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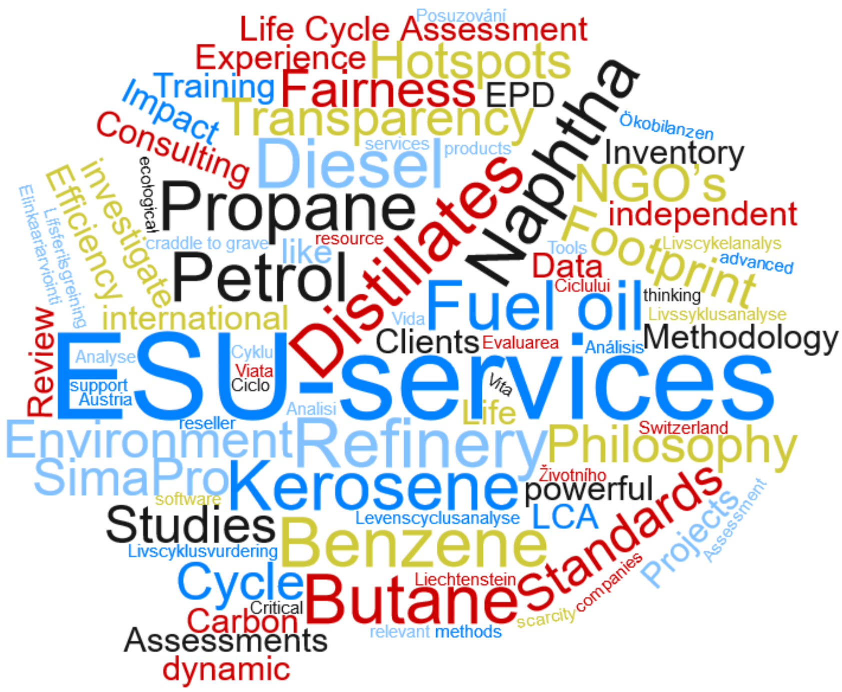
# Life cycle inventories of oil refinery processing and products





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# Life cycle inventories of oil refinery processing and products

## Final report


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# Acknowledgments

We thank Marc Veuve and Armin Heitzer working with VARO for the data and information provided in a personal communication.

# Abbreviations

| | |
|---|---|
| a | year (annum) |
| API | American Petroleum Institute |
| AZ | Azerbaijan |
| BAFU | Bundesamt für Umwelt |
| B(a)P | Benzo(a)Pyren |
| BAT | Best available Technologies |
| bbl | Barrel |
| bcm | billion cubic meters |
| bld | below limit of detection |
| bn | Billion |
| BEW | Bundesamt für Energiewirtschaft (Federal office for the energy industry) |
| BFE | Bundesamt für Energie |
| BOD5 | Biochemical oxygen demand for 5 days of microbial degardation |
| BOOS | Burner Out Of Service |
| BTU | British Thermal Unit (1 BTU = 1055 J) |
| BTX | Benzene, Toluene, and Xylenes |
| Bq | Becquerel |
| BUWAL | Bundesamt für Umwelt, Wald und Landschaft; (Federal offices for |

| | |
|---|---|
| | environment, forest and landscape |
| CEL | Central European Pipeline |
| cf | Cubic Feet |
| CH4 | Methane |
| CHP | Combined Heat and Power |
| Ci | Curie |
| CIS | Commonwealth of Independent States |
| CMC | Carboxymethyl Cellulose |
| CO | Carbon monoxide |
| CO2 | Carbon dioxide |
| COD | Chemical oxygen demand |
| Concawe | Conservation of Clean Air and Water in Europe (the oil companies' European organization for environmental and health protection, established in 1963) |
| d | day |
| DeNOx | Dentirification method (general) |
| DGMK | Deutsche Wissenschaftliche Gesellschaft für Erdöl, Erdgas und Kohle e.V. (German scientific assosciation for oil, natural gas and coal) |
| DM | Dry matter |
| DoE | Department of Energy, US |
| dwt | Dead weight tons |
| E5/10/15/85• | Petrol with 5%/10%/15%/85% ethanol |
| EdF | Electricité de France |
| EdP | Electricidade de Portugal S.A. |
| EMPA | Swiss federal material testing institute |
| ENEA | Italian National Agency for New Technology, Energy and the Environment |
| EOR | Enhanced Oil Recovery |
| EOS SA | l'Energie de l'Ouest-Suisse |
| EPA | Environmental Protection Agency, US |
| FGD | Flue Gas Desulphurisation system |
| GGFR | Global Gas Flaring Reduction Partnership |
| GRT | Gross Registered Tonne |
| GWP | Global Warming Potential |
| HC | Hydro carbons |
| HEC | Hydroxyethyle cellulose |
| I.f. | insignificant fraction |
| IEA | International Energy Agency |
| IMO | International Maritime Organization |
| IPCC | International Panel on Climate Change |
| IQ | Iraq |
| J | Joule |
| KBOB | Koordinationsgremium der Bauorgane des Bundes |
| KZ | Kazakhstan |
| LCI | Life cycle inventory analysis |
| LCIA | Life cycle impact assessment |
| LRV | Luftreinhalte-Verordnung (Swiss Clean Air Act) |
| MEEPD | Ministry of the Environment, Environmental Protection Department |

| | |
|---|---|
| M. | Million |
| MJ | Megajoule |
| Mt | Megaton = 1 million tons |
| MTBE | Methyl tert-butyl ether |
| MW | Megawatt |
| MX | Mexico |
| NCI | Nelson complexity index |
| NDP | Norvegian Petroleum Directorate |
| NG | Nigeria |
| NGL | Natural Gas Liquids |
| NL | Netherlands |
| Nm3 | Normal-cubic metre (for gases) |
| NMVOC | Non-Methane-Volatile Organic Compounds |
| NO | Norway |
| NOAA | National Oceanic and Atmospheric Administration |
| NORM | Naturally-Occuring Radioactive Materials |
| NOX | Nitrogen oxides |
| NR | Not Reported |
| Ns | not specified |
| OBM | Oil Based Mud, |
| OE | Oil equivalent |
| OECD | Organisation for Economic Cooperation and Development |
| OFA | Over Firing Air |
| PAH | Polycyclic Aromatic Hydrocarbons |
| PARCOM | Paris Commission |
| PC | Personal Communication |
| PM | Particulate Matter |
| PRTR | Pollutant Release and Transfer Register |
| RMPE | Royal Ministry of Petroleum and Energy Norway |
| Rn | Radon |
| RODP | Relative Ozone Depletion Potential |
| RSO | Raffinerie du Sud-Ouest SA |
| RU | Russia |
| SA | Saudi-Arabia |
| SEPL | South European Pipeline |
| SMA | Schweizerische Meteorologische Anstalt (Swiss Meterological Institute) |
| SN | Smoke number |
| SNCR | Selective-Non-Catalytic-Reduction |
| SPCA | State Pollution Control Authority |
| SPSE | Société du pipeline sud-européen (South European Pipeline) |
| SRE | Société Romande d'Electricité |
| SRI | Sustainable Recycling Industries |
| TDS | Total Dissolved Solids |
| TEL | Tetraethyl lead |
| toe | Ton Oil Equivalent |
| TSP | Total Suspended Particulates |
| TSS | Total Suspended Solids |

| | |
|---|---|
| UBA | Umweltbundesamt (Federal Office for the Environment) |
| UCTE | Union for the Co-ordination of Transmission of Electricity |
| ULCC | Ultra Large Crude Carrier |
| ULS | Ultra low sulphur |
| UNEP | United Nations Environment Programme |
| Unipede | International Union of Producers and Distributors of Electrical Energy |
| US (A) | United States of America |
| UVEK | Federal Department for Environment, Transport, Energy and Communications |
| VDEW | Vereinigung Deutscher Elektrizitätswerke e.V. (Union of German Electricity Works) |
| VEÖ | Verband der Elektrizitätswerke Österreichs (Association of Austrian Electricity Works) |
| VFWL | Verein zur Förderung der Wasser- und Lufthygiene (Society to Support Water and Air Hygiene) |
| VLCC | Very Large Crude Carrier |
| VOC | Volatile Organic Compounds |
| VVS | Verordnung über den Verkehr mit Sonderabfällen, (Regulation on handling of hazardous wastes) |
| WBM | Water Based Mud, |
| WEC | World Energy Council |

# Indices

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

# 1 Introduction

## 1.1 Overview

This document describes the update of data from version v2.0 of the ecoinvent database (Jungbluth 2007).

To keep this report legible, outdated and obsolete information has been partially removed. If the LCI data is still based on very old information, they are cited as (Jungbluth 2007) which means that they were often published before the year 2000.

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

In this report, the life cycle inventory of the following oil products is described for refineries in Switzerland and/or Europe:

- Bitumen (pitch[1], asphalt), only for Europe
- Coke (petroleum coke), only for Europe
- Diesel
- Electricity, high voltage, only for Europe
- Heavy fuel oil (named gasoil in ecoinvent v3)
- Kerosene (jet fuel diesel)
- Light fuel oil
- Liquefied petroleum gas (LPG)
- Naphtha or naphtha (basic product to produce chemicals and plastics)
- Petrol (gasoline)[2]
- Refinery gas
- Sulphur (secondary)

The following optional refinery products are not investigated due to lack of sufficient data about produced amounts and allocation criteria:

- Benzene (only for Switzerland)
- Distillates (Reformate gasoline (source of BTX))
- Lubricating oil (only produced in very specialized refineries). Modelled in ecoinvent as an additional processing stage.

Refinery sludge und spent catalyst which are treated in ecoinvent v3 as by-products are modelled according to ecoinvent v2 guidelines as wastes for treatment.

The inventory investigates the environmental impacts from gate-to-gate for the refinery premises. Transports of crude oil to the refinery gate are considered in the previous stage (Meili et al. 2018). All inputs and outputs due to the distribution of products are covered in the next stage of investigation (Jungbluth & Meili 2018).

[1] It is not clear why the name pitch is now used in ecoinvent. It does not seem to be common. Sometimes asphalt is used. In ecoinvent v2.2 it was bitumen.

[2] No differentiation between 95 and 98 octanes.

The material flows of the European refineries are known for the routinely measured or recorded quantities of substances such as SO2, NOX, oil in waste water, waste etc. For substances that are more complex to analyse, such as trace elements or substances that do not cause acute problems and which are not regulated, only selective (and often old) measurements are available. In this respect, the composition of the energy and material flows of the Swiss and European refineries can be described as heterogeneous. However, cross-comparisons help to provide representative averages for substances that are hardly regularly measured.

The focus of the update lies on the most relevant environmental aspects which are the input/output balance for crude oil and refinery products, the internal energy use and air emissions caused by this energy use. Water emissions have some relevance and have also been revised. Infrastructure, additives and chemicals used in the process are less relevant from an environmental point of view and therefore, less attention has been paid to the update of these inputs.

The life cycle inventory is first compiled for the entire refinery in Switzerland and an average refinery for Europe based on 1 kg of crude oil input and then allocated among the various products. Differences in the accounting of Swiss and European refineries are only considered if the data basis is reliable. Different individual measured values are averaged to one value.

## 1.2 Work on global refinery model for ecoinvent

The ecoinvent centre is working in parallel on updating the refinery model for ecoinvent v3.x data. Therefore, less emphasis will be placed on updating refinery data in this project as an even more detailed model will be available soon.

## 1.3 Description of refinery processes

A detailed but old description of refinery processes can be found in the former report (Jungbluth 2007). This chapter is not included in the present report.

A desulphurisation stage can reduce the amount of nitrogen and the metal fraction in the products.[3] So far this is not considered for the product properties. Desulphurisation is included in the LCI but not stated explicitly.

## 1.4 Updates for this study

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

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

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

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

Parts of the text which are not relevant (anymore) for the final estimation of the life cycle inventory have been removed to improve the readability of the new report and shorten the

[3] Personal communication with Fabian Bilger, Erdöl-Vereinigung, 7.11.2017.

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

The update focused on the most relevant issues from evaluating the former data with the 3 LCIA methods applied in this project. Most relevant is the internal energy consumption of refineries, including data sets on emissions from the incineration of different fuels. Up-to-date information is available on these aspects.

According to current data, coke covers a relevant part of energy consumption in refineries. As there was no record for the combustion of petroleum coke, this was newly examined.

A recent report of Concawe provides a very detailed estimation for different sources of air emissions in a refinery (CONCAWE 2017a). The level of detail is so high that it is not possible to easily include all estimates for this report. But at least the emissions of combustion facilities were updated and extended with these data.

The other most important aspect is the use of crude oil. To support an easy update of the life cycle inventory data investigated here for refineries, the supply mix of crude oil is now modelled in a separate dataset (see Meili et al. 2018) which can easily be changed without changing the data for each single refinery product or the whole refinery directly. Furthermore, the allocation for this input has been revised and is now based on the energy content of products instead of mass.

For emissions to water also a lot of new or updated data is found and considered in the inventories. But, this is of lesser relevance for the results.

The use of materials and process related air emissions are of lower relevance and thus no full updates have been made for these estimates.

The former report on these aspects was written in German. Some parts have been translated by machine translation.[4] In doubt about these aspects, the original German report can be consulted (Jungbluth 2007). As written before less emphasis has been used for this report on refineries as a parallel project works on revising the whole model.

# 2 Annual production of refinery products

## 2.1 Switzerland

Since 2015 only one refinery in Cressier (now operated by VARO and earlier known as Raffoil) is running.

### 2.1.1 Cressier

The following information is available on the website:[5]

*Refining crude oil is at the core of VARO's business. They own and operate a refinery in Cressier (Switzerland) and own a major share in Bayernoil (Germany), one of Europe's largest and most modern refineries. Both refineries produce a range of oil products for everyday use,*

4 www.deepl.com/translator
5 http://varoenergy.com/de/uber-uns/wo-wir-arbeiten/cressier, 22.01.2018

*sold locally and including jet fuel for airlines, gasoline and diesel for personal cars, fuel to heat houses or asphalt for road construction.*

*Cressier is currently the only operating refinery in Switzerland and accounts for approximately 25 percent, by volume, of all refined products sold nationally.*

*Crude oil supply arrives through the SPSE pipeline from the marine shipping terminal in Fos-sur-Mer in the south of France. Light and middle distillates such as gasoline, diesel, blended diesel and jet fuel are sold, mainly to the Swiss market. Products are dispatched from truck-loading racks and railcar-loading facilities.*

*The site is an integrated atmospheric-vacuum distillation, visbreaking and thermal cracking refinery. It can process sweet crude oil and a smaller amount of sour crude oil. The Cressier Refinery has a Nelson Complexity*[6] *of 6.4.*

*The refinery processes 68.000 barrels of crude per day. It has 270 employees. The total area covered by the refinery is 74 hectares in the Kanton Neuenburg. It has been erected in 1966. Modernisations have been made in 1976, 1993 und 2000. The Cressier refinery is supplied via the Oléoduc du Jura feeder pipeline via the Rhone Valley in the Marseille area.*

Data for output of refinery products for this refinery is presented in Tab. 2.1 (CARBURA 2017; Erdöl-Vereinigung 2017). The company has been approached directly for further information about relevant environmental aspects. Relevant data were provided in a personal communication.[7]

Bitumen, coke and electricity were no longer produced in Swiss refineries in 2016. Estimates have been made for refinery production including internal fuel use. The fuel oil used for internal use is part of refinery production. It is added to the quantity of products sold. Refinery gas also had to be included as a product that is not included in the statistics of the products sold.

Some changes to the original data were necessary to close the balance between inputs and outputs. This estimate to produce the Swiss refinery is displayed in the last column of Tab. 2.1. The estimated amount of biofuels according to the share investigated for Switzerland (Jungbluth & Meili 2018) has been deducted from the fuel produced, as these proportions are included in a subsequent data set on fuel distribution. The average amount of Methyl tert-butyl ether (MTBE) is estimated with data provided in statistics for Switzerland (Erdöl-Vereinigung 2017) and also subtracted from the amount of petrol. Other products and stocks used by the refinery were estimated with the list of additives investigated in this report. The balance is closed with the input of naphtha. Thus, the total output of products equals the relevant inputs.

6 The Nelson complexity index (NCI) is a measure to compare the secondary conversion capacity of a petroleum refinery with the primary distillation capacity.

7 Varo 2018, Marc Veuve, personal communication, 16.1.2018

Tab. 2.1 Tons of refinery products sold in 2016 by the refinery in Switzerland for the domestic market and for exports (Erdöl-Vereinigung 2017), total production calculated with this, production of refineries according to a second source (CARBURA 2017, not considered as different unit, but similar order of magnitude) and information on refinery production provided by the refinery itself (VARO 2018). Estimation of refinery product portfolio and amounts including internal consumption for this study

| **Refinery products** | **domestic market (t)** | **export (t)** | **total production (t)** | ***total production (1000 m3)*** | **total (t)** | **Biofuel (t)** | **MTBE (t)** | **total refinery production (t)** |
|---|---|---|---|---|---|---|---|---|
| petrol | 723'267 | 15 | 723'282 | *940* | 728'200 | 3'293 | 47'624 | 677'283 |
| diesel oil | 873'672 | - | 873'672 | *1'099* | 864'100 | 9'083 | | 855'017 |
| light fuel oil | 819'022 | - | 819'022 | *895* | 805'300 | | | 805'300 |
| heavy fuel oil | 166'434 | 177'761 | 344'195 | *345* | 354'950 | | | 354'950 |
| propane/ butane (liquid gases) | 98'410 | 7'048 | 105'458 | | 105'100 | | | 105'100 |
| kerosene | 45'165 | 8 | 45'173 | *54* | 42'500 | | | 42'500 |
| benzene | - | 27'318 | 27'318 | | 26'500 | | | 26'500 |
| other distillates and products | 50 | 7'796 | 7'846 | *-4* | | | | - |
| naphtha | 5'151 | 2'199 | 7'350 | | 5'400 | | | 5'400 |
| secondary sulphur | 5'265 | - | 5'265 | | 5'300 | | | 5'300 |
| bitumen | - | - | - | | | | | - |
| refinery gas | n.a. | n.a. | n.a. | | 123'300 | | | 123'300 |
| **Total refinery products** | **2'736'436** | **222'145** | **2'958'581** | ***3'329*** | **3'060'650** | | | **3'000'650** |
| Crude oil input | | | 2'875'500 | | 2'929'756 | | | 2'929'756 |
| Bioethanol, MTBE, and FAME for gasoline and diesel production | | | | - | 60'000 | 12'376 | | - |
| Mixed products from SAPPRO and various components from internal storage | | | | | 70'000 | | | 70'894.00 |
| **Total inputs** | | | **2'875'500** | | **3'059'756** | | | **3'000'650** |
| | *Erdöl-Vereinigung 2017* | | *Calculated* | *Carbura 2017* | *Varo 2018, personal communication* | *Own estimation with Jungbluth & Meili 2018* | *EV 2016* | *This study* |

### 2.1.2 Collombey

Until 2015 there was a second refinery operating in Switzerland in Collombey. It has been closed in 2015.[8]

## 2.2 Europe

In Europe, there are currently 90 refineries at several locations (Fig. 2.2). A valuable source of information are the webpage and reports provided by CONCAWE[9], the association of the European refining industry.[9] The refining capacity is estimated with 676 million tonnes crude oil for 2016. The average refining capacity is 7.4 million tonnes of crude oil per year. The baseline for the calculations is a refined amount of 554 million tonnes crude oil.[10]

The product portfolio is estimated with the shares provided in Fig. 2.1. Were necessary a further split has been made according to the data used in the former report. The electricity production is given with 11’902.5 GWh (ecoinvent Centre 2016, “Electricity, high voltage {Europe without Switzerland}| petroleum refinery operation | Cut-off, U”). Unfortunately, the background of this figure is not clear, but all other statistics consulted on European refineries did not provide details about the electricity sold. Therefore, this figure is used as best guess and divided by the total crude oil throughput.

8 Tamoil SA interrupts the operation of its refinery in Collombey-Muraz VS indefinitely (13 January 2015). Tamoil SA noted in a press release that the refinery had suffered considerable losses in recent years.

9 www.concawe.eu, online 18.01.2018

10 https://data.europa.eu/euodp/data/dataset/eu-crude-oil-imports-and-supply-cost/resource/0fd25e22-3985-4b01-8156-a4b866e6b024, online 22.10.2018

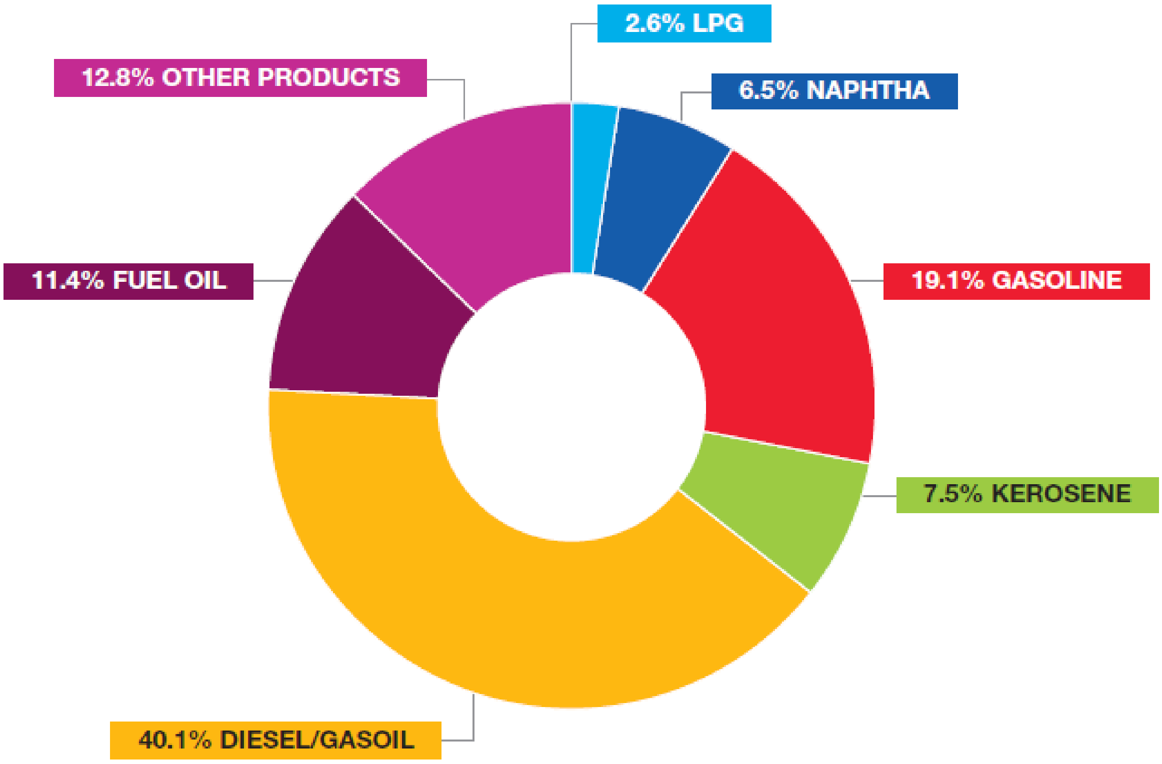


Fig. 2.1 Average refinery output by weight and product type in OECD Europe in 2016 (FuelsEurope 2017)

So far, a full and closed input-output balance for European refineries is not available. Therefore, the product portfolio is based on the following assumptions.

