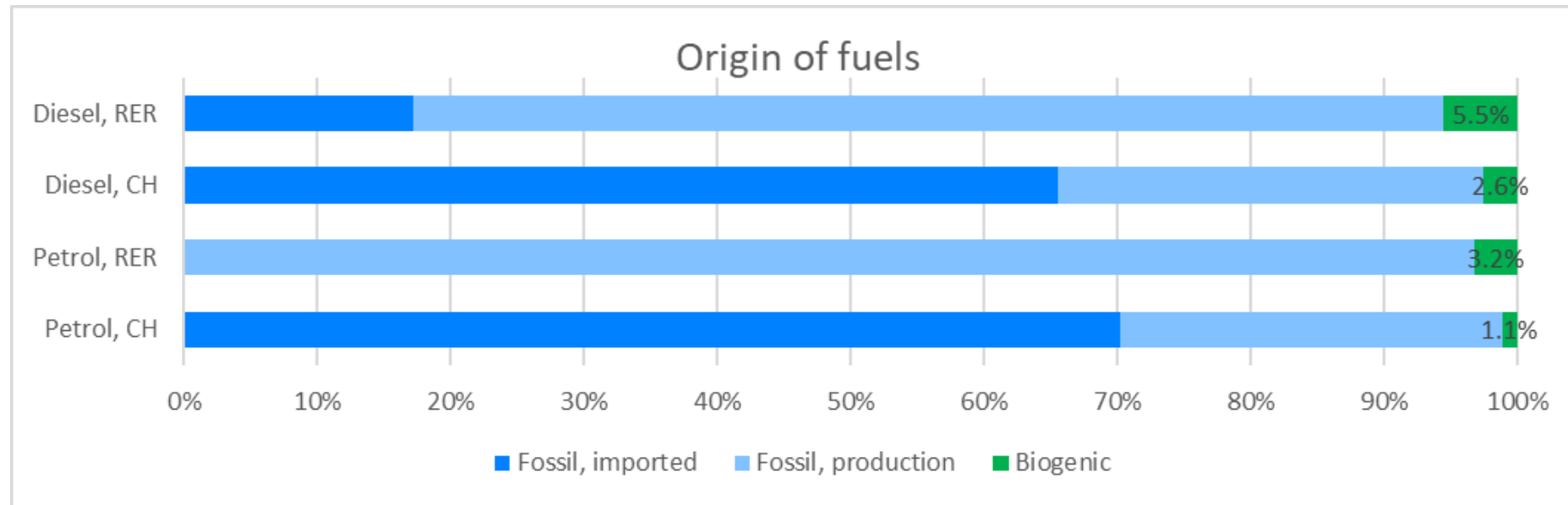
Last update published 2018

# **DISTRIBUTION OF OIL PRODUCTS**

## Updates: storage and distribution of oil products

- Share of biofuels in transportation fuels modelled at this stage
- Update of fugitive emissions
- Update on transport distances
- No investigation of specific products like E10/85 as not relevant anymore

# Blending with biofuels



- Share of import and domestic biofuels considered
- Biomass feedstocks considered
- Assumption all fuels are blended (average supply of petrol and diesel) and no set a side for “green” fuels sold separately
- Credit for biogenic carbon content to correct the inventories which use these fuel inputs

## Results: storage and distribution

Refinery products	reference value	primary energy factor, total	primary energy factor, fossil	primary energy factor, nuklear	primary energy factor, renewable	CO2 equivalents	eco-points	primary energy factor, fossil	Lower heating value
		MJ-eq	MJ-eq	MJ-eq	MJ-eq	kg CO2- eq	eco-points 2013	MJ-eq/MJ	MJ-eq/kg
diesel/CH	kg	54.8	53.8	0.74	0.25	0.79	1'312	1.25	43.0
diesel/RER	kg	56.6	53.1	0.96	2.34	0.79	1'587	1.24	43.0
heavy fuel oil/CH	kg	52.8	51.5	1.03	0.29	0.77	1'256	1.25	41.2
heavy fuel oil/RER	kg	52.5	51.4	0.84	0.28	0.76	1'209	1.25	41.2
kerosene/CH	kg	55.9	54.5	1.02	0.32	0.84	1'306	1.26	43.2
kerosene/RER	kg	55.7	54.6	0.80	0.27	0.85	1'292	1.26	43.2
light fuel oil/CH	kg	55.8	54.4	1.03	0.31	0.85	1'327	1.27	42.9
light fuel oil/RER	kg	55.7	54.6	0.82	0.28	0.86	1'308	1.27	42.9
naphtha/CH	kg	57.7	56.1	1.27	0.37	0.83	1'361	1.25	45.0
naphtha/RER	kg	57.5	56.2	1.03	0.34	0.84	1'341	1.25	45.0
petrol/CH	kg	56.9	54.5	1.28	1.08	0.88	1'412	1.28	42.6
petrol/RER	kg	57.1	54.1	1.09	1.85	0.86	1'546	1.27	42.6