- The production of coke and refinery gas equals the internal consumption.
- The amount of all products is estimated as the crude oil input plus additives minus the two internal fuels.
- The proportion of other products is estimated based on the data in Fig. 2.1. The allocation of "Other products" according to Fig. 2.1 to the individual products is based on the data reported in the previous report (Jungbluth 2007). The final estimation is shown in Tab. 2.2. The total amount of products is higher than 1 kg because of additional additives purchased by the refinery and added to the sold products.

Tab. 2.2 Estimation for the amounts of products made from 1 kg of crude oil in the European refinery

| Name | Location | Category | SubCategory | InfrastructurePr | Unit | crude oil, in refinery |
|---|---|---|---|---|---|---|
| Location | | | | | | RER |
| InfrastructureProcess | | | | | | 0 |
| Unit | | | | | | kg |
| petrol, at refinery | RER | - | - | 0 | kg | 1.83E-1 |
| bitumen, at refinery | RER | - | - | 0 | kg | 7.34E-4 |
| diesel, at refinery | RER | - | - | 0 | kg | 3.84E-1 |
| light fuel oil, at refinery | RER | - | - | 0 | kg | 1.09E-1 |
| heavy fuel oil, at refinery | RER | - | - | 0 | kg | 1.18E-1 |
| kerosene, at refinery | RER | - | - | 0 | kg | 7.18E-2 |
| naphtha, at refinery | RER | - | - | 0 | kg | 6.22E-2 |
| propane/ butane, at refinery | RER | - | - | 0 | kg | 2.49E-2 |
| refinery gas, at refinery | RER | - | - | 0 | kg | 3.04E-2 |
| secondary sulphur, at refinery | RER | - | - | 0 | kg | 3.71E-3 |
| petroleum coke, at refinery | RER | - | - | 0 | kg | 1.32E-2 |
| electricity, at refinery | RER | - | - | 0 | kWh | 2.15E-2 |

Where possible, the information provided by CONCAWE[9] is used as a basis for the life cycle inventory.

Some further information is available from (older) environmental reports for several European refinery sites. Most of these reports have already been considered for the previous version of data. In 2018, such environmental reports are not as detailed as before, or reporting is more linked to a summary of several types of activities and can therefore no longer be linked to the single processes developed for this study:

- Germany: Ecker & Winter 2000; Shell 2000a, b,
- France: CPDP 2001,
- Finland: Fortum 2002,
- Sweden: Janson 1999,
- Austria:Ecker & Winter 2000.

This information is supplemented with statistical data for oil refining (CPDP 2001; EIA 2001; IEA 2001) and with the publication of the CONCAWE Association of European Oil Companies (Cecil et al. 1998; CONCAWE 2000; Dando et al. 1998; Fredriksson et al. 2000). Valuable information is also available in the Best Available Techniques (BAT) documentation (Barthe et al. 2015).

Fig. 2.2 Location of European refineries - Interactive map of the European commission: http://ec.Europe.eu/energy/infrastructure/transparency_platform/map-viewer/main.html, online 02.10.2017

## 2.3 European refineries delivering to Switzerland

The European refinery model in this study represents the average processing in European refineries and not the production for the supply situation for products exported to Switzerland. The modelling thus follows the nomenclature of the datasets which are labelled as (RER) and are thus representative for the whole European situation. Investigating datasets such as "European refinery delivery mix to Switzerland" is not foreseen in the data structure of ecoinvent.

Therefore, the share of crude oil from Russia imported through refinery products from Europe to Switzerland might be overestimated compared to the real situation (Meili et al. 2018). Northern European refineries mainly refine light crude oil, Eastern Europe mainly heavy crude oil. For Switzerland there should be a higher importance of products refined in the North Sea region due to major imports via the Rhine.

Improving the accuracy of the supply situation in Switzerland would be possible by investigating different regions of refinery processing in Europe (e.g. North Sea region, Eastern Europe, Northern Europe) and the related exports to Switzerland. Within the time frame and budget of this project this was not possible. Some further information and discussion about this issue is also provided in the report for long distance transports of crude oil (Meili et al. 2018).

## 2.4 Refineries outside Europe

For this study, only the average petroleum products refined in Europe and Switzerland are investigated. Product imports from Russia and overseas to Switzerland account for only a very small proportion of volumes, less than 1% (Erdöl-Vereinigung 2017). Refinery locations outside Europe are not considered for the balance sheet.

# 3 Characteristics of refinery products

An update of product properties has been made with regard to the properties of Swiss products as documented in a recent report (Röthlisberger 2016) for energy content and $CO_2$ emissions. Some information has been searched and found regarding the content of sulphur and trace elements which are regulated e.g. by Swiss laws. The remaining characteristics of refinery products were investigated in more detail in the former study (Jungbluth 2007). These characteristics can be considered when developing datasets for the combustion of these products. But, it is recommended to use real measurements on e.g. trace elements instead of these general product properties as far as possible.

## 3.1 Benzene

The lower heating value (LHV) of benzene is 40,579 kJ/kgC6H6.[11]

## 3.2 Bitumen

In a simplified element inventory of the refinery "Raffoil", for vanadium a share of 110 mg V/kg bitumen results and for Nickel 75 mg Ni/kg Bitumen. Higher values are reported in (Speight 1991). Sulphur content lies between 3 and 5% by weight (Raffoil 1991). The calorific value is approximately 40.7 MJ/kg (Speight 1991). An overview on properties and composition of bitumen is given in Tab. 3.1.

Tab. 3.1 Chemical composition, calorific value and density of bitumen according to different sources

| | Unit | (Speight 1991) | (Concawe 1992) | "Raffoil" 3) |
|---|---|---|---|---|
| C-Content | % by weight | 83.1 | 83 | n.s. |
| H-Content | % by weight | 10.6 | 10 | n.s. |
| O-Content | % by weight | 1.1 | 7 1) | n.s. |
| N-Content | % by weight | 0.4 | - | n.s. |
| S-Content | % by weight | 4.8 | - | 3 - 5 |
| Vanadium | | 250 | - | 110 |
| Nickel | ppm | 100 | - | 75 |
| Iron | ppm | 75 | - | n.s. |
| Copper | ppm | 5 | - | n.s. |
| Types of HC | | | | |
| - asphalt | % | 19 | - | n.s. |
| - resin | % | 32 | - | n.s. |
| - oils | % | 49 | - | n.s. |
| - PAH mg/kg | ppm | - | 0 - 10 2) | n.s. |
| Net cal. Value | MJ/kg | 40.7 | n.s. | n.s. |
| Density | kg/l | n.s. | 1.0 - 1.05 | n.s. |

1) Incl. N and S 2) detailed composition in (Concawe 1992) 3) calculated with simplified element inventory

11 https://www.chegg.com/homework-help/questions-and-answers/lower-heating-value-lhv-benzene-40-579-kj-kgc6h6-enthalpy-vaporization-water-44-010-kj-kmo-q24100405

## 3.3 Diesel

The composition of diesel is similar to the one of light fuel oil (see Tab. 3.2). To improve combustion characteristics, different additives are added (see chapter 9; Jungbluth 2007).

Today the maximum sulphur content in diesel sold in Europe is limited to 10 ppm. With this, it is possible to equip diesel-run vehicles with catalysts. Sulphur content in diesel in other countries might be considerable higher as shown in Fig. 3.1. This must be considered when modelling e.g. transport processes outside of Europe.

A special topic is the delivery of diesel fuels produced in European refineries with high sulphur content > 2000 ppm to the African market. A limit of 2000 ppm has been introduced in Europe already in 1994. These products are linked to Swiss traders of oil products (Guéniat et al. 2016). Until now, the production of such diesel and its use is not investigated for ecoinvent. Most important would be an elaboration of transport datasets for countries which still allow much higher sulphur content in fuels. Users of datasets generated here should take this aspect into account if they model the use of diesel in non-European countries. But, this was not part of this study and has not been done yet.

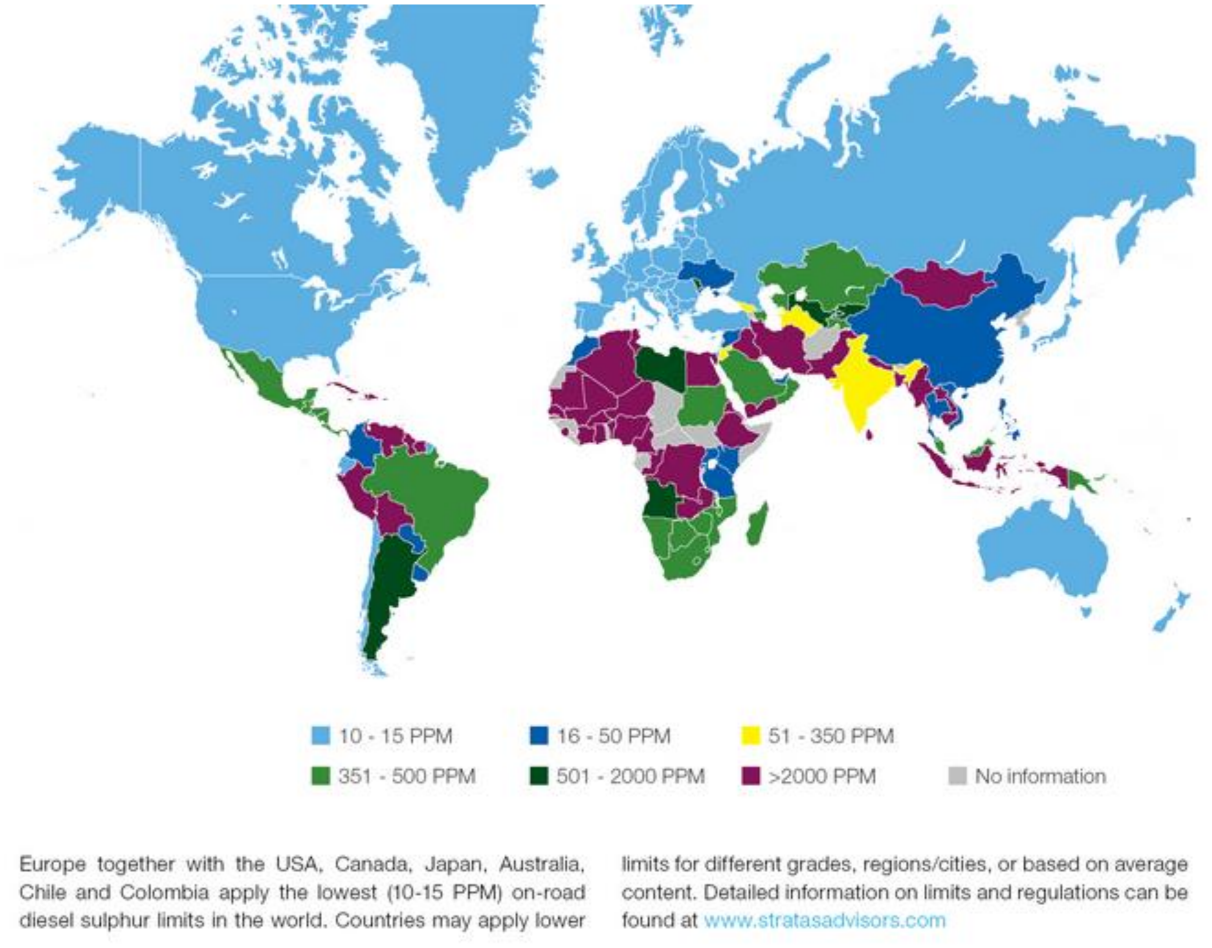


Fig. 3.1 Maximum sulphur limits for diesel per country in 2015

For mercury, a content of 20 µg/kg is used (Jungbluth 2007). Emission factors for further heavy metals are given in (Ahlvik et al. 1997). They correspond to the values shown in Tab. 3.3 for petrol.

Tab. 3.2 Chemical composition, calorific value and density of diesel for this study

| | unit | Diesel | Source |
|---|---|---|---|
| C | % by weight | 86.0 | Roethlisberger 2016 |
| H | % by weight | 14.0 | Changed to model 100% and calorific value |
| O | % by weight | 0 | Jungbluth 2007 |
| N | % by weight | 0 | Jungbluth 2007 |
| S | % by weight | 0.001 | https://www.admin.ch/opc/de/classified-compilation/19850321/index.html, Annexe 6, 2018 |
| Pb | % by weight | 0.06 | 5 mg/l, https://www.bafu.admin.ch/bafu/de/home/themen/luft/fachinformationen/massnahmen-zur-luftreinhaltung/anforderungen-an-treibstoffe-und-brennstoffe.html, 2018 |
| Hg | ppb | 20 | Jungbluth 2007 |
| Heavy metals | mg/kg | see Tab. 3.3 | Ahlvik et al. 1997 |
| Net cal. value | MJ/kg | 43.0 | Roethlisberger 2016 |
| Gross cal. value | MJ/kg | 45.4 | Calculated |
| Density | kg/l | 0.83 | Roethlisberger 2016 |

## 3.4 Gasoline/Petrol

In Europe various types of gasoline are sold. Today, especially unleaded normal and super gasolines are on the market. The quality of gasoline and super fuels fluctuates considerably between different countries.

The gasoline in our latitudes is delivered in summer and winter quality to account for changing climatic conditions. Thereby, summer quality tends to have a higher content of aromatics (DGMK 1992).

The lead content of unleaded gasoline in Switzerland may not exceed 5 mg/l.[12] According to measurements it is below 2 mg/l (Dörmer et al. 1998). Mercury content of light products is estimated with 70 µg/kg (Jungbluth 2007).

In Europe the sulphur content must be below 10ppm. The sulphur content of gasoline might vary considerable depending on the location as shown in Fig. 3.2. This must be considered if transport processes are adapted for countries outside Europe.

12 https://www.bafu.admin.ch/bafu/de/home/themen/luft/fachinformationen/massnahmen-zur-luftreinhaltung/anforderungen-an-treibstoffe-und-brennstoffe.html

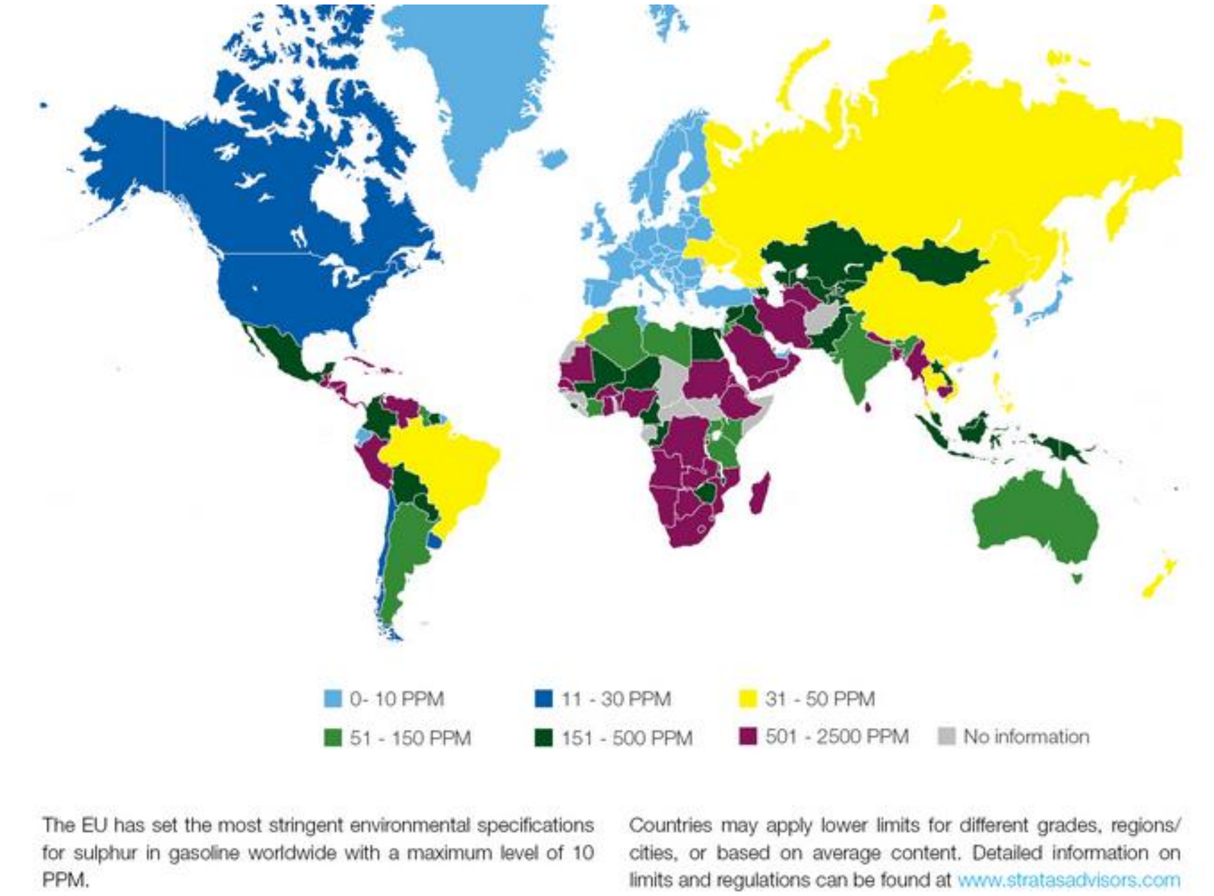


Fig. 3.2 Maximum sulphur limits for gasoline per country in 2015

Tab. 3.3 shows the chemical composition, calorific value and density of petrol investigated in this study.

Tab. 3.3 Chemical composition, calorific value and density of petrol for this study

| | Unit | Petrol | Source |
|---|---|---|---|
| C | % by weight | 85.8% | Roethlisberger 2016 |
| H | % by weight | 13.9% | Changed to model 100% and calorific value |
| O | % by weight | 0.3% | Changed to model 100% and calorific value |
| N | % by weight | - | Jungbluth 2007 |
| S | % by weight | 0.001% | https://www.admin.ch/opc/de/classified-compilation/19850321/index.html, Annexe 5 |
| Pb | % by weight | 0.002% | Jungbluth 2007 |
| Hg | ppb | 70 | Jungbluth 2007 |
| Cd | mg/kg | 0.01 | Ahlvik et al. 1997 |
| Cu | mg/kg | 1.7 | Ahlvik et al. 1997 |
| Cr | mg/kg | 0.05 | Ahlvik et al. 1997 |
| Ni | mg/kg | 0.07 | Ahlvik et al. 1997 |
| Se | mg/kg | 0.01 | Ahlvik et al. 1997 |
| Zn | mg/kg | 1 | Ahlvik et al. 1997 |
| MTBE | % by weight | 2.5 | Jungbluth 2007 |
| Net calorific value | MJ/kg | 42.6 | Roethlisberger 2016 |
| Gross calorific value[1)] | MJ/kg | 45.1 | Calculated |
| Density | kg/l | 0.737 | Roethlisberger 2016 |

If used in two-stroke engines, two-stroke oil is added to the petrol. Hereby, mixing ratios of 1:5 (1 litre of oil with 5 litres of petrol) up to 1:100 are possible. Usually, filling stations sell mixtures between 1:25 or 1:50 for mopeds. For this study, a ratio of 1:50 is used. This is e.g. also used for motor saws.[13] For other mixing ratios, the respective amount of lubricating oil needs to be considered. Other additives are not required.

## 3.5 Heavy fuel oil, intermediate fuel oil and bunker oil

Sulphur content in the residue depends on the origin and processing of crude oil. For instance, sulphur content of a light crude oil (e.g. North Sea) is 0.3% by weight, whilst residues from South American crude oil can contain 6% by weight sulphur.

A sulphur content of heavy oil between 0.3 and 3.5% is specified in (Richardson 1999). And a bandwidth of 0.5 to 2.2% is reported in (IPPC 2001). Heavy oil produced in Europe contained 0.96-2.15% sulphur in 1998 (Poot et al. 2002). In 2003 the threshold for heavy oil was lowered to 1% and to 1.5% sulphur for bunker oil (IPPC 2001).

To minimise sulphur dioxide emissions, the maximum sulphur content is defined in the LRV for heating oil types extra light, medium and heavy (Annex 5, point 11).[14] The sulphur content of heating oil "medium" and "heavy" must not exceed 2.8 percent (% by mass).

Tab. 3.4 shows the compilation of sulphur content in heavy fuels for power plants in different countries. If no specific data is available, a sulphur content of 1.5% can be used for calculations (3.5% for bunker oil).

13 Personal communication, Hartmut Austel, Stihl, DE, 9.9.2002.
14 https://www.admin.ch/opc/de/classified-compilation/19850321/index.html, online 22.01.2018

Tab. 3.4 Sulphur content of heavy fuels for oil-thermal power plants

| Country | S-Content | Source |
|---|---|---|
| | % | |
| Belgium | 0.93 | (Electrabel 2002) |
| Denmark, Orimulsion | 2.0 | UNFCCC DK 1997 |
| Denmark, fuel oil | 0.92 | UNFCCC DK 1997 |
| Germany | 1.0-1.8 | Öko-Institut 2002 |
| France | <1 | EDF 2002 |
| Greece | 0.7 (3.5) | Data for Athens and Thessaloniki (NOA 2002) |
| Italy | 1.3 | (Pastorino et al. 1993) |
| Croatia | 2.1 | |
| The Netherlands | 1.3 | |
| Austria | 1.1 | |
| Portugal | 3.0 | |
| Spain | 3.2 | |
| Europe | 1.8 | Öko-Institut 2002 after DGMK report of 1992 |
| Europe | <3.5 | Maximal value domestic (CONCAWE 1998) |
| Europe | <1 | Limit as of 1.2003 (EG-Rat 1999) |
| Europe | **1.5** | **Estimation of this study** |
| Heating | 0.84 | Jungbluth 2007 |
| Switzerland | 1 | BAFU 2011 |
| Switzerland | 2.8 | LRV maximum for heating oil types extra light, medium and heavy (Annex 5, point 11).[15] |
| Switzerland | **1.0** | **Estimation of this study** |

Regarding trace elements, information is available for instance from (Pacyna 1982 & King 1981). Furthermore, fuel analysis of a European power plant (Kraftwerk 1996) and analysis results by EMPA Dübendorf from the years 1984 to 1986 (EMPA 1986) were evaluated (see appendix tab. A5 and A6; Jungbluth 2007).

Whilst for Swiss refineries, analysis data of liquid fuels is available and used; for European refineries, the contents of trace elements of European heavy fuel oil are adopted. Elements in Swiss refinery fuel which were not analysed are complemented with the results of the analysis data by EMPA Dübendorf.

Data for density, carbon content and heating value for Swiss heavy fuel oil have been harmonised with actual estimations (Röthlisberger 2016).

In heavy fuel oil, there are significant amounts of the elements Cl, Na, Ni and V. Out of the fuel analysis done by EMPA it is shown that particularly intermediate fuel oil contains high contents of Pb. Because this quality of fuel oil is not intended for Switzerland, the results of the analysis of both qualities are put together. Lead probably origins from a contamination of the additives.

In deep sea shipping, predominantly marine fuel oil, a mixture of residues with components from distillation is used. There are also marine gas oil distillates and marine diesel. While the former has properties like those of light fuel oil, the latter are distillates which are contaminated by residues (DGMK 1992). In this study, for deep-sea shipping, marine fuel oil is modelled. The content of main components C, H, O and N and the calorific value are obtained from (Gemis 1989). The sulphur content is modelled according to (Hannan 1990). The data on other trace elements are from (Hannan 1990 & Lloyd's 1995).

15 https://www.admin.ch/opc/de/classified-compilation/19850321/index.html, online 22.01.2018

For motor-technical reasons, only bunker oil with a maximum sulphur content of 5%, and a limited content of trace elements may be used (Sulzer 1991).

According to analyses of fuel (Sulzer 1991) sulphur content is between 2 to 5% by weight and vanadium content between 50 and 200 ppm. Fig. 3.3 shows that the sulphur content mostly is around 3.5% by weight and the vanadium content at around 100 ppm. It is hereinafter calculated with data by (Lloyd's 1995) or from fuel test A for bunker oil (see compilation of analyse-data in appendix tab. A5, Jungbluth 2007).

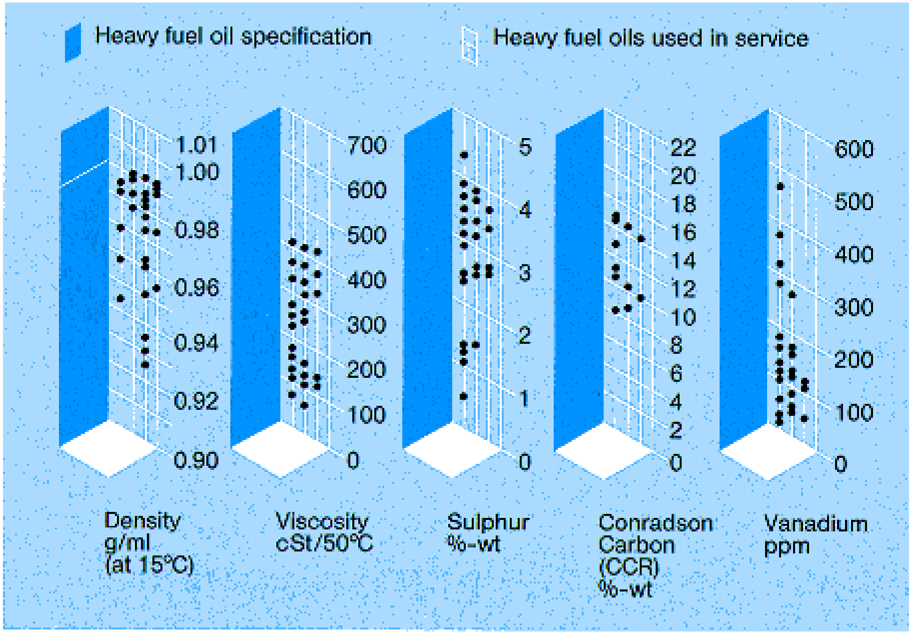


Fig. 3.3 Requirements for fuels and analysis results from used fuels (Sulzer 1991)

An overview on properties and composition of heavy fuel oil for refineries, furnaces and power plants as well as bunker oil is given Tab. 3.5.

If datasets for the use of heavy fuel oil are developed it is recommended to search for information about the specific properties of the heavy fuel oil used as there is a large variation possible.

Tab. 3.5 Fuel data for heavy fuel oil for refineries, furnaces and power plants as well as bunker oil for this study; sources see text

| Element | Unit | Refinery | Refinery | Refinery | Furnaces | Power plants | Bunker oil |
|---|---|---|---|---|---|---|---|
| | | Raffoil | RSO SA | RER | CH | RER | |
| C | % by weight | 87.8 | 87.8 | 84.9 | 86.5 | 85.0 | 84 |
| H | % by weight | 10.3 | 10.3 | 10.6 | 12.0 | 11 | 10 |
| O | % by weight | 0.44 | 0.44 | 1.0 | 0.5 | 1.0 | 1.3 |
| N | % by weight | 0.46 | 0.46 | 0.5 | 0.45 | 0.45 | 1.0 |
| S | % by weight | 0.82 | 0.5 | 1.5 | 0.84 | 1.5 | 3.5 |
| Al | ppm | n.s. | n.s. | n.s. | n.s. | n.s. | 7 |
| As | ppm | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.7 |
| Ca | ppm | 7 | 7 | 7 | 7 | 5 | 6 |
| Cd | ppm | 0 | 0 | 2 | 0 | 2 | ns |
| Cl | ppm | 90 | 90 | 90 | 90 | 90 | ns |
| Co | ppm | 0.8 | 0.8 | 2 | 2 | 2 | 0.43 |
| Cr | ppm | 0.3 | 0.3 | 1 | 0.3 | 1 | 0.35 |
| Cu | ppm | 1 | 1 | 3 | 1 | 3 | 0.4 |
| F | ppm | 9 | 9 | 9 | 92) | 92) | ns |
| Fe | ppm | 10 | 10 | 11 | 50 | 11 | 13 |
| Hg[1)] | ppm | 0.006 | 0.006 | 0.006 | 0.006 | 0.006 | 0.02 |
| Mo | ppm | 0.5 | 0.5 | 1 | 0.5 | 1 | 0.56 |
| Na | ppm | 46 | 46 | 46 | 46 | 46 | 35 |
| Ni | ppm | 19 | 19 | 40 | 30 | 40 | 34 |
| P | ppm | n.s. | n.s. | n.s. | n.s. | n.s. | 4 |
| Pb | ppm | 9 | 9 | 3.5 | 9 | 3.5 | 0.15 |
| Se | ppm | 0.8 | 0.8 | 0.75 | 0.75 | 0.75 | 0.2 |
| Si | ppm | n.s. | n.s. | n.s. | n.s. | n.s. | 6 |
| V | ppm | 21 | 21 | 160 | 60 | 160 | 89 |
| Zn | ppm | 3.5 | 3.5 | 2.5 | 3.5 | 2.5 | ns |
| Net cal. value | MJ/kg | 41.2 | 41.2 | 41.2 | 41.2 | 41.2 | 41.2 |
| Gross cal. value[2)] | MJ/kg | 43.7 | 43.7 | 43.7 | 43.7 | 43.7 | 43.7 |
| Density | kg/l | 1.0 | 1.0 | 1.0 | 0.96 | 1.0 | |

Value according to Tab 3.5 in (Jungbluth 2007) 2) 1.058 net calorific value (Baehr 1989)

## 3.6 Kerosene

For the composition of kerosene, data from DGMK and Ellison is listed (DGMK 1992; Ellison et al. 1999). Its composition is evident in Tab. 3.6. Kerosene produced in Europe contains between 200 and 610 mg S/kg (Poot et al. 2002). Concerning additives see chapter 9 in the former report (Jungbluth 2007). For petrol used in planes, a limit for lead of 0.56 g/l applies.

Tab. 3.6 Chemical composition, calorific value and density of kerosene

| | Unit | Kerosene | Source |
|---|---|---|---|
| C | % by weight | 85.8 | Roethlisberger 2016 |
| H | % by weight | 13.5 | Changed to model 100% and calorific value |
| O | % by weight | 0.29 | Changed to model 100% and calorific value |
| N | % by weight | 0.001 | Jungbluth 2007 |
| S | % by weight | 0.05 | Poot et al. 2002 |
| Hg | ppb | 0.7 | 0.56 g/l, https://www.admin.ch/opc/de/classified-compilation/19850321/index.html, Annexe 5 |
| Pb | ppb | | Ahlvik et al. 1997 |

| | | | |
|---|---|---|---|
| Net cal. value | MJ/kg | 43.2 | Roethlisberger 2016 |
| Gross cal. value | MJ/kg | 45.6 | Calculated |
| Density | kg/l | 0.799 | Roethlisberger 2016 |

## 3.7 Light Fuel Oil

In Switzerland, heating oil is generally offered in 2 standard qualities: Heating oil extra light (HEL) and low-sulphur eco heating oil (HEL low-sulphur or "Öko-Heizöl"). The main difference between the two varieties is the different content of sulphur and nitrogen.

An overview on properties and composition of light fuel oil is given in Tab. 3.7.

The limit in Europe is lowered in 2008 to 0.1% sulphur (IPPC 2001). The sulphur content of heating oil "Extra light" in Switzerland also must not exceed 0.1 percent (% m/m) as defined in the LRV (Annex 5, point 11).[16]

In Switzerland, additionally, the so-called Eco-light fuel oil) with a sulphur content of less than 0.05% by weight is sold (Erdöl-Vereinigung 2002).[17]

In Switzerland the eco-lightweight heating oil has a nitrogen content of 0.01% by weight or 100 mg/kg (Erdöl-Vereinigung 2002).[18] The nitrogen content of normal light fuel oil is estimated with 125 mg/kg (Jungbluth 2007).

In the previous study, a compilation of different elementary analyses was compiled (Jungbluth 2007: table A.3 in its appendix). For mercury, a share of 20 μg/kg is applied. Because of contact with copper wires etc., light fuel oil also contains traces of the metals copper and zinc. According to a fuel analysis by DGMK, it amounts to about 30 μg/kg (DGMK 1992).

16 https://www.admin.ch/opc/de/classified-compilation/19850321/index.html, online 22.01.2018
17 https://www.heizoel24.ch/heizoel-sorten, 17.4.2018
18 http://www.minerol.ch/produkte/prd/heizoel, 17.4.2018

Tab. 3.7 Chemical composition, calorific value and density of light fuel oil for this study. For eco-light fuel oil, the same values can be used if not stated otherwise

| | Unit | Light fuel oil | Eco-light fuel oil | Source |
|---|---|---|---|---|
| C | % by weight | 86.2% | | Roethlisberger 2016 |
| H | % by weight | 13.7% | | Changed to model 100% and calorific value |
| O | % by weight | - | | Changed to model 100% and calorific value |
| N | % by weight | 0.0125% | 0.01% | Jungbluth 2007 / http://www.minerol.ch/produkte/prd/heizoel, 17.4.2018 |
| S | % by weight | 0.01% | 0.005% | https://www.admin.ch/opc/de/classified-compilation/19850321/index.html, Annexe 5.11 |
| Ba | mg/kg | 5 | | https://www.admin.ch/opc/de/classified-compilation/19850321/index.html, Annexe 5.132, 2018 |
| Cl | mg/kg | 50 | | |
| Pb | mg/kg | 5 | | |
| Ni | mg/kg | 5 | | |
| V | mg/kg | 10 | | |
| Zn | mg/kg | 5 | | |
| P | mg/kg | 5 | | |
| Cu | ppb | 30 | | Jungbluth 2007 |
| F | ppb | 400 | | Jungbluth 2007 |
| Hg | ppb | 20 | | Jungbluth 2007 |
| Net calorific value | MJ/kg | 42.9 | | Calculated |
| Gross calorific value | MJ/kg | 45.2 | | Roethlisberger 2016 |
| density | kg/l | 0.839 | | Roethlisberger 2016 |

## 3.8 Naphtha

The chemical composition, calorific value and density of naphtha are listed in Tab. 3.8 (BFE 2001; L-B-Systemtechnik et al. 2002).

Tab. 3.8 Chemical composition, calorific value and density of naphtha (BFE 2001; L-B-Systemtechnik et al. 2002)

| | Unit | Naphtha |
|---|---|---|
| Density | kg/l | 0.75 |
| Net calorific value | MJ/kg | 45.0 |
| Gross calorific value | MJ/kg | 47.7 |
| CO2-Emissions | g/MJ | 70.7 |

## 3.9 Natural Gas

The composition of natural gas is dealt with in Schori et al. (2012). There is no distinction for the properties of gases (natural gas) which is flared, burnt, or vented/blown-off[19] during production and natural gas which is produced.

## 3.10 Petroleum Coke

The chemical composition, calorific value and density of petroleum coke are listed in Tab. 3.9. The data in bold print is used for this study. The world production in 2001 was about 140'000 tonnes. The most important producers in Europe were Spain, Italy, Germany and France. Around three quarters of the petroleum coke are used as fuel in refineries, 14% is burnt in power plants and 16% is used for cement production (Roskill 2002)

Tab. 3.9 Chemical composition, calorific value and density of petroleum coke

| | Unit | Petroleum coke | Petroleum coke | Petroleum coke | **Petroleum coke** |
|---|---|---|---|---|---|
| C-Content | % by wt | 88.5 | 72.7 | 79.3 | **79.3** |
| H-Content | % by wt | 3.9 | | | **3.9** |
| O-Content | % by wt | 1.75 | | | **12.6** |
| N-Content | % by wt | 2.0 | | | **2.0** |
| S-Content | % by wt | 2.2 | 0.8 | | **0.8** |
| Ash | % by wt | 0.3 | | | **0.3** |
| Ni | Mg/kg | 300 | | | **300** |
| V | Mg/kg | 1000 | | | **1000** |
| Moisture | % by wt | 1.35 | | | **1.35** |
| Net cal. value | MJ/kg | 35.0 | | 31.8 | **31.8** |
| Gross cal. value | MJ/kg | 36.1 | | | **33** |
| Source | | Jungbluth 2007 | BAFU 2014 | Röthlisberger 2016 | **This study** |

## 3.11 Refinery Gas

The composition of refinery gas strongly depends on the installed processes (hydrocracker, hydrotreater, steam reforming) and the crude oil which is being treated. Within the same refinery, depending on the process, hydrogen-contents can differ (see e.g. compilation of literature values in table A.2; Jungbluth 2007).

An update to the properties has been made to use the same properties as used in Swiss statistics (BAFU 2016; BFE 2016).

For the refinery locations Switzerland and Europe, the following fuel data is used (see Tab. 3.10):

[19] Emitted directly without combustion.

Tab. 3.10 Elemental analysis refinery gas

| | Unit | Last version | This study | Source |
|---|---|---|---|---|
| C | % by weight | 77 | 79.4 | BAFU 2016 |
| H | % by weight | 5.6 | 14.6 | Calculated |
| S | % by weight | 0.1 | 0.06 | BAFU 2016 |
| Hg | ppb | 70 | 18 | CONCAWE 2017a |
| Net calorific value | MJ/kg | 50.3 | 48.7 | BFE 2016 |
| Gross calorific value | MJ/kg | 55.2 | 54.0 | calculated |
| Density | kg/Nm$^3$ | 0.8 | 0.8 | BAFU 2016 |
| | | Jungbluth 2007 | | |

### 3.12 Sulphur

Sulphur has a lower heating value of 19.1 MJ/kg.[20]

# 4 Crude oil input

Crude oil input per kg of product and the mix of crudes used is quite relevant for the LCIA.

The total amount of crude oil processed in Switzerland in 2016 was 2'929'756 tonnes (Erdöl-Vereinigung 2017: page 45, see also Tab. 2.1). It must be noted that figures for imported crude oil, reported in the same publication, are higher than the amount processed. This might be due to e.g. stock changes.

About 554 million tonnes of crude oil were processed in the European refineries in 2016.[21]

The mix of crude oil processed in Swiss and European refineries is modelled in a separate report (Meili et al. 2018). The use of such import mix datasets facilitates future updates of this important factor for environmental impacts.

# 5 Material input and construction costs for infrastructure

No updates have been commissioned concerning the data on material inputs. A pre-evaluation of the data has shown a low relevance for overall results and thus an update was not part of this project. Information from the previous report was partly translated here by machine translation to inform the reader (Jungbluth 2007).

## 5.1 Material input

The material requirements of the infrastructure can be roughly divided into process and storage infrastructure. An atmospheric distillation column with a capacity of 110'000 bbl. /d weighs around 210 t, 40% of which is for the internals. While the external cladding is made of unalloyed boiler construction steel, the internal fittings are mainly made of high-alloyed steel. In addition, around 3 tons of mineral wool is used as insulation and 100 tons of concrete are used for fire protection (Sulzer 1992). The service life is assumed to be 30 years.

20 https://de.wikipedia.org/wiki/Heizwert
21 www.concawe.eu

For this study, the material use is calculated based on values in Tab. 5.1.

Tab. 5.1 Material requirements for a refinery with an annual capacity of 1 million tonnes, service life 30 years, utilisation: 80% (Jungbluth 2007)

| | Distillation | Factor [1]) | **Refinery** |
|---|---|---|---|
| | t | - | **t** |
| Steel, unalloyed | 130 | 160 | **4160** |
| Steel, high-alloyed | 80 | 20 | **320** |
| Mineral wool | 3 | 50 | **30** |
| Concrete | 100 | 50 | **1000** |
| Plastics [1]) | | | **48** |

[1]): Estimate for extrapolation for whole refinery

A comparison with the rough data in Tab. 5.2 indicates a specific cement demand (probably as concrete) of about 30% and a plastic demand of 1% (Infras 1981).

Except for steel, which is supplied to the scrap trade, the corresponding quantities are classified as waste to be disposed of.

Tab. 5.2 Specific material requirements for refineries

| | A | B |
|---|---|---|
| | $g/t_{product}$ | $g/t_{product}$ |
| Steel, unalloyed | 175 | 180 [1]) |
| Steel, high-alloyed | 15 | - |
| Mineral wool | 1 | kA |
| Concrete | 40 | 50 [2]) |
| plastics | kA | 2 [2]) |
| Total | 230 | 230 |

[1]): incl. high-alloyed steels (Infras 1981), [2]): Share of steel demand according to (Gemis 1989)
A: Calculated based on information from (Sulzer 1992)
B: (Infras 1981) complemented by (Gemis 1989), see Tab. 5.1.

## 5.2 Construction costs for infrastructure

Tab. 5.3 gives an overview of construction expenditures for distillation columns incl. internals for a refinery with an annual capacity of 5 million tonnes, utilisation rate 80% and a service life of 30 years (Sulzer 1993). Extrapolation is used to deduce the total energy and material input for the refinery.

It is shown, for example, that the electricity requirement for construction is negligibly small compared to the specific requirement for operation. If it is assumed that 1/3 of the total primary energy requirement (materials and construction expenditure) is required for the construction, the primary energy requirement results in the same order of magnitude (approximately 3 $MJ/t_{product}$).

Tab. 5.3 Construction expenditure for distillation columns incl. internals for a refinery with an annual capacity of 5 million tonnes, utilisation rate 80 %, service life 30 years (Sulzer 1993)

| | unit | distillation columns | factor [1]) | Total refinery |
|---|---|---|---|---|
| | | $t_{Product}$ | - | $t_{Product}$ |
| Electricity | TJ | 5.98E-08 | 10 | 6E-07 |
| Heating oil extra light | TJ | 1.37E-08 | 50 | 7E-07 |
| Water | $m^3$ | 1.45E-04 | 50 | 7E-03 |
| Chemicals/acids [2]) | kg | 1.65E-04 | 50 | 8E-03 |
| Welding consumables [3]) | kg | 1.42E-04 | 50 | 7E-03 |

[1]): Gross assumptions for extrapolation to total refinery, [2]): booked as cadmium-free brazing alloy, [3]): booked as sulphuric acid

## 5.3 Transports

Transport of building materials is estimated using standard distances.

## 5.4 Area required

The Cressier refinery's premises cover an area of 740,000 $m^2$.[22] With annual product sales of 2.8 million tonnes and a capacity utilization of 80%, this results in a load of 0.26 m2 a/t of product. In studies values from 0.24 to 0.3m2*a/t of product are indicated for refineries (Gemis 1989, Jensch 1988). In this study, the mean value of the available data is calculated according to Tab. 5.4.

## 5.5 Compilation of the input data

In Tab. 5.4, the life cycle inventory for the refinery is compiled according to the data available. As written in the introduction to this chapter no updates were foreseen during this study.