- Most changes explained by changes until refinery and due to oil extraction
- Biofuels used for blending are very relevant for eco-points and renewable energy → Higher eco-points for European fuels with agricultural biomass

Last update published 2018

# HEATING WITH OIL PRODUCTS

## Updates: Heating with light fuel oil

- Update of key air emissions and efficiencies with new data
- Renaming of main datasets to “average” in order to reflect today average technology
- Better explanation of efficiency and temperature levels
- Keep differences between “burned in” and “heat, at” in ESU-database to allow the easy change of working conditions and efficiency of heating

## Results: oil heatings

technology	reference value	primary energy factor, total		eco-points		CO2 equivalents	
		MJ-eq		eco-points		kg CO2-equivalents	
light fuel oil, 10kW, non-modulating	MJ	1.42	1.44	75.8	78.1	0.096	0.101
light fuel oil, 10kW condensing, non-modulating	MJ	1.34	1.36	71.7	73.6	0.090	0.095
light fuel oil, 100kW, non-modulating	MJ	1.39	1.41	73.8	75.8	0.095	0.100
light fuel oil, 100kW condensing, non-modulating	MJ	1.31	1.32	69.8	71.4	0.090	0.094
light fuel oil, 1MW, CH	MJ	1.36	1.38	77.2	70.5	0.094	0.099
light fuel oil, 1MW, RER	MJ	1.37	1.37	79.5	70.2	0.094	0.099
heavy fuel oil, 1MW, CH	MJ	1.39	1.36	85.8	83.4	0.098	0.101
heavy fuel oil, 1MW, RER	MJ	1.43	1.35	111.4	83.1	0.098	0.101
<b>Source</b>		KBOB v2.2: 2016	This study	KBOB v2.2: 2016	This study	KBOB v2.2: 2016	This study

- Lower eco-points for European heavy fuel oil burned in industrial furnace due to lowered air emission factors and reduced emissions in the production
- Increase in GWP due to higher venting rates found for crude oil extraction

# CHALLENGES FOR UPDATES IN 2016-22 COMPARED TO 1994-2003



# First version in 1996

## Ökoinventare von Energiesystemen

- Estimates often based on bottom-up approaches
- Data available from measurements done e.g. at universities
- Comprehensive inventory of pollutants, e.g. detailed emission profiles for single NMVOC

## Updates 2000-2003 ecoinvent v1 and v2

- More data are available in environmental reports of single companies
- Focus on energy use and main pollutants
- No newer data for many pollutants reported in the first version
- Different data sources had to be combined for an estimate

# Updates in 2016-22 UVEK/KBOB/ESU databases

- Most information available on the internet
- Data available from global statistics, large measurement campaigns or industry associations
- More information found for European situation and less for Africa, Russia or Middle East
- Reports of global oil companies cannot be assigned to single countries nor single stages, often only relative changes are shown → **Not suitable for LCI work anymore**
- Focus in literature on main air pollutants like CO, NO<sub>x</sub>, SO<sub>x</sub>, NMOVC
- No current information found for specific pollutants (heavy metals, single NMVOC, water pollutants) reported in former versions