[22] https://varoenergy.com/what-we-do/refining, 17.4.2018

Tab. 5.4 Unit process raw data for the infrastructure of the refinery with an annual processing volume of 1 Mio. Tons of crude oil and 30 years of service life

| | Name | Location | InfrastructureProcess | Unit | refinery | Uncertainty | StandardDeviation95% | GeneralComment | refinery, 5Mio. t capacity | refinery, Collombey | refinery, Cressier | Mitteldeutsche Erdöl-Raffinerie | refinery, Pernis |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Location | | | | RER | | | | RER | CH | CH | DE | NL |
| | InfrastructureProcess | | | | 1 | | | | 1 | 1 | 1 | 1 | 1 |
| | Unit | | | | unit | | | | unit | unit | unit | unit | unit |
| product | refinery | RER | 1 | unit | 1.00E+0 | | | | | | | | |
| resource, land | Occupation, industrial area, built up | - | - | m2a | 2.69E+6 | 1 | 3.24 | (2,3,5,3,1,3); Plant data | | | | | |
| | Occupation, industrial area, vegetation | - | - | m2a | 2.10E+6 | 1 | 1.79 | (2,3,5,3,1,3); Plant data | | | | | |
| | Transformation, from unknown | - | - | m2 | 1.60E+5 | 1 | 2.24 | (2,3,5,3,1,3); Plant data | | 1.35E+6 | 7.40E+5 | 2.50E+6 | 9.00E+5 |
| | Transformation, to industrial area, built up | - | - | m2 | 8.97E+4 | 1 | 2.24 | (2,3,5,3,1,3); Plant data | | 6.13E+5 | 5.60E+5 | | |
| | Transformation, to industrial area, vegetation | - | - | m2 | 7.01E+4 | 1 | 1.52 | (2,3,5,3,1,3); Plant data | | 7.37E+5 | 1.80E+5 | | |
| resource, in water | Water, unspecified natural origin, GLO | - | - | m3 | 1.68E+2 | 1 | 3.56 | (3,5,5,3,4,5); Literature | 8.40E+2 | | | | |
| technosphere | electricity, medium voltage, production ENTSO, at grid | ENTSO | 0 | kWh | 4.00E+6 | 1 | 1.89 | (3,5,5,3,4,5); Literature | 2.00E+7 | | | | |
| | light fuel oil, burned in industrial furnace 1MW, non-modulating | CH | 0 | MJ | 1.68E+7 | 1 | 1.89 | (3,5,5,3,4,5); Literature | 8.40E+7 | | | | |
| | concrete, normal, at plant | CH | 0 | m3 | 4.55E+2 | 1 | 1.89 | (3,5,5,3,4,5); Literature | 2.27E+3 | | | | |
| | brazing solder, cadmium free, at plant | RER | 0 | kg | 1.68E+5 | 1 | 1.89 | (3,5,5,3,4,5); Literature | 8.40E+5 | | | | |
| | rock wool, packed, at plant | CH | 0 | kg | 3.00E+4 | 1 | 1.89 | (3,5,5,3,4,5); Literature | 1.50E+5 | | | | |
| | polyethylene, HDPE, granulate, at plant | RER | 0 | kg | 4.80E+4 | 1 | 1.89 | (3,5,5,3,4,5); Literature | 2.40E+5 | | | | |
| | sulphuric acid, liquid, at plant | RER | 0 | kg | 1.92E+5 | 1 | 1.89 | (3,5,5,3,4,5); Literature | 9.60E+5 | | | | |
| | chromium steel 18/8, at plant | RER | 0 | kg | 3.20E+5 | 1 | 1.89 | (3,5,5,3,4,5); Literature | 1.60E+6 | | | | |
| | steel, converter, unalloyed, at plant | RER | 0 | kg | 4.16E+6 | 1 | 1.89 | (3,5,5,3,4,5); Literature | 2.08E+7 | | | 3.40E+7 | |
| | disposal, building, cement (in concrete) and mortar, to sorting plant | CH | 0 | kg | 1.00E+6 | 1 | 1.89 | (3,5,5,3,4,5); Literature | 2.27E+3 | | | | |
| | disposal, plastics, mixture, 15.3% water, to sanitary landfill | CH | 0 | kg | 4.80E+4 | 1 | 1.89 | (3,5,5,3,4,5); Literature | 2.40E+5 | | | | |
| | disposal, building, mineral wool, to sorting plant | CH | 0 | kg | 3.00E+4 | 1 | 1.89 | (3,5,5,3,4,5); Literature | 1.50E+5 | | | | |
| | transport, lorry >16t, fleet average | RER | 0 | tkm | 5.42E+5 | 1 | 2.09 | (4,5,na,na,na,na); Standard distance 100km | | | | | |
| | transport, freight, rail | RER | 0 | tkm | 2.95E+6 | 1 | 2.09 | (4,5,na,na,na,na); Standard distance 600km | | | | | |
| emission air, high population density | Heat, waste | - | - | MJ | 1.44E+7 | 1 | 1.89 | (3,5,5,3,4,5); Literature | 7.20E+7 | | | | |
| | | | | | | | | | | | | | |
| capacity | | | | | 1.00E+9 | | | | 5.00E+09 | 1.81E+9 | 2.80E+9 | 1.07E+10 | 1.90E+10 |
| source | | | | | | | | | see text | | | www.totalfinaelf-service.de | www.bp.be |

# 6 Energy demand

The energy demand and emissions due to the combustion of fuels are a very relevant issue for the update of the refinery data.

Refineries generate the necessary process energy with heavy fuel oil, petroleum coke and/or refinery gas from their own production (IPPC 2001).

The energy requirements of a refinery are very much dependent on the complexity of the plant and the product structure. Because of the increased demand for light products and the decline in heavy fuel oils, petroleum oils, which always have a residue content of between 30 and 50%, must be hydrogenated and cracked.

The power requirements of the refineries for pumps, etc. are considerable. In some refineries, it is produced by thermal power coupling units themselves. Consumption of self-generated electricity does not appear in the life cycle inventory.

The 96 EU mainstream refineries consumed in 2010 together nearly 50 Mtoe total energy per year, which is equivalent to about 7% of their crude oil intake (CONCAWE 2012). The mix of energy sources is provided in Fig. 6.1. Energy delivered by purchased steam is considered in the LCI with the combustion of natural gas.

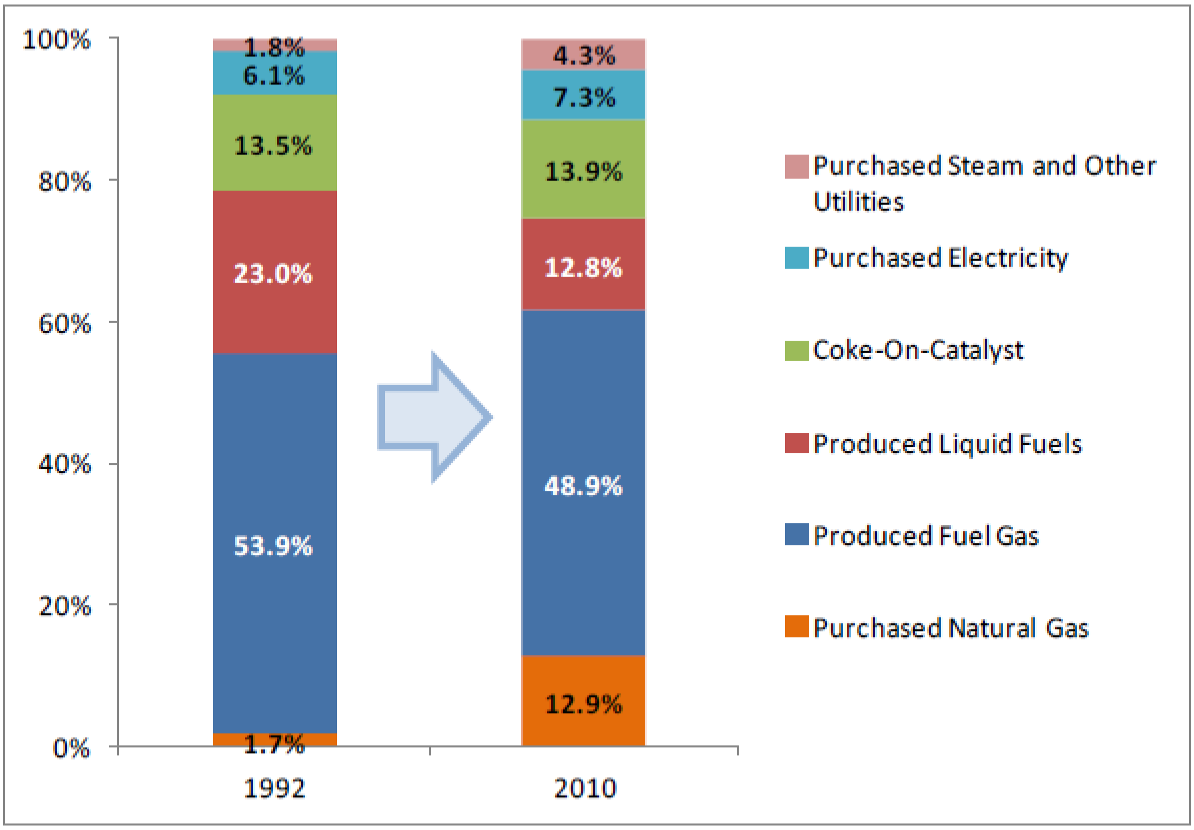


Fig. 6.1 Evolution of refinery fuel mix in EU refineries, as % of TPEC (total primary energy consumption) (CONCAWE 2012:Figure 11)

For Switzerland direct data on internal energy consumption are available from the refinery operator.[7] They are similar to published statistics (BFE 2017; Erdöl-Vereinigung 2016). The energy requirements for the refinery sites are summarized in Tab. 6.1 in the form of energy carrier flows.

Tab. 6.1 Specific energy requirements of the refineries (Switzerland: refinery operator[7], Europe: CONCAWE 2012)

| | | Switzerland | Europe |
|---|---|---|---|
| | | kg oil input | kg oil input |
| electricity, medium voltage, at grid | kWh | 0.042 | 0.06 |
| natural gas and steam | MJ | | 0.52 |
| refinery gas, burned in furnace | MJ | 2.088 | 1.48 |
| heavy fuel oil | MJ | 0.078 | 0.39 |
| petroleum coke | MJ | - | 0.42 |
| **Total fuel consumption** | **MJ** | **2.319** | **3.027** |
| Internal energy use on crude input | % | 5.4% | 7.0% |

# 7 Emissions to air

Air emissions are a relevant factor for the environmental impacts caused by refineries. Most of the emissions are due to the combustion of fuels. But, some emissions are also caused due to direct emissions of the regular operation (e.g. fugitive emissions during handling of crude oil and oil products).

Data are available in different forms:

- Emission factors for fuels used in refinery furnaces (e.g. BAFU 2011, 2016; CONCAWE 2017a)
- Total emissions of refinery operation in Switzerland or Europe as reported in public inventories. Data are available online on E-PRTR data 2007-2011.[23]
- Total emissions of single refineries are reported in environmental reports (e.g. Bayernoil 2016; Fortum 2002; OMV 2015; Shell 2000a, b).

The air emissions are modelled based on the energy use and emission factors for three types of furnaces for refinery gas, fuel oil and petroleum coke.

If only emission factors for single refineries were available an estimate has been made using the mean value of the previous emission factor (according to Jungbluth 2007) and the newly available data.

Carbon dioxide ($CO_2$) is modelled based on fuel properties.

Preliminary calculations show that most of the emissions of the following pollutants are due to the combustion of fuels. Thus, data reported for total emissions of the refinery are not considered for these substances as they are considered with emission factors for fuels used in refinery furnaces:

- Carbon monoxide (CO)
- Sulphur Dioxide ($SO_2$)
- Nitrogen oxides ($NO_X$)
- Dinitrogen oxide ($N_2O$)
- Nickel

## 7.1 Combustion-related emissions

### 7.1.1 Heat loss

According to ecoinvent methodology, it is assumed that the energy content in the fuel is emitted as heat. Based on the specific water requirement, it is assumed that 75% of the energy produced in the furnaces is finally released into the air as waste heat (Frischknecht et al. 1996). The remaining 25% are fed with the cooling water into a receiving watercourse. The calorific value of the fuels is used as waste heat. It must be noted that a part of the fuel energy goes to feed chemical reactions (cracking, re-forming, isomerization, desulphurisation) and thus the standard assumption might not be fully correct. Today these elementary flows are rarely used in LCIA and thus no further investigation has been made on this issue.

### 7.1.2 Heavy fuel oil

Tab. 7.2 shows the unit process raw data for the combustion of heavy fuel oil in refinery furnaces. The most relevant emissions are estimated based on emission factors for fuels used in

[23] https://www.eea.Europe.eu/data-and-maps/data/member-states-reporting-art-7-under-the-european-pollutant-release-and-transfer-register-e-prtr-regulation-14

refinery furnaces (BAFU 2011, 2016; CONCAWE 2017a). Some other emissions are estimated with the data documented in the former version of this report (Jungbluth 2007).

The split up of total particle emissions is shown in Tab. 7.1.

Tab. 7.1 Split up of particle emissions in g/kg$_{\text{fuel oil}}$ (Berdowski et al. 2002)

| | PM 2.5 | PM 10 | TSP |
|---|---|---|---|
| (Berdowski et al. 2002) | **1.5** | **1.7** | **2.1** |

Tab. 7.2 Unit process raw data for combustion of heavy fuel oil in refinery furnaces

| | Name | Location | InfrastructureProcess | Unit | *heavy fuel oil, burned in refinery furnace* | *heavy fuel oil, burned in refinery furnace* | UncertaintyType | StandardDeviation95% | GeneralComment | *Concawe* | *Emission factors* | *heavy fuel oil, burned in refinery furnace* | *heavy fuel oil, burned in refinery furnace* |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Location | | | | *CH* | *RER* | # | | | *RER* | *CH* | *CH* | *RER* |
| | InfrastructureProcess | | | | *0* | *0* | # | | | *2017* | *2015* | *0* | *0* |
| | Unit | | | | *MJ* | *MJ* | # | | | *g/GJ* | *MJ* | *kg* | *kg* |
| technosphere | heavy fuel oil, at refinery | CH | 0 | kg | 2.43E-2 | 0 | 1 | 1.05 | (1,1,1,1,1,1); Product properties | | | 1.00E+0 | 0 |
| | heavy fuel oil, at refinery | RER | 0 | kg | 0 | 2.43E-2 | 1 | 1.05 | (1,1,1,1,1,1); Product properties | | | 0 | 1.00E+0 |
| | industrial furnace 1MW, oil | CH | 1 | unit | 2.78E-9 | 2.78E-9 | 1 | 3.00 | (1,1,1,1,1,1); Estimation 5000h use per year | | | 0 | 0 |
| | chimney | CH | 1 | m | 3.47E-8 | 3.47E-8 | 1 | 3.00 | (1,1,1,1,1,1); Calculated | | | 0 | 0 |
| emission air, high population density | Heat, waste | - | - | MJ | 7.96E-1 | 7.96E-1 | 1 | 1.12 | (3,1,1,1,1,3); Product properties, 75% of waste heat to air | | | 3.28E+1 | 3.28E+1 |
| | Arsenic | - | - | kg | 3.98E-9 | 3.98E-9 | 1 | 1.19 | (3,4,1,2,1,4); Literature data | 3.98E-3 | | 8.00E-7 | 8.00E-7 |
| | Cadmium | - | - | kg | 1.20E-9 | 1.20E-9 | 1 | 3.04 | (3,4,1,2,1,4); Literature data | 1.20E-3 | | 1.30E-6 | 2.00E-6 |
| | Calcium | - | - | kg | 1.70E-7 | 1.70E-7 | 1 | 5.09 | (3,4,4,3,1,4); Literature data | | | 7.00E-6 | 7.00E-6 |
| | Carbon dioxide, fossil | - | - | kg | 7.70E-2 | 7.70E-2 | 1 | 1.11 | (3,1,1,1,1,1); Product properties | | 7.70E-2 | 3.17E+0 | 3.17E+0 |
| | Carbon monoxide, fossil | - | - | kg | 6.00E-6 | 6.00E-6 | 1 | 5.01 | (3,na,1,na,1,na); Literature data | 6.00E+0 | 1.50E-5 | | |
| | Chromium | - | - | kg | 1.48E-8 | 1.48E-8 | 1 | 1.19 | (3,4,1,2,1,4); Literature data | 1.48E-2 | | 2.97E-7 | 9.90E-7 |
| | Chromium VI | - | - | kg | 7.28E-11 | 2.43E-10 | 1 | 1.55 | (3,4,5,3,1,4); Literature data | | | 3.00E-9 | 1.00E-8 |
| | Cobalt | - | - | kg | 1.94E-8 | 4.85E-8 | 1 | 5.30 | (3,4,5,3,1,4); Literature data | | | 8.00E-7 | 2.00E-6 |
| | Copper | - | - | kg | 1.19E-8 | 1.19E-8 | 1 | 1.19 | (3,4,1,2,1,4); Literature data | 1.19E-2 | | 1.00E-6 | 3.00E-6 |
| | Dinitrogen monoxide | - | - | kg | 8.00E-7 | 1.60E-6 | 1 | 1.55 | (3,4,1,2,1,4); Swiss greenhouse gas inventory | 1.60E+0 | 8.00E-7 | | |
| | Hydrogen chloride | - | - | kg | 2.18E-6 | 2.18E-6 | 1 | 1.82 | (3,4,5,3,1,4); Literature data | - | | 9.00E-5 | 9.00E-5 |
| | Hydrogen fluoride | - | - | kg | 2.18E-7 | 2.18E-7 | 1 | 1.55 | (3,4,5,3,1,4); Literature data | | | 9.00E-6 | 9.00E-6 |
| | Iron | - | - | kg | 2.43E-7 | 2.43E-7 | 1 | 5.30 | (3,4,5,3,1,4); Literature data | | | 1.00E-5 | 1.00E-5 |
| | Lead | - | - | kg | 4.56E-9 | 4.56E-9 | 1 | 3.04 | (3,4,1,2,1,4); Literature data | 4.56E-3 | | 9.00E-6 | 3.50E-6 |
| | Mercury | - | - | kg | 1.46E-10 | 1.46E-10 | 1 | 1.55 | (3,4,5,3,1,4); Literature data | nd | | 6.00E-9 | 6.00E-9 |
| | Methane, fossil | - | - | kg | 4.00E-6 | 3.02E-6 | 1 | 3.04 | (3,4,1,2,1,4); Swiss greenhouse gas inventory | 3.02E+0 | 4.00E-6 | | |
| | Molybdenum | - | - | kg | 1.21E-8 | 2.43E-8 | 1 | 5.30 | (3,4,5,3,1,4); Literature data | | | 5.00E-7 | 1.00E-6 |
| | Nickel | - | - | kg | 7.73E-7 | 7.73E-7 | 1 | 5.01 | (1,3,1,2,1,3); Emission factor published by CONCAWE | 7.73E-1 | | | |
| | Nitrogen oxides | - | - | kg | 1.10E-4 | 1.10E-4 | 1 | 3.04 | (3,4,1,2,1,4); Literature data | × | 1.10E-4 | | |
| | NMVOC, non-methane volatile organic compounds, unspecified origin | - | - | kg | 2.50E-6 | 8.45E-7 | 1 | 1.55 | (3,4,1,2,1,4); Literature data | 8.45E-1 | 2.50E-06 | | |
| | Particulates, < 2.5 um | - | - | kg | 1.05E-5 | 1.05E-5 | 1 | 1.17 | (2,4,2,2,1,4); Literature data | 1.50E+1 | | 3.50E-5 | 1.15E-3 |
| | Particulates, > 2.5 um, and < 10um | - | - | kg | 1.50E-6 | 1.50E-6 | 1 | 1.17 | (2,4,2,2,1,4); Literature data | | | 5.00E-6 | |
| | Particulates, > 10 um | - | - | kg | 3.00E-6 | 3.00E-6 | 1 | 1.54 | (2,4,2,2,1,4); Literature data | | | 1.00E-5 | |
| | Selenium | - | - | kg | 1.94E-8 | 1.94E-8 | 1 | 5.09 | (3,4,4,3,1,4); Literature data | | | 8.00E-7 | 8.00E-7 |
| | Sodium | - | - | kg | 1.12E-6 | 1.12E-6 | 1 | 5.09 | (3,4,4,3,1,4); Literature data | | | 4.60E-5 | 4.60E-5 |
| | Sulfur dioxide | - | - | kg | 4.90E-4 | 7.28E-4 | 1 | 1.19 | (3,4,1,3,1,4); Literature data | | 4.90E-4 | | |
| | Vanadium | - | - | kg | 5.10E-7 | 8.59E-7 | 1 | 1.29 | (3,4,4,3,1,4); Literature data | | | 2.10E-5 | |
| | Zinc | - | - | kg | 4.93E-8 | 4.93E-8 | 1 | 1.19 | (3,4,1,2,1,4); Literature data | 4.93E-2 | | 3.50E-6 | 2.50E-6 |
| | Dioxin, 2,3,7,8 Tetrachlorodibenzo-p- | - | - | kg | 1.24E-15 | 1.24E-15 | 1 | 3.04 | (3,4,1,2,1,4); Literature data | 1.24E-9 | | | |
| | Benzene | - | - | kg | 6.47E-10 | 6.47E-10 | 1 | 3.04 | (3,4,1,2,1,4); Literature data | 6.47E-4 | | | |
| | PAH, polycyclic aromatic hydrocarbons | - | - | kg | 3.67E-12 | 3.67E-12 | 1 | 3.04 | (3,4,1,2,1,4); Literature data | 3.67E-6 | | | |
| emission water, river | Heat, waste | - | - | MJ | 2.65E-1 | 2.65E-1 | 1 | 1.14 | (3,3,1,3,1,3); Literature data, 25% of waste heat to cooling water | | | | |
| Source | | | | | | | | | | *Concawe 2017* | *BAFU 2011* | *Jungbluth 2007* | *Jungbluth 2007* |

### 7.1.3 Refinery gas

Tab. 7.3 shows the unit process raw data for the combustion of refinery gas in refinery furnaces. Nearby all emissions are estimated based on emission factors for fuels used in refinery furnaces (BAFU 2011, 2014, 2016; CONCAWE 2017a). Only radon emissions are estimated with the data documented in the former version of this report (Jungbluth 2007).

Tab. 7.3 Unit process raw data for combustion of refinery gas in refinery furnaces

| | Name | Location | InfrastructureProcess | Unit | refinery gas, burned in furnace | refinery gas, burned in furnace | UncertaintyType | StandardDeviation95% | GeneralComment | GHG inventory | Concawe 2017 | Concawe |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Location | | | | CH | RER | | | | CH | RER | RER |
| | InfrastructureProcess | | | | 0 | 0 | | | | 2013 | 2016 | 2017 |
| | Unit | | | | MJ | MJ | | | | kg/MJ | g/GJ | g/GJ |
| product | refinery gas, burned in furnace | CH | 0 | MJ | 1.00E+0 | 0 | | | | | | |
| | refinery gas, burned in furnace | RER | 0 | MJ | 0 | 1.00E+0 | | | | | | |
| technosphere | refinery gas, at refinery | CH | 0 | kg | 2.05E-2 | 0 | 1 | 1.05 | (1,1,1,1,1,1); Input | | | |
| | refinery gas, at refinery | RER | 0 | kg | 0 | 2.05E-2 | 1 | 1.05 | (1,1,1,1,1,1); Input | | | |
| | industrial furnace 1MW, oil | CH | 1 | unit | 2.78E-9 | 2.78E-9 | 1 | 3.00 | (1,1,1,1,1,1); Estimation 5000h use per year | | | |
| | chimney | CH | 1 | m | 3.47E-8 | 3.47E-8 | 1 | 3.00 | (1,1,1,1,1,1); Calculated | | | |
| emission air, high population density | Heat, waste | - | - | MJ | 4.05E+1 | 4.05E+1 | 1 | 1.17 | (3,3,3,3,1,3); Higher heating value, 75% waste heat to air | | | |
| | Methane, fossil | - | - | kg | 1.00E-6 | 3.26E-7 | 1 | 3.02 | (1,3,1,3,1,4); Literature data | 1.00E-6 | | 3.26E-1 |
| | Carbon monoxide, fossil | - | - | kg | 1.50E-5 | 1.21E-5 | 1 | 5.02 | (1,3,1,3,1,4); Literature data | 1.50E-5 | | 1.21E+1 |
| | Carbon dioxide, fossil | - | - | kg | 5.98E-2 | 5.98E-2 | 1 | 1.13 | (1,3,1,3,1,4); Literature data | 5.98E-2 | | |
| | Dinitrogen monoxide | - | - | kg | 6.00E-7 | 3.89E-8 | 1 | 1.52 | (1,3,1,3,1,4); Literature data | 6.00E-7 | | 3.89E-2 |
| | NMVOC, non-methane volatile organic compounds, unspecified origin | - | - | kg | 2.30E-6 | 2.58E-6 | 1 | 1.52 | (1,3,1,3,1,4); Literature data | 2.30E-6 | | 2.58E+0 |
| | Nitrogen oxides | - | - | kg | 5.50E-5 | 5.50E-5 | 1 | 3.02 | (1,3,1,3,1,4); Literature data | 5.50E-5 | | × |
| | Sulfur dioxide | - | - | kg | 2.50E-5 | 2.50E-5 | 1 | 1.13 | (1,3,1,3,1,4); Literature data | 2.50E-5 | | |
| | Particulates, < 2.5 um | - | - | kg | 8.90E-7 | 8.90E-7 | 1 | 1.17 | (2,4,2,1,1,4); Literature data | | | 8.90E-1 |
| | Arsenic | - | - | kg | 3.52E-10 | 3.52E-10 | 1 | 1.11 | (1,1,1,1,1,4); Literature data | | 3.52E-4 | - |
| | Cadmium | - | - | kg | 2.19E-9 | 2.19E-9 | 1 | 3.01 | (1,1,1,1,1,4); Literature data | | 2.19E-3 | 2.19E-3 |
| | Chromium | - | - | kg | 6.69E-9 | 6.69E-9 | 1 | 1.11 | (1,1,1,1,1,4); Literature data | | 6.69E-3 | - |
| | Copper | - | - | kg | 3.29E-9 | 3.29E-9 | 1 | 1.11 | (1,1,1,1,1,4); Literature data | | 3.29E-3 | 3.29E-3 |
| | Lead | - | - | kg | 1.61E-9 | 1.61E-9 | 1 | 3.01 | (1,1,1,1,1,4); Literature data | | 1.61E-3 | 1.61E-3 |
| | Mercury | - | - | kg | 3.72E-10 | 3.72E-10 | 1 | 1.11 | (1,1,1,1,1,4); Literature data | | 3.72E-4 | 3.72E-4 |
| | Nickel | - | - | kg | 7.37E-9 | 7.37E-9 | 1 | 5.01 | (1,1,1,1,1,4); Literature data | | 7.37E-3 | 7.37E-3 |
| | Selenium | - | - | kg | 1.56E-9 | 1.56E-9 | 1 | 5.01 | (1,1,1,1,1,4); Literature data | | 1.56E-3 | |
| | Zinc | - | - | kg | 1.70E-8 | 1.70E-8 | 1 | 1.11 | (1,1,1,1,1,4); Literature data | | 1.70E-2 | 1.70E-2 |
| | Dioxin, 2,3,7,8 Tetrachlorodibenzo-p- | - | - | kg | 0 | 0 | 1 | 3.01 | (1,1,1,1,1,4); Literature data | | | - |
| | Benzene | - | - | kg | 2.13E-9 | 2.13E-9 | 1 | 3.01 | (1,1,1,1,1,4); Literature data | | | 2.13E-3 |
| | PAH, polycyclic aromatic hydrocarbons | - | - | kg | 3.07E-12 | 3.07E-12 | 1 | 3.01 | (1,1,1,1,1,4); Literature data | | | 3.07E-6 |
| | Radon-222 | - | - | kBq | 6.57E-3 | 6.57E-3 | 1 | 1.54 | (2,4,5,1,1,4); Literature data | | | |
| emission water, river | Heat, waste | - | - | MJ | 1.35E+1 | 1.35E+1 | 1 | 1.29 | (3,4,4,3,1,4); Literature data, 25% waste heat to cooling water | | | |
| Source | | | | | | | | | | BAFU 2014 | report no. 9/16 | report no. 4/17 |

## 7.1.4 Petroleum coke

Tab. 7.4 shows the unit process raw data for the combustion of petroleum coke in refinery furnaces. This dataset has been newly investigated for this study.

Almost all emissions are estimated based on emission factors for fuels used in refinery furnaces (BAFU 2011, 2014, 2016; CONCAWE 2017a). If such factors are not available data documented for the heavy fuel oil furnace as shown in Tab. 7.2 have been applied. The relevance of this extrapolation for the LCIA is low.

Tab. 7.4 Unit process raw data for combustion of petroleum coke in refinery furnaces

| | Name | Location | Infrastruc | Unit | *petroleum coke, burned in refinery furnace* | *petroleum coke, burned in refinery furnace* | Uncertain | Standard Deviation 95% | GeneralComment | *Emission factors* | *heavy fuel oil, burned in refinery furnace* | *heavy fuel oil, burned in refinery furnace* |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Location | | | | *RER* | *CH* | # | | | *CH* | *CH* | *RER* |
| | InfrastructureProcess | | | | *0* | *0* | # | | | *2015* | *0* | *0* |
| | Unit | | | | *MJ* | *MJ* | # | | | *MJ* | *MJ* | *MJ* |
| technosphere | petroleum coke, at refinery | CH | 0 | kg | 0 | 3.14E-2 | 1 | 1.05 | (1,1,1,1,1,1); Product properties | | 2.43E-2 | 0 |
| | petroleum coke, at refinery | RER | 0 | kg | 3.14E-2 | 0 | 1 | 1.05 | (1,1,1,1,1,1); Product properties | | 0 | 2.43E-2 |
| | industrial furnace 1MW, oil | CH | 1 | unit | 2.78E-9 | 2.78E-9 | 1 | 3.00 | (1,1,1,1,1,1); Estimation 5000h use per year | | 2.78E-9 | 2.78E-9 |
| | chimney | CH | 1 | m | 3.47E-8 | 3.47E-8 | 1 | 3.00 | (1,1,1,1,1,1); Calculated | | 3.47E-8 | 3.47E-8 |
| emission air, high population density | Heat, waste | - | - | MJ | 7.78E-1 | 7.78E-1 | 1 | 1.12 | (3,1,1,1,1,3); Product properties, 75% of waste heat to air | | 7.96E-1 | 7.96E-1 |
| | Arsenic | - | - | kg | 3.98E-9 | 3.98E-9 | 1 | 2.24 | (5,na,1,1,5,na); Estimation with data for HFO | | 3.98E-9 | 3.98E-9 |
| | Cadmium | - | - | kg | 1.20E-9 | 1.20E-9 | 1 | 3.90 | (5,na,1,1,5,na); Estimation with data for HFO | | 1.20E-9 | 1.20E-9 |
| | Calcium | - | - | kg | 1.70E-7 | 1.70E-7 | 1 | 6.04 | (5,na,1,1,5,na); Estimation with data for HFO | | 1.70E-7 | 1.70E-7 |
| | Carbon dioxide, fossil | - | - | kg | 9.97E-2 | 9.97E-2 | 1 | 1.11 | (3,na,1,na,1,na); Product properties | 9.14E-2 | 7.70E-2 | 7.70E-2 |
| | Carbon monoxide, fossil | - | - | kg | 1.50E-5 | 1.50E-5 | 1 | 5.02 | (3,1,1,1,1,3); Swiss emission factors | 1.50E-5 | 6.00E-6 | 6.00E-6 |
| | Chromium | - | - | kg | 1.48E-8 | 1.48E-8 | 1 | 2.24 | (5,na,1,1,5,na); Estimation with data for HFO | | 1.48E-8 | 1.48E-8 |
| | Chromium VI | - | - | kg | 2.43E-10 | 7.28E-11 | 1 | 2.24 | (5,na,1,1,5,na); Estimation with data for HFO | | 7.28E-11 | 2.43E-10 |
| | Cobalt | - | - | kg | 4.85E-8 | 1.94E-8 | 1 | 6.04 | (5,na,1,1,5,na); Estimation with data for HFO | | 1.94E-8 | 4.85E-8 |
| | Copper | - | - | kg | 1.19E-8 | 1.19E-8 | 1 | 2.24 | (5,na,1,1,5,na); Estimation with data for HFO | | 1.19E-8 | 1.19E-8 |
| | Dinitrogen monoxide | - | - | kg | 6.00E-7 | 6.00E-7 | 1 | 1.52 | (3,1,1,1,1,3); Swiss emission factors | 6.00E-7 | 8.00E-7 | 1.60E-6 |
| | Hydrogen chloride | - | - | kg | 2.18E-6 | 2.18E-6 | 1 | 2.46 | (5,na,1,1,5,na); Estimation with data for HFO | | 2.18E-6 | 2.18E-6 |
| | Hydrogen fluoride | - | - | kg | 2.18E-7 | 2.18E-7 | 1 | 2.24 | (5,na,1,1,5,na); Estimation with data for HFO | | 2.18E-7 | 2.18E-7 |
| | Iron | - | - | kg | 2.43E-7 | 2.43E-7 | 1 | 6.04 | (5,na,1,1,5,na); Estimation with data for HFO | | 2.43E-7 | 2.43E-7 |
| | Lead | - | - | kg | 4.56E-9 | 4.56E-9 | 1 | 3.90 | (5,na,1,1,5,na); Estimation with data for HFO | | 4.56E-9 | 4.56E-9 |
| | Mercury | - | - | kg | 1.46E-10 | 1.46E-10 | 1 | 2.24 | (5,na,1,1,5,na); Estimation with data for HFO | | 1.46E-10 | 1.46E-10 |
| | Methane, fossil | - | - | kg | 1.00E-5 | 1.00E-5 | 1 | 3.02 | (3,1,1,1,1,3); Swiss emission factors | 1.00E-5 | 4.00E-6 | 3.02E-6 |
| | Molybdenum | - | - | kg | 2.43E-8 | 1.21E-8 | 1 | 6.04 | (5,na,1,1,5,na); Estimation with data for HFO | | 1.21E-8 | 2.43E-8 |
| | Nickel | - | - | kg | 7.73E-7 | 7.73E-7 | 1 | 6.04 | (5,na,1,1,5,na); Estimation with data for HFO | | 7.73E-7 | 7.73E-7 |
| | Nitrogen oxides | - | - | kg | 2.00E-4 | 2.00E-4 | 1 | 3.02 | (3,1,1,1,1,3); Swiss emission factors | 2.00E-4 | 1.10E-4 | 1.10E-4 |
| | NMVOC, non-methane volatile organic compounds, unspecified origin | - | - | kg | 1.00E-5 | 1.00E-5 | 1 | 1.52 | (3,1,1,1,1,3); Swiss emission factors | 1.00E-05 | 2.50E-6 | 8.45E-7 |
| | Particulates, < 2.5 um | - | - | kg | 1.05E-5 | 3.50E-5 | 1 | 2.24 | (5,na,1,1,5,na); Estimation with data for HFO | | 3.50E-5 | 1.05E-5 |
| | Particulates, > 2.5 um, and < 10um | - | - | kg | 1.50E-6 | 5.00E-6 | 1 | 2.24 | (5,na,1,1,5,na); Estimation with data for HFO | | 5.00E-6 | 1.50E-6 |
| | Particulates, > 10 um | - | - | kg | 3.00E-6 | 1.00E-5 | 1 | 2.46 | (5,na,1,1,5,na); Estimation with data for HFO | | 1.00E-5 | 3.00E-6 |
| | Selenium | - | - | kg | 1.94E-8 | 1.94E-8 | 1 | 6.04 | (5,na,1,1,5,na); Estimation with data for HFO | | 1.94E-8 | 1.94E-8 |
| | Sodium | - | - | kg | 1.12E-6 | 1.12E-6 | 1 | 6.04 | (5,na,1,1,5,na); Estimation with data for HFO | | 1.12E-6 | 1.12E-6 |
| | Sulfur dioxide | - | - | kg | 5.00E-4 | 5.00E-4 | 1 | 1.12 | (3,1,1,1,1,3); Swiss emission factors | 5.00E-4 | 4.90E-4 | 7.28E-4 |
| | Vanadium | - | - | kg | 8.59E-7 | 5.10E-7 | 1 | 2.24 | (5,na,1,1,5,na); Estimation with data for HFO | | 5.10E-7 | 8.59E-7 |
| | Zinc | - | - | kg | 4.93E-8 | 4.93E-8 | 1 | 2.24 | (5,na,1,1,5,na); Estimation with data for HFO | | 4.93E-8 | 4.93E-8 |
| | Dioxin, 2,3,7,8 Tetrachlorodibenzo-p- | - | - | kg | 1.24E-15 | 1.24E-15 | 1 | 3.90 | (5,na,1,1,5,na); Estimation with data for HFO | | 1.24E-15 | 1.24E-15 |
| | Benzene | - | - | kg | 6.47E-10 | 6.47E-10 | 1 | 3.90 | (5,na,1,1,5,na); Estimation with data for HFO | | 6.47E-10 | 6.47E-10 |
| | PAH, polycyclic aromatic hydrocarbons | - | - | kg | 3.67E-12 | 3.67E-12 | 1 | 3.90 | (5,na,1,1,5,na); Estimation with data for HFO | | 3.67E-12 | 3.67E-12 |
| emission water, river | Heat, waste | - | - | MJ | 2.59E-1 | 2.59E-1 | 1 | 1.17 | (3,3,3,3,1,3); Literature data, 25% of waste heat to cooling water | | 2.65E-1 | 2.65E-1 |
| Source | | | | | | | | | | *BAFU 2014* | This study | This study |

## 7.2 Process emissions of hydrocarbons (NMVOC)

In a refinery, a distinction must be made between evaporation losses and emissions due to incomplete combustion.

Tab. 7.5 shows NMVOC emission factors for refineries. The current information for these direct refinery emissions in Switzerland ist considerable lower than the former estimation and the figures available for some European refineries. No further information is available for explaining these differences. As it is not possible to directly measure these emissions, the uncertainty of such an estimation will be higher than e.g. measurements for emissions through stacks. This is already considered with the higher basic uncertainty of NMVOC emissions.

These NMVOCs are further broken down into individual alkanes, alkenes, and aromatics in accordance with Tab. 7.6.

Tab. 7.5 NMVOC emission factors for refineries

| | NMVOC |
|---|---|
| | $kg/t_{Output}$ |
| Jungbluth 2007, RER | 0.268 |
| OMV (2015), DE | 0.29 |
| Barthe et al. 2015, RER | 0.19 |
| **Estimation RER** | **0.19** |
| Jungbluth 2007, CH | 0.294 |
| VARO 2018[7] | 0.022 |
| **Estimation CH** | **0.022** |

The composition of process related hydrocarbons can vary considerably, and it is therefore difficult to determine an average. In Concawe (1986) air samples were taken from two refinery sites and analysed (Tab. 7.6). Only non-methane hydrocarbons were considered. There is a clear dominance of saturated hydrocarbons (80-90%). The proportion of unsaturated and/or aromatic hydrocarbons ranges from 10 to 20% and depends on the installed refinery processes.

No newer measurements concerning the composition of NMVOC emissions have been found during this project. All new literature sources report only the total NMVOC. Legal requirements normally do not ask for more detailed measurements.

Tab. 7.6 Estimation for the mix of NMVOC emissions

| %-by weight | %-by weight | %-by weight | %-by weight | **This study** |
|---|---|---|---|---|
| Alkanes | | | 90 | **90** |
| - Ethane | 14.8 | 2.4 | 5 | **5** |
| - Propane | 13.7 | 14.5 | 20 | **20** |
| - n Butane | | | 15 | **15** |
| - i Butane | | | 5 | **5** |
| - Butane + | 55.9 | 68.9 | - | **-*)** |
| - n Pentane | | | 5 | **5** |
| - i Pentane | | | 20 | **20** |
| - Hexane | | | 10 | **10** |
| - Heptane | | | 5 | **5** |
| - Octane + | | | 5 | **5** |
| Alkene | | 0.38 | 2.5 | **2.5** |
| - Ethen | 3.3 | 0.5 | 1 | **1** |
| - Propene | - | - | 1 | **1** |
| - Propene + | 8.3 | 0.4 | - | **-** |
| - Butene | - | - | 0.5 | **0.5** |
| Aromatic | | | 7.5 | **7.5** |
| - Benzene | 1.8 | 2.6 | 2 | **2** |
| - Toluene | 2.2 | 5.7 | 3 | **3** |
| - Xylene | 0 | 5.0 | - | **-** |
| - o-Xylene | - | - | 0.7 | **0.7** |
| - p, m-Xylene | - | - | 1.3 | **1.3** |
| - Ethylbenzene | - | - | 0.5 | **0.5** |
| Total | 100 | 100 | 100 | **100** |
| | First refinery site (Concawe 1986) | Second refinery site (Concawe 1986) | (Veldt et al. 1992) | **Own estimation in Jungbluth 2007** |

***)** Butane + = Summary indicator for NMVOC like butane, pentane, it is not used in the list of ecoinvent elementary flows.

# 8 Emissions to water

Emissions to water are less relevant for the impact assessment with the ecological scarcity method.

As a rule of thumb, irrespective of the type, size and state of the refinery's process technology, the following wastewater constituents can be found:

- Hydrocarbons (usually combined as mineral oil, oil)
- Phenols
- Ammonium or ammonia
- Sulphur compounds
- Cyanides
- Heavy metals

In the following section, the waste water loads are determined and the composition of pollutants is discussed. These two parameters are used to calculate the specific pollutant loads for this project. The uncertainty of determination is relatively high. Often only concentrations, waste water accumulation or freight rates are known. The variation between individual refineries is quite high.

Most of the information is based on an actual report (Barthe et al. 2015: Table 3.16). Some estimates are used from the former report (Jungbluth 2007) or have been estimated with actual environmental reports (Bayernoil 2016; OMV 2015).

## 8.1 Waste water discharge

The waste water loads in refineries vary widely due to different cooling water systems (open or closed circuit). Freight rates can range from 0.1 to over 6 $m^3$/t of output.

In this study, effluent loads for the determination of pollutant loads are estimated according to the consumption of river water in Tab. 9.1. The cooling water is assumed to be returned without significant contamination. The waste heat for this purpose is balanced in the firing systems.

Depending on the location of the refinery, this waste water can then be discharged directly into the sea or into inland waterways (e.g. rivers). Freight from Europe is divided into the corresponding proportions of emissions to the sea and rivers. It is assumed that the Swiss refinery directly emits into a river while European refineries discharge 63.5% to the sea and 36.5% to rivers (Jungbluth 2007 based on data for 1994).

## 8.2 Estimation of emissions to water

The emission factors for water emissions in the European refineries are shown in Tab. 8.1. Were possible, emissions have been estimated based on an actual report (Barthe et al. 2015: Table 3.16). If factors were not available in this report, figures from actual environmental reports have been applied were possible (Bayernoil 2016; OMV 2015). An average of these newer values has been calculated together with the former estimation (Jungbluth 2007). Only if no newer data were available the former estimations have been further used (Jungbluth 2007).