# Archetype models for LCI based on global statistics

	B	F	G	J	K	L	P	Q	R	V	W	X	AB	AC	AD	AE
	US_obs	Name	Location	InfrastructureProcess	Unit	combined gas and oil production offshore	crude oil, at production offshore	natural gas, at production offshore	combined gas and oil production onshore	crude oil, at production onshore	natural gas, at production onshore	combined gas and oil production	combined gas and oil production offshore	combined gas and oil production onshore	Data for this scenario	Explanation for Data entry
		Location				US_obs	US_obs	US_obs	US_obs	US_obs	US_obs	US_obs	US_obs	US_obs	US_obs	
		InfrastructureProcess				0	0	0	0	0	0	0	0	0	2016_obsolete	
		Unit				a	kg	Nm3	a	kg	Nm3	a	kg OE	kg OE	kg OE	
14	resources, in ground	Oil, crude	-	-	kg	1.02E+11	100%		4.54E+11	100%		5.56E+11			5.56E+11	kg crude oil extracted per country and year (total kg on- and offshore per year)
15		Oil, crude	-	-	kg	9.36E+6	100%		4.16E+7	100%		5.09E+7	4.29E-5	4.29E-5	4.29E-05	Value calculated based on entries below.
16		Gas, natural/m3	-	-	Nm3	1.38E+11		100%	6.12E+11		100%	7.50E+11			7.50E+11	Billion cubic meters natural gas extracted per country and year (total m3 on- and offshore per year)
17	water resource	Water, unspecified natural origin,	GLO	-	m3	0	100%	0%	1.63E+8	100%	0%	1.63E+8		3.60E-4	3.60E-04	Fresh water withdrawn for enhanced oil recovery
18		Water, salt, ocean	GLO	-	m3	3.68E+7	100%	0%	0	100%	0%	3.68E+7	3.60E-4	3.60E-4	3.60E-04	salt water use for offshore production assumed to be the same as freshwater use onshore
19		Water, fossil	GLO	-	m3	9.60E+07	100%	0%	2.64E+08	100%	0%	3.60E+08	9.40E-4	5.81E-4	3.60E-04	Line stays empty (used to balance water input and output)
20	water emission	Water, US_obs	-	-	m3	0	100%	0%	4.27E+8	100%	0%	4.27E+8		9.41E-4	9.41E-01	assumed to be equal to produced water discharged
21		Water, US_obs	-	-	m3	1.33E+8	100%	0%	0	100%	0%	1.33E+8	1.30E-3	1.30E-00	1.30E+00	assumed to be equal to produced water discharged
22		Water, US_obs	-	-	m3	0	100%	0%	0	100%	0%	0		0	0.00E+00	Line stays empty (used to balance water input and output)
23		discharge, produced water, offshore	OCE	0	kg	1.33E+11	100%	0%	0	100%	0%	1.33E+11	1.30E+0	1.30E+0	1.30E+00	Amount of untreated, produced water discharged offshore per kg OE produced offshore
24		discharge, produced water, onshore	GLO	0	kg	0	100%	0%	4.27E+11	100%	0%	4.27E+11		9.41E-1	9.41E-01	Amount of untreated, produced water discharged onshore per kg OE produced onshore
25	technosphere	chemicals inorganic, at plant	GLO	0	kg	1.21E+8	47%	53%	5.36E+8	47%	53%	6.56E+8	5.53E-4	5.53E-4	5.53E-04	Inorganic chemicals used for enhanced oil recovery
26		chemicals organic, at plant	GLO	0	kg	9.19E+7	47%	53%	4.09E+8	47%	53%	5.01E+8	4.22E-4	4.22E-4	4.22E-04	Organic chemicals used for enhanced oil recovery
27		transport, lorry >16t, fleet average	RER	0	tkm	1.84E+8	47%	53%	8.18E+8	47%	53%	1.00E+9	8.45E-4	8.45E-4	8.45E-04	Distance for chemical transport by lorry (km) multiplied by sum of chemicals (kg).
28		transport, freight, rail	RER	0	tkm	1.27E+8	47%	53%	5.66E+8	47%	53%	6.94E+8	5.85E-4	5.85E-4	5.85E-04	Distance for chemical transport by rail (km) multiplied by sum of chemicals (kg) / 1000
29	Infrastructure	well for exploration and production, offshore	OCE	1	m	8.07E+5	47%	53%	0	0%	0%	8.07E+5	3.70E-6		3.70E-06	Average meter of well to produce one kg of oil equivalent
30		well for exploration and production, onshore	GLO	1	m	0	0%	0%	1.03E+8	47%	53%	1.03E+8	1.06E-4	1.06E-4	1.06E-04	Average meter of well to produce one kg of oil equivalent
31	oil	pipeline, crude oil, offshore	OCE	1	km	0	100%	0	0	0	0	0	0	0	0.00E+00	length of Pipeline to production plant, offshore per kg oil equivalent extracted
32		pipeline, crude oil, onshore	RER	1	km	0	0	0	4.25E+3	100%	0	4.25E+3	0	6.95E-9	6.95E-09	length of Pipeline to production plant, onshore per kg oil equivalent extracted

➤ Excel models for extraction and transports facilitate data imports

# Publication

- Life cycle inventory analysis (LCI) and not a full LCA
- All reports and data until 2021 edition are available on <http://esu-services.ch/data/public-lci-reports/>
- Full SimaPro library based on UVEK 2018 with latest updates offered by ESU-services  
<http://www.esu-services.ch/fileadmin/download/tender/ESU-background-databases.pdf>
- Integration in ecoinvent v3.9 (only extraction and mixes) ongoing (to be announced by ecoinvent)

## Outlook/Suggestion

- Huge changes due to Russian war on mixes and flaring
- Regular updates of oil/gas mixes, e.g. every 2-3 years and/or usage of 5-year average data
- Link PlasticsEurope and other industry data to up-to-date LCI
- Include future emissions due to abandoned oil and gas fields
- Harmonize and update data for coal (ongoing at PSI)  
(effect seems to be of low relevance)

## Conclusions

- Full methane emissions need to be accounted for all products from oil and gas. Industry data do not show the full picture
- Mainly relevant for cradle-to-gate analysis
- This changes relative comparisons between fossil-based products with biobased products and other alternative products
- Regular updates of mix and emissions necessary

# Thank you very much for your attention!

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Here we present only our own personal conclusions



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