Tab. 8.1 Emission factors for water pollutants in the European refinery (kg per kg crude oil input)

| | crude oil, in refinery | crude oil, in refinery | crude oil, in refinery | crude oil, in refinery | crude oil, in refinery | crude oil, in refinery | crude oil, in refinery |
|---|---|---|---|---|---|---|---|
| | RER 2007 kg | DE 2014 kg | DE 2014 kg | DE 2014 kg | DE 2016 kg | RER 2015 kg | RER 2016 kg |
| Water, RER | 7.00E-4 | 4.36E-4 | 1.42E-03 | #WERT! | 4.01E-4 | 6.60E-03 | 6.60E-03 |
| Aluminium | 1.28E-8 | | | | | | 1.28E-08 |
| Ammonium, ion | 1.53E-6 | | | | | 1.20E-06 | 1.20E-06 |
| AOX, Adsorbable Organic Halogen as Cl | 4.04E-9 | 8.00E-9 | | | 6.50E-9 | 6.00E-08 | 6.00E-08 |
| Arsenic | 2.56E-9 | | | | | 7.00E-10 | 7.00E-10 |
| Barium | 2.56E-8 | | | | | | 2.56E-08 |
| Benzene | 5.71E-9 | | | | | 2.00E-09 | 2.00E-09 |
| Benzene, ethyl- | 5.11E-11 | | | | | 4.00E-09 | 4.00E-09 |
| BOD5, Biological Oxygen Demand | 1.62E-6 | 1.34E-6 | | 1.08E-6 | 1.78E-6 | 4.40E-06 | 4.40E-06 |
| Boron | 1.02E-7 | | | | | 2.64E-12 | 2.64E-12 |
| Cadmium | 2.56E-9 | | | | | 1.00E-09 | 1.00E-09 |
| Calcium | 1.28E-5 | | | | | | 1.28E-05 |
| Chloride | 2.03E-5 | 2.11E-4 | | | 2.10E-4 | | 1.47E-04 |
| Chromium | 5.71E-8 | | | | | 1.00E-09 | 1.00E-09 |
| Chromium VI | | | | | | 1.00E-09 | 1.00E-09 |
| COD, Chemical Oxygen Demand | 1.56E-5 | | | 2.63E-5 | | 2.72E-05 | 2.72E-05 |
| Cobalt | | | | | | 6.60E-15 | 6.60E-15 |
| Copper | 2.56E-9 | | | | | 2.00E-09 | 2.00E-09 |
| Cyanide | 4.43E-8 | | | | | 4.00E-09 | 4.00E-09 |
| DOC, Dissolved Organic Carbon | 1.58E-8 | | | | | | 1.58E-08 |
| Fluoride | 1.14E-6 | | | | | 6.00E-07 | 6.00E-07 |
| Hydrocarbons, aromatic | 1.84E-7 | | | | | 1.00E-08 | 1.00E-08 |
| Hydrocarbons, unspecified | 7.00E-8 | 1.11E-7 | | 4.66E-9 | 6.09E-8 | 5.00E-07 | 5.00E-07 |
| Iron | 1.28E-7 | | | | | 1.50E-07 | 1.50E-07 |
| Lead | 8.08E-8 | | | | | 5.00E-09 | 5.00E-09 |
| Magnesium | 6.39E-6 | | | | | | 6.39E-06 |
| Manganese | 5.11E-8 | | | | | 4.00E-08 | 4.00E-08 |
| Mercury | 2.56E-11 | | | | | 1.00E-10 | 1.00E-10 |
| Molybdenum | 2.56E-9 | | | | | 6.60E-14 | 6.60E-14 |
| Nickel | 3.37E-9 | | | | | 6.00E-09 | 6.00E-09 |
| Nitrate | 2.10E-6 | | | | | 6.20E-06 | 6.20E-06 |
| Nitrite | | | | | | 1.00E-07 | 1.00E-07 |
| Nitrogen, organic bound | 3.38E-6 | | | | | 4.00E-06 | 4.00E-06 |
| Oils, unspecified | 6.79E-7 | | | | | | 6.79E-07 |
| PAH, polycyclic aromatic hydrocarbons | 4.04E-9 | | | | | 3.00E-10 | 3.00E-10 |
| Phenol | 4.43E-8 | | | 2.85E-10 | | 2.00E-08 | 2.00E-08 |
| Phosphate | | | | | | 1.30E-07 | 1.30E-07 |
| Phosphorus | 9.90E-8 | 1.23E-7 | | 3.80E-7 | 1.07E-7 | 3.00E-07 | 3.00E-07 |
| Potassium | 2.56E-6 | | | | | | 2.56E-06 |
| Selenium | 3.83E-9 | | | | | 2.64E-13 | 2.64E-13 |
| Silver | 1.28E-8 | | | | | | 1.28E-08 |
| Sodium | 7.67E-5 | | | | | | 7.67E-05 |
| Strontium | 1.79E-7 | | | | | | 1.79E-07 |
| Sulfate | 5.11E-5 | | | | | | 5.11E-05 |
| Sulfide | 2.56E-8 | | | | | 2.50E-08 | 2.50E-08 |
| Suspended solids, unspecified | 2.56E-6 | | | | | 6.30E-06 | 6.30E-06 |
| t-Butyl methyl ether | 8.08E-8 | | | | | 5.00E-09 | 5.00E-09 |
| Tin | | | | | | 4.00E-09 | 4.00E-09 |
| TOC, Total Organic Carbon | 6.39E-6 | 5.06E-6 | | | 5.29E-6 | 5.50E-06 | 5.50E-06 |
| Toluene | 2.56E-7 | | | | | 4.00E-09 | 4.00E-09 |
| Vanadium | 7.67E-9 | | | | | 3.00E-09 | 3.00E-09 |
| Xylene | 2.56E-8 | | | | | 4.00E-09 | 4.00E-09 |
| Zinc | 4.41E-8 | | | | | 1.50E-08 | 1.50E-08 |
| | Jungbluth 2007 | Bayernoil 2014 | OMV 2015 | OMV 2015 | Bayernoil 2016 | Barthe et al. 2015 | This study |

Not much specific information was available for the Swiss refinery. Thus, in most cases the assumptions shown in Tab. 8.1 have been used. Tab. 8.2 shows only the factors which deviate from the European factors. Some data have been provided by the Swiss refinery itself.[24] Some data were available from the Swiss Pollutant Release and Transfer Register (S-PRTR) for 2015.[25] Some data have been provided for this refinery and date back to 2000. They were first used in the former study (Jungbluth 2007).

24 Varo 2018, Marc Veuve, personal communication, 16.1.2018

25 www.prtr.admin.ch/PublicWebSite/CompanyDetails.aspx?IDCompany=11&Year=2015&lng=de

Tab. 8.2 Emission factors for water pollutants in the Swiss refinery which are different from European factors (kg per kg crude oil input). All other emissions are estimated for the Swiss refinery with factors provided in Tab. 8.1

| Name | Location | Unit | *crude oil, in refinery* | *crude oil, in refinery* | *crude oil, in refinery Cressier* | *refinery operation, Cressier* | *crude oil, in refinery Cressier* |
|---|---|---|---|---|---|---|---|
| Location | | | *CH* | *CH* | *CH* | *CH* | *CH* |
| InfrastructureProcess | | | *0* | *2016* | *2016* | *2015* | *2006* |
| Unit | | | *kg* | *kg* | *kg* | *kg* | *kg* |
| Water, CH | - | m3 | 1.38E-4 | 1.38E-4 | 1.38E-4 | | 3.96E-5 |
| Chloride | - | kg | 1.87E-5 | 1.87E-5 | - | | 1.87E-5 |
| Hydrocarbons, unspecified | - | kg | 2.18E-7 | 2.18E-7 | 2.18E-7 | | |
| Nickel | - | kg | 3.11E-9 | 3.11E-9 | - | | 3.11E-9 |
| Oils, unspecified | - | kg | 2.08E-7 | 2.08E-7 | - | | 2.08E-7 |
| Phenol | - | kg | 1.92E-8 | 1.92E-8 | 1.92E-8 | 2.19E-8 | |
| Zinc | - | kg | 4.06E-8 | 4.06E-8 | - | | 4.06E-8 |
| *Literature* | | | | *This report* | *Varo 2018* | *PRTR 2015* | *Jungbluth 2007* |

# 9 Semi-finished products and operating materials

A range of information is available for individual plants on operating materials and semi-finished products. Since data from different refineries are used for the life cycle inventory, the need for different chemicals might be overestimated, as not all chemicals are used in all refineries. It is difficult to obtain an accurate average of all chemicals. Except for water requirements, these figures are used as the standard value for all refinery sites. Unless otherwise specified, semi-finished products and supplies are allocated to the various liquid and solid refinery products based on their weight.

Inputs monitored in this chapter are of low relevance for the environmental impacts caused by the refinery operation. Thus, no systematic update has been made for these data. Parts of the German text were translated by machine translation and proof-read by the authors.

## 9.1 Water use

Several data from various studies and environmental reports were available for the water requirements in refineries (see Tab. 9.1). Both the process and cooling water are considered (see also chapter 7.2).

Tab. 9.1 Specific water requirements for refineries ($m^3/t_{crude}$)

| | Process water | Cooling water | Tap water |
|---|---|---|---|
| Jungbluth 2007 for Europe | 0.7 | 4 | 0.015 |
| OMV 2015 | 1.4 | | 0.00018 |
| Barthe et al. 2015 | 6.6 | 7.7 | |
| Bayernoil 2016 | 0.4 | | |
| **Estimation Europe** | **6.6** | **7.7** | **0.015** |
| Jungbluth 2007 for CH | 0.57 | 4 | 0.015 |
| Estimation with data for Cressier 2016[7] | 0.14 | 0.37 | |
| **Estimation CH** | **0.14** | **0.37** | **0.015** |

## 9.2 Gases

### 9.2.1 Chlorine

Data on chlorine consumption (42 g/t crude oil) were available for two refineries (Shell 2000a, b).

### 9.2.2 Nitrogen

Bayernoil (2016) reports a consumption of 1.16 g nitrogen per kg processed crude oil in 2015. At (Shell 2000a, b) an average of 0.8 kg/t crude oil was used. An average value of 1.1 g/kg is used here.

## 9.3 Acids and bases

### 9.3.1 Sodium hydroxide solution

In 1990, the Raffoil refinery consumed a total of around 0.16 kg/tLPG sodium hydroxide solution (saturated, density 1.19 kg/l; pure, density 1.75 kg/l) for propane washing (removal of $H_2S$). At (Shell 2000a, b) 0.25 kg/t crude oil were used. This value is used here and allocated to LPG production.

### 9.3.2 Hydrochloric acid

Data on hydrochloric acid consumption (89 g/t crude oil) were available for two refineries (Shell 2000a, b).

### 9.3.3 Sulphuric acid

According to Bayernoil (2016) 8.2 mg sulphuric acid per kg processed crude oil were necessary in 2015. Data on sulphuric acid consumption (12 g/t crude oil) were available for two refineries (Shell 2000a, b). The average is calculated as 10 g/t.

## 9.4 Additives

The additives are of minor relevance from an environmental point of view. No updates were searched systematically for the use of additives because this study is focused on the more relevant aspects of the life cycle inventory. In the literature consulted for other parts of this study not much information was found. A further problem might be the confidentiality about additives promoted by single companies and the lack of inventory data for the integration of such very specific substances in the LCI.

The estimates reported in Jungbluth (2007) are applied.

### 9.4.1 Additive bitumen

To increase the adhesion and emulsifying capacity of the bitumen, an emulsifier is added in a dosage of 1.5 kg/t bitumen (Jungbluth 2007). No further information on the composition of the substance is available. It is recorded under organic chemicals.

### 9.4.2 Additive extra light fuel oil

#### 9.4.2.1 Cold Flow Property Improver

An ethylene-vinyl acetate copolymer, dissolved in a higher boiling point gasoline fraction, in a concentration of 400 ppm (by weight) was used (Raffoil 1991). No further information on the composition of the substance is available. It is recorded under organic chemicals.

#### 9.4.2.2 Antifouling

The antifouling-additive is added in a concentration of 33 $g/t_{heating\ oil}$ (Raffoil 1991). No further information on the composition of the substance is available. It is recorded under organic chemicals.

### 9.4.3 Additive diesel fuel

#### 9.4.3.1 Cold Flow Property Improver

An ethylene-vinyl acetate copolymer, dissolved in a higher boiling point gasoline fraction, in a concentration of 400 ppm (by weight) was used (Raffoil 1991). No further information on the composition of the substance is available. It is recorded under organic chemicals.

#### 9.4.3.2 Cetane Improver

In the USA, cyclohexane nitrate and cyclohexene nitrate are used as cetane improver. Amyl nitrate was used as well (Korte 1977). The concentrations vary between 0.1 (value in this study) and 1%. No further information on the composition of the substance is available. It is recorded under organic chemicals.

### 9.4.4 Additive kerosene

#### 9.4.4.1 Antioxidants

As an antioxidant, a mixture of monomethyl and dimethyl tertiary butyl phenol is used in concentrations between 19 and 26 ppm (by weight) (Scanraff 1991; Raffoil 1991). In the following, the values for Switzerland and Europe are assumed to be equal to 25 ppm. No further information on the composition of the substance is available. It is recorded under organic chemicals.

#### 9.4.4.2 Antistatics

Mixtures of chromium dialkyl salicylates, calcium-diethyl sulfonates and alkyl methyl acrylate copolymers + methyl vinyl pyridine (in a ratio of 1:1:1) are possible antistatic agents. (Korte 1977). The application rate is 0.85 to 1 ppm (weight) (Raffoil 1991), (Korte 1977). No further information on the composition of the substance is available. It is recorded under organic chemicals.

### 9.4.5 Additive petrol

#### *9.4.5.1 Tapping resistance, methyl tertiary butyl ether (MTBE)*

MTBE is added to petrol. The amount is estimated in the report on distribution (Jungbluth & Meili 2018).

#### *9.4.5.2 Antifreeze agent*

Fatty acid esters, amine salts, alcohols or glycols are used as antifreeze. They are not necessary in alcoholic fuels (Dabelstein 1986). In Raffoil, dipropylen-glycol is used in the gasoline "winter quality" in concentrations of 400 ppm (weight). The demand for di-propylene glycol is 210 g/t petrol per year (Raffoil 1991). It is recorded in the LCI as propylene glycol.

#### *9.4.5.3 Cleaning additives*

Polymer amines with carrier oil (not quantified) are used to keep the carburetor, intake system and combustion chamber clean (Dabelstein 1986).

#### *9.4.5.4 Combustion improvers*

Organic phosphorus compounds (not quantified) are used to prevent spark plug contamination (Dabelstein 1986).

#### *9.4.5.5 Antioxidants*

Oxidation inhibitors and metal deactivators are alkyl phenols, amines and phenylene diamines (not quantified) (Dabelstein 1986).

### 9.4.6 Additives LPG

For safety reasons, liquefied gases are odorized with methyl mercaptans in dosages of 15 ppm (by weight). The sulphur content is thus 10 ppm.

## 9.5 Anorganic chemicals

The anorganic chemicals are of minor relevance from an environmental point of view. No updates were searched systematically for the use of these substances because this study is focused on the more relevant aspects of the life cycle inventory. In the literature consulted for other parts of this study no information was found.

The estimates reported in Jungbluth (2007) are applied.

### 9.5.1 Ammonium - pH-surveillance

Approximately 2 g ammonium per metric ton of product is used for pH control. It is accounted for as ammonia.

### 9.5.2 Biocides - NaClO

Cooling water treatment uses around 1 g of biocides per metric ton of product. These are considered as Javel water (NaClO).

### 9.5.3 Calcium chloride

Calcium chloride consumption data (16 g/t crude oil) were available for two refineries (Shell 2000a, b).

### 9.5.4 Flocculation – FeSO4

Approximately 50 g/t of flocculants are used for wastewater treatment. These are ferric chloride (FeCl3) or ferrous sulphate. Iron sulphate is balanced.

### 9.5.5 Lime – water treatment

About 40 g/t of lime ($Ca(OH)_2$) is used in water treatment. (Shell 2000a) requires 28 g/t crude oil. Here, 35 g/t crude oil is estimated.

### 9.5.6 Sodium chloride

About 50 g/t of salt (NaCl) product is used to regenerate the ion exchanger in water treatment. It is assumed that the use of calcium chloride is equivalent to calcium chloride (see above). Therefore, this quantity is not posted.

## 9.6 Organic chemicals

The organic chemicals are of minor relevance from an environmental point of view. No updates were searched systematically for the use of these substances because this study is focused on the more relevant aspects of the life cycle inventory. In the literature consulted for other parts of this study no information was found.

The estimates reported in Jungbluth (2007) are applied.

### 9.6.1 Cleaning agents

Data on detergent consumption (3 g/t crude oil) were available for two refineries (Shell 2000a, b) and are recorded as soap.

### 9.6.2 Corrosion inhibitors

For cooling and process water in refineries about 5.5 g/t of corrosion inhibitors are used. Amongst others, sodium triphosphate (16%) and an additive (38%) in aqueous solution of the following composition are used:

- Organic polymer
- Organophosphates (p-toluene-sulfonic acid), 1.5% by weight
- Zinc salt ($ZnCl_2$), 20 % by weight

To account for manufacturing costs, the corrosion inhibitors are subsequently booked under organic chemicals.

### 9.6.3 Demulsifiers – Polyglycol ester

Approximately 6 g/t of product demulsifiers are used in crude oil desalination. Since no data are available on the substance, it is assumed that it is a polyglycol ester. It is recorded as propylene glycol.

### 9.6.4 Lubricating oil

Lubricating oil consumption data (15 g/t crude oil) were available for three refineries (Bayernoil 2016; Shell 2000a, b).

### 9.6.5 Methanol

Data on methanol consumption (82 g/t crude oil) were available for two refineries (Shell 2000a, b). It is assumed that MTBE is produced in these refineries. Therefore, this quantity is not considered.

### 9.6.6 Naphtha

Finished products and feedstocks are purchased from the refineries. Data were available for four refineries (Fortum 2002; Shell 2000a, b) and show an average demand of 115 kg/t crude oil. In these refineries, the sum of products is significantly higher than the crude oil input. For this reason, the average demand would be much too high. For this reason, only the assumed product output minus crude oil input and purchase of additives is recorded as naphtha (approx. 10 kg/t crude oil for Swiss refineries).

### 9.6.7 Oxygen scavenger

About 1 g/t of product oxygen scavenger are used. To account for manufacturing costs, they are subsequently recorded under organic chemicals.

### 9.6.8 Total organic chemicals

Data on the total consumption of semi-finished products and additives (7 kg/t crude oil) were available for two refineries (Shell 2000a, b). Since some of these substances are also accounted for directly, the total amount of organic chemicals is estimated to be 300 g/t crude oil. There are probably considerable differences between refineries in terms of type and quantity. Due to the mixture of different data sources, there are relatively large uncertainties in the balance sheet. To allocate the amount of chemicals to different products, the additive quantities in accordance with chapter 9.4 are also considered.

## 9.7 Catalysts

The catalysts are estimated to be of minor relevance from an environmental point of view. No updates were searched systematically for the use of these substances because this study is focused on the more relevant aspects of the life cycle inventory. In the literature consulted for other parts of this study no information was found.

The estimates reported in Jungbluth (2007) are applied. The following section has been translated by machine translation and proof-read by the authors.

Raffoil refinery requires 11.6 g of catalysts per ton of product. A specific demand of 69 g/t product can be determined from (Concawe 1989). The difference lies in the high demand for catalysts for the catalytic cracker, which accounts for around 2/3 of the total catalyst quantity at the European level. However, the Raffoil refinery is equipped with a thermal cracker.

According to IPPC 2001, the demand can only be roughly calculated with 200-375 g/t crude oil. For two specific refineries only about 2-4 g/t crude oil is used on average (Shell 2000a, b). Here, the total quantity of catalysts is estimated at 10 g/t crude oil (see Tab. 9.2).

Tab. 9.2 Data for the use of refinery catalysts

| Source | Amount of catalysts |
|---|---|
| | g/t crude Oil |
| (Raffoil 1991) | 11.6 |
| (Shell 1990) | 30 |
| (Concawe 1989) | 69 |
| (Shell 2000a, b) | 2-4 |
| (IPPC 2001) | 200-375 |
| **This study** | **10** |

Tab. 9.3 provides information on the material composition of the individual catalysts. With the help of the composition and the consumption of catalysts, a material vector can be calculated that is used for refineries.

Tab. 9.3 Percentages (or ppm) of carrier materials and metals of refinery catalysts (IPPC 2001: 153)

| Process | S | C | Mo | V | Ni | Co | Al | Other |
|---|---|---|---|---|---|---|---|---|
| FCC, RCC | < 1 | < 1 | | 4 - 8000 * | 2 - 3000 * | | 30 | |
| Cat.Reforming & Isomerisation | | | | | | | 30 | 0.5 Pt, Pa, Rh |
| Hydro processing | 6 - 16 | 10 - 30 | 4 - 8 | 2 - 12 | 1 - 2 | 1 - 2 | 20 - 30 | |
| Claus plant | 5 | 5 | 4 - 8 | | 2 - 3 | | 20 - 30 | |
| Hydrofinish | 5 | 1 - 2 | | | 2 - 4 | | 30 | 24 W |
| Hydrogen | 5 - 15 | | | | | | 0 | 30 Zn |
| Hydrodemetal. | 5 - 15 | 10 - 30 | | 10 - 20 | 2 - 5 | | 30 | |
| (*: ppm) | | | | | | | | |

Tab. 9.4 shows data on the consumption of catalysts in various processes of a refinery (IPPC 2001: 152). The quantity of catalysts produced worldwide rose sharply in the 1990s and is estimated at 100,000 tonnes. There are capacities of about 125,000 t/a for processing. Nevertheless, it is assumed that 5-10% of the catalysts are deposited after use. A 10% landfill is assumed here.

Tab. 9.4 Consumption of catalysts in a refinery (IPPC 2001:152)

| Type | Process stage | Amount | Capacity |
|---|---|---|---|
| | | t/a | t/a |
| Co/Mo | hydrodesulphurisation, hydrocracking, hydrotreating | 50-200 | 5 Mio. |
| Ni/Mo | hydrotreaters, hydrocracking units | 20-100 | 5 Mio. |
| Ni/W | lube oil hydrofinishing | 50 | 50000 |
| FCC | heavy oil and residue cracking | 400-500 | 1 Mio. FCC |
| Pt | reformer and isomerisation | 20-25 | 5 Mio. |
| V | hydrometallisation | 500-1000 | n.a. |
| Zn | beds from H2 plant | 50 | n.a. |

# 10 Transports

The transports of semi-finished products and supplies are generally estimated at standard distances (100 km, 600 km for trucks and railways).

# 11 Wastes

The amount of waste in European refineries has been investigated for the year 2013. For hazardous wastes the range in relative waste production across the country groups is 0.44 to 1.99 g/kg feedstock throughput, with a sector average of 1.07 g/kg feedstock throughput. For non-hazardous wastes the range in relative waste production across the country groups is 0.59 to 2.66 g/kg feedstock throughput, with a sector average of 1.45 g/kg feedstock throughput (CONCAWE 2017b).

Data for the Swiss refinery have been reported[7] as 0.020 g household waste per kg input and 0.4 g special waste (refinery sludge) per kg input.

No changes have been made to waste treatment processes and the composition of such wastes (Doka 2009).

# 12 Upgrading and blending

Upgrading and blending of products must be inventoried in a second stage. Now fossil fuels are blended in Switzerland and Europe before sold on the market:

- Diesel is blended with 2-5% of bio-diesel
- Petrol is blended with 1-3% of bio-ethanol
- For heating oil there are some offers for biogenic oils, the situation needs to be investigated

This issue is further elaborated in the reports on the distribution of mineral oil products (Jungbluth & Meili 2018).

# 13 Allocation of inputs and outputs to products

Oil refineries produce several different products simultaneously from a single feedstock. Whereas the total amount of energy (and other resources) used by refineries is well documented, there is no simple, non-controversial way to allocate energy, emissions or costs to a specific product. Distributing the resources used in refining amongst the various products invariably involves the use of allocation rules that can have a major influence on the results (Edwards et al. 2014).

The allocation of inputs and outputs to refinery products is documented in this chapter. Generally, no distinction is made between the Swiss and the European refinery concerning the allocation rules.

Already within the former studies the allocation was made flow specific which is also in line with ecoinvent guidelines for v2 (Frischknecht et al. 2007). It follows the ISO recommendation that allocations should be accomplished at the sub process level when possible. Such an approach is also recommended in newer publications (e.g. Silveira et al. 2017; Wang et al. 2004).

Such an allocation has not been applied in the present ecoinvent v3.3 version (ecoinvent Centre 2016) for the data published in SimaPro 8.5.3. In this database version "Cut-Off" all inputs and outputs are allocated based on the same energy allocation factor, which leads e.g. to a direct crude oil input for electricity.

Policy studies in the European context that estimate the savings from substituting conventional fuels use a marginal allocation approach (Edwards et al. 2014). The energy and GHG emissions associated with the production and use of conventional fuels should be representative of how the EU refineries would have to adapt to a marginal reduction in demand. In recent years Europe has seen an unprecedented growth in diesel fuel demand while gasoline has been stagnating or even dropping. From this analysis it appears that, in Europe, marginal diesel fuel is more energy-intensive than marginal gasoline (Edwards et al. 2014).

Another study investigates different ways of allocating greenhouse gases emissions deriving from refining and upstream crude oil supply. Allocation methods based on mass, energy content, economic value and, innovatively, added-value, are compared with the marginal refining emissions calculated by CONCAWE's linear-programming model to the average EU refinery, which has been adopted as reference in EU legislation. Beside the most important transportation fuels (gasoline, diesel, kerosene/jet fuel and heavy fuel oil), the analysis extends to petroleum coke and refinery hydrogen. Moreover, novel criteria, based on the implications due to hydrogen usage by each fuel pathway, have been introduced to test the consistency of the analysed approaches. It is found that only two economic-based allocation methods are consistent with the introduced criteria. These two methods also give negative refinery emissions for heavy products, which is coherent with the marginal emissions calculated through the CONCAWE refinery model (Moretti et al. 2017). It is questionable if such a model fits with the idea of attributional allocation in ecoinvent.

The allocation in a Brazilian refinery was discussed in a recent article (Silveira et al. 2017). With this approach, the incoming raw materials and effluents are weighted by specific allocation factors for the distillation, coking, FCC, hydrotreating, and propene main process and their sub-process calculated from the total of each principal process refining amount and the percentage outputs of the intermediate products. Unfortunately, results are only presented for a specific case but not with allocation factors that could be easily applied on other cases.

Tab. 13.1 Percentage variation in the energy allocation factor in relation to the mass allocation factor (Silveira et al. 2017)

| Distillation | Percent | Coking | Percent | FCC | Percent |
|---|---|---|---|---|---|
| Light diesel | 1.6 | Medium gas oil | 3.4 | LPG | 5.4 |
| Heavy diesel | 0.1 | Coke | −10.6 | LCO | −5.1 |
| Heavy vacuum gas oil | −1.2 | LPG | 9.9 | Cracked naphtha | 1.7 |
| Light vacuum gas oil | −0.6 | Light gas oil | 5.7 | Heavy cracked naphtha | −0.7 |
| LPG | 8.7 | Heavy gas oil | 2.2 | Oil decanted | −8.0 |
| Kerosene | 2.4 | Heavy cracked naphtha | 5.9 | | |
| Light naphtha | 5.2 | Liquefied cracked naphtha | 8.6 | | |
| Heavy naphtha | 2.3 | | | | |
| Vacuum residue | −3.6 | | | | |

## 13.1 Crude oil input

The crude oil demand is crucial for the environmental impacts caused by refinery products. In principle two main options exist: Allocation by mass or energy content. It must be noted that indirect uses of crude oil by supplying fuels for internal energy uses in the refinery is discussed for this study in the next sub-section. Another option would be economic value of refinery products, but this is considered as less suitable because pricing of products depends also on local policies and internal products like refinery gas do not have a price.

The former study allocated the crude oil input by mass. Thus to all physical products about 1 kg of crude oil was allocated per kg of product.[26] No crude input was allocated to electricity and the by-product sulphur (Jungbluth 2007). With this approach the mass balance of all products is kept correctly. But, mass allocation leads to higher upstream emissions per MJ for products with lower value such as heavy fuel oil and petroleum coke.

The Gabi-databases uses an energy allocation for the crude oil input.[27] The lower heating value of all products is used as a basis for the allocation of crude oil and thus the energy balance of the refinery is maintained. Thermal and electric energy demands are allocated by mass in this database. This approach is also used in the context of the European PEF studies.

The CONCAWE study documented nearly the same amount of emissions from crude oil input for gasoline and petrol. It is not fully clear if mass or energy allocation for this input has been considered in this study (Edwards et al. 2014).

Moretti et al took the following approach for feedstock allocation. Upstream emissions were allocated to each refined oil product in proportion to the ratio between refinery plus combustion emissions and total crude feedstock emissions (Moretti et al. 2017).

A detailed refinery model for sub-processes was investigated for the US (Wang et al. 2004). But, this article shows results only for crude oil input and internal energy use together. Thus, it is difficult to apply it in the context of our study.

The crude oil demand for refineries in Switzerland and Europe is allocated in this updated study to all products in accordance with the lower heating value. This seems to better reflect the purpose of refinery products. The energy balance between crude oil input and output of products is now fully preserved, while the mass balance is no longer completely correct. Thus, the input-output mass balance may be incorrect for individual products but is maintained for the entire refinery.

Indirect crude oil demand is taken also into account by use and combustion of fuels within the refinery. Then the specific crude oil requirement of a product is calculated from the direct demand that goes into the product and the indirect demand for fuels used in the refinery.

## 13.2 Energy and electricity demand

Refineries have the function of dividing crude oil into different fractions to obtain products with specific properties. The range of by-products thus extends from refinery gas to heavy residues, petroleum coke and bitumen. The costs to produce elementary sulphur (Claus plant) and its emissions are also determined in this study. Increased demand for light heating oil and transportation fuels is driving up the energy consumption of the refineries.

A share of the total energy consumption in the refinery operation must be allocated to each petroleum product. How to do this has been analysed in different studies summarized in Tab.

[26] Some rounding errors occur due to the implementation of the allocation function for importing data.

[27] http://www.gabi-software.com/uploads/media/The_GaBi_Refinery_Model_2016.pdf

13.2 for combustion of fuels and Tab. 13.3 for electricity demand. But, these studies use a partly different nomenclature and focus on distinct aspects (energy use or $CO_2$ emissions). The studies report the results in different units. Furthermore, the product portfolio investigated varies between the different studies. Thus, they are not easily comparable. But, one can estimate at least which products have an energy consumption above or below refinery average.

The values and distribution keys for thermal and electrical energy based on analysis of energy and material flow of refinery Raffoil (Raffoil 1991) is shown in Tab. 13.2 and Tab. 13.3.

L-B-Systemtechnik (2002) modelled the $CO_2$ emissions for the refinery products petrol, diesel and naphtha. Here, too, a higher energy emission factor for gasoline has been found.

The results of a modelling project for German refineries were published by (Jess 1996). There are differences especially in heating oil and naphtha.

An European study recommended to allocate the direct impacts of the refinery according to the added value approach (Moretti et al. 2017). This would result in a negative energy use for some of the products investigated. Thus, it is seen more as a consequential type of modelling which is not followed up here according to the general methodology. Results for $CO_2$ intensities are shown in Tab. 13.2. They have been used to estimate $CO_2$ factors showing some differentiation between various products.

A US study recommended energy content-based allocation on the process level (Wang et al. 2004). Results for relative energy requirements are shown in Tab. 13.2.

Thus, there is a huge variation of assumptions and recommendations in different studies on this subject. Furthermore, it was not transparent which assumptions on the direct energy uses in the refinery and its allocation were taken in the newly published papers.

For this study, therefore, the values for energy factor are estimated mainly based on the assumption already taken for the former version (Jungbluth 2007), which were based on the method and results published by Jess (1996). Some slight changes have now been made about sulphur (considered more as a by-product) and petrol/fuel gas (seems to be overestimated compared to the other studies). All publications agree that heavy fuel oil and coke are assigned a below-average value. The same factors are applied to diesel, LFO and kerosene as these products have similar factors in most of the studies.

The factor used for this study as shown in Tab. 13.2 is a first estimate if the specific fuel use for a product lies above or below average of the refinery. A factor of 1 means that the product uses the same amount as the average refinery product.

This factor is multiplied for the allocation with the amount of each specific product produced by the refineries in Switzerland and Europ (see Tab. 2.2). Then, the allocation share is calculated by dividing the results for the specific product through the sum calculated for all refinery products. Thus, the sum of all factors multiplied with the amounts of products produced, must match the average energy use of the refinery. This calculation is shown in the last 4 columns of the table.

The allocation of fuel inputs to electricity production of the refinery is roughly assessed. Therefore, it is assumed that 6.9 MJ fuel are burned for 1 kWh of electricity (efficiency of 52.2%) (Jungbluth 2007).

These factors make it possible to allocate the energy-related air pollutant emissions to the products according to their process route. It should also be noted that the energy demand and associated emissions to produce fuel gas and internally used heating oil are charged to the other products. The same allocation factors are also used for the infrastructure demand of the refinery.

Tab. 13.2 Specific fuel requirements for refinery products and several factors described in literature. The energy factor describes the ratio of energy demand of the specific product to the average energy demand of the refinery. Energy use is reported for a specific unit of output as shown in the second raw. Energy intensity is like the energy factor but reported as a percentage of the refinery. Esimate for this study and justification (Raffoil 1991; L-B-Systemtechnik et al. 2002; Jess 1996; Jungbluth 2007; Moretti et al. 2017; Wang et al. 2004_ENREF_49)

| Product | Energy use | Energy factor | $CO_2$ | Energy factor | Energy intensity | Refinery $CO_2$ | Refinery $CO_2$ | CO2 factor | **Factor** | Justification | Energy use | Energy factor | Energy use | Energy factor |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | MJ/kgOutput | - | g/MJ | $t_{crude\ Oil}/t_{Output}$ | % | g/MJ | g/MJ | - | - | | MJ/kg | - | MJ/kg | - |
| | CH | CH | DE | DE | US | RER | RER | RER | CH/RER | | CH | CH | RER | RER |
| Bitumen | 1.2 | 0.62 | - | 0.7 | 123.0 | | | | **0.7** | Jess 1996 | - | | 1.83 | 0.65 |
| Coke | | | | 0.7 | 109.6 | -80.4 | 1.6 | 0.28 | **0.7** | Jess 1996 | - | | 1.83 | 0.65 |
| Heavy fuel oil | 1.7 | 0.86 | - | 0.7 | 64.0 | -29.8 | 4.0 | 0.69 | **0.7** | Jess 1996 | 1.38 | 0.65 | 1.83 | 0.65 |
| Light fuel oil | 1.0 | 0.52 | - | 1.0 | 112.7 | | | - | **1.0** | Jess 1996 | 1.97 | 0.93 | 2.61 | 0.93 |
| Diesel | 1.0 | 0.52 | 4.7 | 1.0 | 71.8 | 10.3 | 6.0 | 1.03 | **1.0** | Jess 1996 | 1.97 | 0.93 | 2.61 | 0.93 |
| Kerosene | 1.1 | 0.56 | - | 1.0 | 62.4 | 7.9 | 5.9 | 1.02 | **1.0** | Jess 1996 | 1.97 | 0.93 | 2.61 | 0.93 |
| Petrol | 3.8 | 1.94 | 7.4 | 1.8 | 115.9 | 6.0 | 5.8 | 1.00 | **1.4** | Diverging results, estimate in between | 2.76 | 1.31 | 3.65 | 1.30 |
| Naphtha 1) | 3.8 | 1.94 | 4.4 | 0.6 | 50.9 | | | - | **0.6** | Jess 1996 | 1.18 | 0.56 | 1.56 | 0.56 |
| Propane/ Butane | 3.0 | 1.56 | - | 1.5 | 46.2 | | | - | **1.5** | Jess 1996 | 2.96 | 1.40 | 3.91 | 1.39 |
| Fuel Gas | 2.1 | 1.10 | - | 1.5 | 110.0 | | | - | **1.1** | Between Jess 1996 and Wang et al. 2004 / Raffoil 1991 | 2.17 | 1.03 | 2.87 | 1.02 |
| Hydrogen | | | | | 160.3 | 57.7 | 8.4 | 1.45 | **-** | Not included in this study | - | | | - |
| Sulphur | 3.0 | - | - | 1.5 2) | - | | | - | **1.0** | Seen as a by-product and thus no above average | 1.97 | 0.93 | 2.61 | 0.93 |
| **Refinery average** | **1.9** | **1.00** | **-** | 1.0 | 100.0 | 5.8 | 5.8 | 1.00 | **-** | | 2.12 | 1.00 | 2.81 | 1.00 |
| Source | (Raffoil 1991) | (Raffoil 1991) | (L-B-Systemtechnik et al. 2002) | (Jess 1996; Jungbluth 2007) | Wang et al. 2004 | Moretti et al. 2017: Av method | Moretti et al. 2017: Value | Moretti et al. 2017: Value | **Estimate in this study** | | Calculated for this study | Calculated | Calculated for this study | Calculated |

1) For petro-chemistry
2) Estimation

For the allocation of electricity to refinery products, only old values from a Swiss refinery are available (Tab. 13.3). It has been shown that the energy-intensive finishing processes result in a higher process energy requirement for these products.

Tab. 13.3 Specific electricity requirements for refinery products and electricity factors derived for Switzerland and Europe. The factor describes the ratio of electricity demand for a product to average demand of the refinery.

| Product | Electricity use | **Electricity factor** |
|---|---|---|
| | $MJ_e/kg_{Output}$ | **-** |
| Bitumen (petroleum coke) | 0.12 | **1.11** |
| Heating oil (medium/heavy) | 0.10 | **0.90** |
| Heating oil extra light | 0.08 | **0.70** |
| Diesel | 0.08 | **0.70** |
| Kerosene | 0.07 | **0.60** |
| Petrol | 0.18 | **1.59** |
| Naphtha [1]) | 0.18 | **1.59** |
| Propane/ Butane | 0.16 | **1.41** |
| Fuel Gas | 0.11 | **0.95** |
| Sulphur | - | **1.0 [1])** |
| **Refinery average** | 0.11 | **1.0** |
| Source | (Raffoil 1991) | **(Raffoil 1991)** |

[1]) estimate

Different publications on the allocation of fuel and electricity to refinery products show quite diverging results. Updating the assumptions was not in the focus of this study as in parallel a detailed refinery model is developed for the ecoinvent v3 database. This should replace in future also the assumptions taken in this study.

## 13.3 Catalysts

The distribution of the amount of catalyst to different products is estimated on the basis of the data on the used amount and elemental content in a publication by the IPPC (IPPC 2001: Tab. 9.3 and Tab. 9.4, see Tab. 13.4 below).

Based on the energy and material flow analysis of the Raffoil refinery, specific metal consumption can be attributed to the individual refinery products by means of dimensionless factors. The procedure is the same as for energy consumption. It is shown that light products such as motor gasoline and propane/butane have high specific metal and carrier material requirements.

Tab. 13.4 Factors for allocation of metals and carrier materials from refinery catalysts to the products

| | Bitumen | HFO | LFO | Kerosene | Petrol | Propane, Butane | Refinery gas |
|---|---|---|---|---|---|---|---|
| Cobalt | 0.0 | 0.0 | 2.5 | 0.0 | 0.0 | 0.0 | 0.0 |
| Molybdenum | 0.0 | 0.0 | 0.4 | 1.8 | 2.0 | 2.0 | 2.0 |
| Nickel | 0.0 | 0.0 | 0.0 | 2.2 | 2.4 | 2.4 | 2.4 |
| Palladium [1]) | 0.0 | 0.0 | 0.0 | 0.0 | 3.7 | 0.8 | 0.9 |
| Platine | 0.0 | 0.0 | 0.0 | 0.0 | 3.7 | 0.8 | 0.9 |
| Rhenium | 0.0 | 0.0 | 0.0 | 0.0 | 3.8 | 0.2 | 1.2 |
| Rhodium [1]) | 0.0 | 0.0 | 0.0 | 0.0 | 3.7 | 0.8 | 0.9 |
| Chloride | 0.0 | 0.0 | 0.0 | 0.0 | 3.8 | 0.2 | 1.2 |
| Zeolite | 0.0 | 1.1 | 0.4 | 0.7 | 2.1 | 1.3 | 1.4 |

[1]): the same factors as assumed for platinum

## 13.4 Semi-finished products and operating materials

Some semi-finished products are only used for one of the refinery products and thus 100% is allocated to this product. For all other inputs an allocation by mass of output has been applied.

## 13.5 Emissions to water

In the former study the pollution of the waste water partial streams was transferred to the products (Jungbluth 2007). Analogous to the procedure for energy-related emissions into the atmosphere, the factors are rounded generously to consider the different complexity of the refineries. In contrast to energy, emissions are more evenly distributed, and the heavy fractions tend to cause lower emissions. The waste water loads of the individual sub-processes were allocated by mass. The factors are shown in Tab. 13.5. A factor of 1 means emissions for a specific product equal the average emissions. Other factors describe below or above emission intensity. For the other emitters (sulphides and other trace elements) the waste water factors are set as 1.

Tab. 13.5 Product-specific factors for water emissions from a refinery. Factor of 1 for average emissions, others factors show multiplication for below or above average emission intensity

| | Bitumen | Heating oil heavy | Heating oil extra light, diesel | Kerosene | Petrol | Propane, Butane | Refinery gas |
|---|---|---|---|---|---|---|---|
| Ammonium-N | 0.5 | 0.5 | 1.1 | 1.0 | 1.1 | 1.1 | 1.1 |
| AOX | 0.9 | 0.9 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 |
| Benzene | 0.9 | 0.9 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 |
| BSB5 | 0.4 | 0.5 | 1.1 | 1.0 | 1.1 | 1.1 | 1.1 |
| Calcium | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 |
| Chloride | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 |
| Chrome | 1.0 | 1.1 | 1.0 | 0.9 | 1.0 | 1.0 | 1.0 |
| CSB | 0.2 | 0.3 | 1.2 | 1.0 | 1.2 | 1.2 | 1.2 |
| Iron | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 |
| Ethylbenzene | 1.1 | 1.1 | 1.0 | 0.9 | 1.0 | 1.0 | 1.0 |
| Total-BTEX | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 |
| Total-Cyanide | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 |
| Total-KW | 0.3 | 0.3 | 1.2 | 1.1 | 1.2 | 1.2 | 1.2 |
| Total-N | 0.5 | 0.5 | 1.1 | 1.0 | 1.1 | 1.1 | 1.1 |
| $H_2S$ | 0.1 | 0.1 | 1.2 | 1.1 | 1.2 | 1.2 | 1.2 |
| potassium | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 |
| copper | 1.0 | 1.1 | 1.0 | 0.9 | 1.0 | 1.0 | 1.0 |
| Magnesium | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 |
| mercaptans | 0.8 | 0.8 | 1.1 | 1.0 | 1.1 | 1.1 | 1.1 |
| MTBE | 0 | 0 | 0 | 0 | 1.0 | 0 | 0 |
| sodium | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 |
| Nitrate-N | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 |
| organically bound N | 0.3 | 0.3 | 1.2 | 1.1 | 1.2 | 1.2 | 1.2 |
| Phenol | 1.4 | 1.7 | 0.9 | 0.6 | 0.9 | 0.9 | 0.9 |
| mercury | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 |
| Selene | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 |
| Sulphides | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 |
| Sulphates | 0.9 | 0.9 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 |
| TOC | 0.4 | 0.5 | 1.1 | 1.0 | 1.1 | 1.1 | 1.1 |
| Toluene | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 |
| Vanadium | 1.0 | 1.1 | 1.0 | 0.9 | 1.0 | 1.0 | 1.0 |
| Xylene | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 |
| Zinc | 1.0 | 1.1 | 1.0 | 0.9 | 1.0 | 1.0 | 1.0 |

## 13.6 Waste

The allocation of waste arising from the catalyst support material (more than 99% by weight of the total catalyst mass) is based on the factors given in Tab. 13.6. Other waste is allocated according to product weights.

Tab. 13.6 Factor for dividing up the amount of carrier material on catalysts (Frischknecht et al. 1996: Tab. IV.9.64)

| Product | Zeolite Factor |
|---|---|
| | - |
| Bitumen | 0.0 |
| Heavy fuel oil | 1.1 |
| Light fuel oil/ Diesel | 0.4 |
| Kerosene | 0.7 |
| Petrol | 2.1 |
| Propane/ Butane | 1.3 |
| Fuel Gas | 1.4 |
| Refinery | 1.0 |

# 14 Summary of the life cycle inventory data

All inventory data are documented in a large excel table. It is not possible to extract them in a format that can be easily copied to this report. Therefore, a separate PDF is generated showing these data. This is attached to this report at the end.

# 15 Data quality

The data quality of the updated life cycle inventories for refinery processing is generally very good. The data for the environmentally relevant inputs and outputs are based on current references. Different sources of information have been cross checked. The module is also essentially complete in terms of possible environmental factors. The list of air and water emissions was further increased compared to the former version of the data. Furthermore, it has now been checked that the input-output balance for inputs of crude oil and additives equals the amount of products sold or used internally.

The complexity of a refinery is relatively high, and the variety of plant types is also relevant. In individual cases, there can be considerable deviations from the figures published here.

Most of the data comes from European or Swiss statistics, environmental reports and direct contacts with refinery operators in Europe. In addition, it was also possible to use area-wide investigations of the oil industry for relevant pollutants.

The most important aspect is the allocation of crude oil to products. This is now based on the energy content which better reflects the purpose of most refinery products. Only bitumen, sulphur and partly naphtha are products which are not mainly used as fuels. The allocation of energy and catalytic converters, combustion-related emissions and water pollutants was based on a simplified model which was not updated since 2003. The model assumptions are based on energy and material flows of a European refinery but are already 15-20 years old. Especially for the allocation of internal energy uses an in-depth investigation would be recommended as the results of different literature sources vary considerably and are hard to interpret. A new model is elaborated in parallel by the ecoinvent centre and thus, for this study, not much resources have been spent on this issue.

The infrastructure expenditures are to be understood as a rough estimate. Reliable literature data could hardly be found.

It must be noted that the European refinery modelled here represents the average European production of refinery products. Refinery products imported to Switzerland might show a different environmental profile as the share of different refinery locations and thus the share of different origins of crude oil is different from this average European situation (see chapter 2.3).

# 16 Datasets to be replaced in v2.2

Some datasets names used in the former version v2.2 are not adequate anymore. There is no leaded petrol on the market and thus “unleaded” does not have to be specified. Also, today all products in Europe have low-sulphur content. Therefore, the following replacements should be made for older inventories.

- diesel, low-sulphur -→ diesel
- petrol, unleaded → petrol (replace)
- petrol, low-sulphur → petrol (change name)

# 17 Life cycle impact assessment

Tab. 17.1 shows the key indicator results for the refinery products which have been investigated in this report.

Supply of crude oil to the refinery is the dominant factor for most environmental indicators. Second most important is the combustion of fuels meeting the internal energy demand of the refinery. Direct emissions and the use of materials are of minor importance.

Some findings are:

- European products have slightly higher impacts than products of the Swiss refinery. This is mainly due to the lower internal energy use of the Swiss refinery compared to the European average. However, the difference is less pronounced than in the previous version (Jungbluth 2007).
- Products with a larger lower heating value tend to have higher impacts than these with a lower energy content. This is due to the allocation in the refinery which is based for the most important inputs on the lower heating value of the products.

Tab. 17.1 Key indicator results for the updated processes investigating refinery products for the Swiss and European market in 2016 (red marks highest and green lowest values per column of special interest)

| 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 | CO2 equivalents |
|---|---|---|---|---|---|---|---|---|---|
| | | MJ-eq | MJ-eq | MJ-eq | MJ-eq | kg CO2-eq | eco-points 2013 | MJ-eq/MJ | kg CO2-eq/MJ |
| benzene/CH | kg | 56.9 | 55.8 | 0.86 | 0.24 | 0.80 | 1'353 | 1.37 | 19.8 |
| bitumen/RER | kg | 51.2 | 50.4 | 0.63 | 0.22 | 0.72 | 1'140 | 1.24 | 17.6 |
| diesel/CH | kg | 55.0 | 54.3 | 0.57 | 0.18 | 0.83 | 1'317 | 1.26 | 19.3 |
| diesel/RER | kg | 54.6 | 53.8 | 0.56 | 0.20 | 0.80 | 1'233 | 1.25 | 18.6 |
| heavy fuel oil/CH | kg | 52.2 | 51.4 | 0.61 | 0.18 | 0.76 | 1'233 | 1.25 | 18.4 |
| heavy fuel oil/RER | kg | 51.6 | 50.8 | 0.58 | 0.20 | 0.72 | 1'144 | 1.23 | 17.4 |
| kerosene/CH | kg | 55.2 | 54.5 | 0.54 | 0.17 | 0.83 | 1'321 | 1.26 | 19.3 |
| kerosene/RER | kg | 54.7 | 54.0 | 0.54 | 0.20 | 0.80 | 1'234 | 1.25 | 18.5 |
| light fuel oil/CH | kg | 54.9 | 54.2 | 0.57 | 0.18 | 0.83 | 1'315 | 1.26 | 19.3 |
| light fuel oil/RER | kg | 54.5 | 53.7 | 0.56 | 0.20 | 0.80 | 1'231 | 1.25 | 18.6 |
| naphtha/CH | kg | 56.9 | 55.8 | 0.86 | 0.24 | 0.80 | 1'353 | 1.24 | 17.9 |
| naphtha/RER | kg | 56.3 | 55.2 | 0.78 | 0.26 | 0.77 | 1'258 | 1.23 | 17.0 |
| petrol/CH | kg | 56.0 | 54.9 | 0.87 | 0.25 | 0.89 | 1'388 | 1.29 | 21.0 |
| petrol/RER | kg | 56.1 | 55.0 | 0.79 | 0.27 | 0.91 | 1'341 | 1.29 | 21.4 |
| petroleum coke/RER | kg | 40.7 | 39.9 | 0.55 | 0.19 | 0.60 | 926 | 1.26 | 18.9 |
| propane/ butane/CH | kg | 60.4 | 59.3 | 0.88 | 0.26 | 0.97 | 1'485 | 1.29 | 21.0 |
| propane/ butane/RER | kg | 60.5 | 59.3 | 0.85 | 0.29 | 0.98 | 1'431 | 1.29 | 21.4 |
| refinery gas/CH | kg | 62.3 | 61.4 | 0.70 | 0.21 | 0.94 | 1'494 | 1.26 | 19.2 |
| refinery gas/RER | kg | 61.8 | 60.9 | 0.67 | 0.24 | 0.90 | 1'399 | 1.25 | 18.6 |

In Tab. 17.2, results for refined oil products, modelled in this study, are compared with the results in the former version of available production data (Jungbluth 2007; KBOB v2.2: 2016).

Some findings are:

- There is an increase of eco-points for Swiss products and a decrease for European products. Thus, differences between European and Swiss products are less pronounced. This is due to harmonization of assumptions (e.g. concerning emission factors for refinery furnaces) for which differences could not be proofed anymore. Other reasons might also be the change of data e.g. shut down of one of the two refineries and changes in the crude oil supply mix.
- There is a huge increase of the GWP for all products due to new data for venting emissions during crude oil extraction.
- There is no clear trend for the fossil energy demand of the different products. Changes here also due to changes in the allocation factors for crude oil input and internal energy use.
- The increase on renewable energy is due to the introduction of biogenic fuels in Europe and Switzerland. These are used in transport processes e.g. of materials and crude oil used by the refinery.

Tab. 17.2 LCIA-comparison of updated and former datasets for refinery products (red marks highest and green lowest values across this table)

| 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 | -3.0% | -3.5% | 42.3% | 69.1% | 30.4% | -13.5% |
| diesel/CH | 0 | 3.5% | 3.0% | 43.1% | 65.5% | 51.0% | 20.0% |
| diesel/RER | 0 | -0.5% | -1.0% | 39.5% | 71.2% | 30.8% | -12.0% |
| heavy fuel oil/RER | 0 | -4.0% | -4.5% | 38.8% | 67.4% | 30.1% | -14.4% |
| kerosene/CH | 0 | 3.8% | 3.4% | 40.2% | 63.9% | 51.4% | 20.4% |
| kerosene/RER | 0 | 0.3% | -0.1% | 39.3% | 72.3% | 31.7% | -11.4% |
| light fuel oil/CH | 0 | 3.3% | 2.9% | 43.0% | 65.3% | 50.8% | 19.8% |
| light fuel oil/RER | 0 | -0.4% | -0.8% | 39.8% | 71.5% | 31.0% | -11.9% |
| naphtha/CH | 0 | 7.8% | 7.0% | 66.7% | 82.5% | 58.8% | 24.9% |
| naphtha/RER | 0 | 4.7% | 4.0% | 51.9% | 77.4% | 40.8% | -6.4% |
| petrol/CH | 0 | 1.3% | 0.7% | 47.6% | 61.2% | 30.1% | 14.5% |
| petrol/RER | 0 | -2.6% | -3.3% | 39.6% | 63.6% | 13.0% | -15.7% |
| propane/ butane/CH | 0 | 11.1% | 10.4% | 62.2% | 78.5% | 56.6% | 27.4% |
| propane/ butane/RER | 0 | 6.9% | 6.3% | 49.2% | 74.1% | 34.2% | -6.2% |
| refinery gas/CH | 0 | 15.0% | 14.5% | 57.8% | 81.0% | 53.4% | 29.3% |
| refinery gas/RER | 0 | 9.7% | 9.2% | 50.3% | 82.8% | 26.0% | -7.4% |

# 18 Outlook

The data used for European refinery products imported to Switzerland do not fully reflect the real situation concerning such imports. A proposal to improve the situation would be to model refinery processes in different European regions (North Sea, Mediterranean Sea, Eastern Europe, etc.). Like this it would also be possible, to better reflect the origin of crude oil for products used in Switzerland.

Refinery sites in North America are relevant for the supply situation of diesel in Europe and should therefore be considered in a future update.

For simplification it would be recommended to make an inventory of the additives for specific products in the next version directly on the next stage of LCI (Jungbluth & Meili 2018).

Allocation factors for the internal energy uses in the refinery need further clarification. If there is newer and more transparent literature available this should be considered.

# 19 Export of mineral oil products to African countries

A special topic is the delivery of diesel fuels produced in European refineries (mainly in the North Sea region) with extremely high sulphur content to the African market. These products are linked to Swiss traders of oil products (Guéniat et al. 2016).

While researching trade flows for a study (Guéniat et al. 2016), it was found that Belgian and Dutch statistics sort diesel exports according to their sulphur content. They provide four categories: below 10 ppm; between 10 and 20 ppm; between 20 and 1000 ppm; and, finally, above 1000 ppm. Statistics on these categories show that products with high sulphur content are exported to Africa. At least 61 percent of the total high sulphur diesel (over 1000 ppm) exported from Belgium and the Netherlands was delivered to Africa in 2014. And this figure is likely to be even higher because a further 12 percent of exports went to Gibraltar, which is a transit hub between the European refineries and Africa or Asia. Overall, this makes Africa the largest user for low quality fuel produced in Europe (Guéniat et al. 2016).

So far, such fuels for export are not investigated here. It is recommended to check the real sulphur content if the products modelled in this chapter are used in inventories related to other continents than Europe.

# 20 References

## 20.1 Emission inventories

Data for the total emissions at Varo Cressier are available online in S-PRTR.[28] The same data are found on the European E-PRTR.[29]

Air pollutant emission estimation methods for E-PRTR reporting by refineries: https://www.concawe.eu/wp-content/uploads/2017/04/Rpt_17-4.pdf. Data are published online, but it was not easily possible to use them for estimation of average emissions.

Water use and trends in emissions to water from EU refineries: https://www.concawe.eu/wp-content/uploads/2017/01/3_FINAL_Concawe-symposium-water-use-and-effluent-trends-20-02-15.pdf

Refinery BREF related environmental parameters for aqueous discharges from refineries in Europe https://www.concawe.eu/wp-content/uploads/2017/01/report-no.-2_10.pdf

Integrated Pollution Prevention and Control (IPPC) Reference Document on Best Available Techniques for Mineral Oil and Gas Refineries http://eippcb.jrc.ec.Europe.eu/reference/BREF/ref_bref_0203.pdf

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# 21 Annexe (Compilation of unit process raw data)

The unit process raw data (inventory data) of the Swiss and European refinery are directly printed out from Excel and are provided as an attachment to this report.

| | Name | Location | Category | SubCategory | InfrastructureProcess | Unit | crude oil, in refinery | | | | petrol, at refinery | diesel, at refinery | light fuel oil, at refinery | heavy fuel oil, at refinery | kerosene, at refinery | benzene, at refinery | naphtha, at refinery | propane/ butane, at refinery | secondary sulphur, at refinery | refinery gas, at refinery |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Location | | | | | | CH | | | | CH | CH | CH | CH | CH | CH | CH | CH | CH | CH |
| | InfrastructureProcess | | | | | | 0 | | | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | Unit | | | | | | kg | | | | kg | kg | kg | kg | kg | kg | kg | kg | kg | kg |
| products | petrol, at refinery | CH | - | - | 0 | kg | 2.31E-1 | | | Varo 2016 | 100 | - | - | - | - | - | - | - | - | - |
| | diesel, at refinery | CH | - | - | 0 | kg | 2.92E-1 | | | Varo 2016 | - | 100 | - | - | - | - | - | - | - | - |
| | light fuel oil, at refinery | CH | - | - | 0 | kg | 2.75E-1 | | | Varo 2016 | - | - | 100 | - | - | - | - | - | - | - |
| | heavy fuel oil, at refinery | CH | - | - | 0 | kg | 1.21E-1 | | | Varo 2016 | - | - | - | 100 | - | - | - | - | - | - |
| | kerosene, at refinery | CH | - | - | 0 | kg | 1.45E-2 | | | Varo 2016 | - | - | - | - | 100 | - | - | - | - | - |
| | benzene, at refinery | CH | - | - | 0 | kg | 9.05E-3 | | | Varo 2016 | - | - | - | - | - | 100 | - | - | - | - |
| | naphtha, at refinery | CH | - | - | 0 | kg | 1.84E-3 | | | Varo 2016 | - | - | - | - | - | - | 100 | - | - | - |
| | propane/ butane, at refinery | CH | - | - | 0 | kg | 3.59E-2 | | | Varo 2016 | - | - | - | - | - | - | - | 100 | - | - |
| | secondary sulphur, at refinery | CH | - | - | 0 | kg | 1.81E-3 | | | Varo 2016 | - | - | - | - | - | - | - | - | 100 | - |
| | petroleum coke, at refinery | CH | - | - | 0 | kg | 0 | | | Varo 2016 | - | - | - | - | - | - | - | - | - | - |
| | refinery gas, at refinery | CH | - | - | 0 | kg | 4.21E-2 | | | Varo 2016 | - | - | - | - | - | - | - | - | - | 100 |
| | bitumen, at refinery | CH | - | - | 0 | kg | 0 | | | Varo 2016 | - | - | - | - | - | - | - | - | - | - |
| | electricity, at refinery | CH | - | - | 0 | kWh | 0 | | | Varo 2016 | - | - | - | - | - | - | - | - | - | - |
| resource, in water | Water, unspecified natural origin, CH | - | resource | in water | - | m3 | 1.38E-4 | 1 | 1.05 | (1,1,1,1,1,1); Varo 2016 | 22.57 | 28.49 | 26.84 | 11.83 | 1.42 | 0.88 | 0.18 | 3.50 | 0.18 | 4.11 |
| | Water, cooling, unspecified natural origin, CH | - | resource | in water | - | m3 | 3.69E-4 | 1 | 1.05 | (1,1,1,1,1,1); Varo 2016 | 22.57 | 28.49 | 26.84 | 11.83 | 1.42 | 0.88 | 0.18 | 3.50 | 0.18 | 4.11 |
| water discharge | Water, CH | - | water | river | - | m3 | 5.22E-4 | 1 | 1.50 | (1,1,1,1,1,1); Varo 2016 | 22.57 | 28.49 | 26.84 | 11.83 | 1.42 | 0.88 | 0.18 | 3.50 | 0.18 | 4.11 |
| crude input | crude oil, import mix, at long distance transport | CH | - | - | 0 | kg | 1.00E+0 | 1 | 1.05 | (1,1,1,1,1,1); Varo 2016 | 22.37 | 28.50 | 26.78 | 11.34 | 1.42 | 0.92 | 0.19 | 3.75 | 0.08 | 4.65 |
| energy | electricity, medium voltage, at grid | CH | - | - | 0 | kWh | 4.24E-2 | 1 | 1.05 | (1,1,1,1,1,1); Varo 2016 | 37.06 | 20.60 | 19.40 | 11.00 | 0.88 | 1.45 | 0.30 | 5.10 | 0.18 | 4.03 |
| | natural gas, burned in industrial furnace low-NOx >100kW | RER | - | - | 0 | MJ | 0 | 1 | 1.16 | (2,4,1,3,1,4); Not used | 29.47 | 26.58 | 25.03 | 7.72 | 1.32 | 0.49 | 0.10 | 4.90 | 0.16 | 4.22 |
| | refinery gas, burned in furnace | CH | - | - | 0 | MJ | 2.09E+0 | 1 | 1.05 | (1,1,1,1,1,1); Varo 2016 | 29.47 | 26.58 | 25.03 | 7.72 | 1.32 | 0.49 | 0.10 | 4.90 | 0.16 | 4.22 |
| | heavy fuel oil, burned in refinery furnace | CH | - | - | 0 | MJ | 7.81E-2 | 1 | 1.05 | (1,1,1,1,1,1); Varo 2016 | 29.47 | 26.58 | 25.03 | 7.72 | 1.32 | 0.49 | 0.10 | 4.90 | 0.16 | 4.22 |
| | petroleum coke, burned in refinery furnace | CH | - | - | 0 | MJ | 0 | 1 | 1.09 | (2,1,1,1,1,3); Swiss statistic | 29.47 | 26.58 | 25.03 | 7.72 | 1.32 | 0.49 | 0.10 | 4.90 | 0.16 | 4.22 |
| | refinery gas, burned in flare | GLO | - | - | 0 | MJ | 0 | 1 | 1.16 | (2,4,1,3,1,4); Swiss plant | 29.47 | 26.58 | 25.03 | 7.72 | 1.32 | 0.49 | 0.10 | 4.90 | 0.16 | 4.22 |
| | tap water, unspecified natural origin CH, at user | CH | - | - | 0 | kg | 1.52E-2 | 1 | 1.10 | (2,3,1,3,1,3); Average of plant data | 22.57 | 28.49 | 26.84 | 11.83 | 1.42 | 0.88 | 0.18 | 3.50 | 0.18 | 4.11 |
| chemicals | ammonia, liquid, at regional storehouse | RER | - | - | 0 | kg | 2.00E-6 | 1 | 1.13 | (3,1,1,3,1,3); Estimation for Europe | 22.61 | 28.54 | 26.89 | 11.85 | 1.42 | 0.88 | 0.18 | 3.51 | - | 4.12 |
| | calcium chloride, CaCl2, at plant | RER | - | - | 0 | kg | 1.62E-5 | 1 | 1.13 | (3,1,1,3,1,3); Estimation for Europe | 22.57 | 28.49 | 26.84 | 11.83 | 1.42 | 0.88 | 0.18 | 3.50 | 0.18 | 4.11 |
| | chlorine, liquid, production mix, at plant | RER | - | - | 0 | kg | 4.20E-5 | 1 | 1.13 | (3,1,1,3,1,3); Estimation for Europe | 89.87 | - | - | - | - | 3.52 | 0.72 | 0.73 | - | 5.17 |
| | chemicals organic, at plant | GLO | - | - | 0 | kg | 3.00E-4 | 1 | 1.13 | (3,1,1,3,1,3); Estimation for Europe | 12.71 | 37.36 | 36.84 | 6.66 | 0.85 | 0.99 | 0.20 | 1.97 | 0.10 | 2.31 |
| | hydrochloric acid, 30% in H2O, at plant | RER | - | - | 0 | kg | 8.90E-5 | 1 | 1.13 | (3,1,1,3,1,3); Estimation for Europe | 22.57 | 28.49 | 26.84 | 11.83 | 1.42 | 0.88 | 0.18 | 3.50 | 0.18 | 4.11 |
| | iron sulphate, at plant | RER | - | - | 0 | kg | 5.00E-5 | 1 | 1.13 | (3,1,1,3,1,3); Estimation for Europe | 22.57 | 28.49 | 26.84 | 11.83 | 1.42 | 0.88 | 0.18 | 3.50 | 0.18 | 4.11 |
| | lime, hydrated, packed, at plant | CH | - | - | 0 | kg | 3.50E-5 | 1 | 1.13 | (3,1,1,3,1,3); Estimation for Europe | 22.57 | 28.49 | 26.84 | 11.83 | 1.42 | 0.88 | 0.18 | 3.50 | 0.18 | 4.11 |
| | lubricating oil, at plant | RER | - | - | 0 | kg | 1.23E-5 | 1 | 1.13 | (3,1,1,3,1,3); Estimation for Europe | 22.57 | 28.49 | 26.84 | 11.83 | 1.42 | 0.88 | 0.18 | 3.50 | 0.18 | 4.11 |
| | naphtha, at refinery | RER | - | - | 0 | kg | 2.38E-2 | 1 | 1.13 | (3,1,1,3,1,3); Estimation for Europe | 22.37 | 28.50 | 26.78 | 11.34 | 1.42 | 0.92 | 0.19 | 3.75 | 0.08 | 4.65 |
| | nitrogen, liquid, at plant | RER | - | - | 0 | kg | 1.13E-3 | 1 | 1.13 | (3,1,1,3,1,3); Estimation for Europe | 22.57 | 28.49 | 26.84 | 11.83 | 1.42 | 0.88 | 0.18 | 3.50 | 0.18 | 4.11 |
| | propylene glycol, liquid, at plant | RER | - | - | 0 | kg | 6.00E-6 | 1 | 1.13 | (3,1,1,3,1,3); Estimation for Europe | 87.64 | 3.07 | 2.89 | 1.28 | 0.15 | 3.43 | 0.70 | 0.38 | 0.02 | 0.44 |
| | soap, at plant | RER | - | - | 0 | kg | 2.68E-6 | 1 | 1.13 | (3,1,1,3,1,3); Estimation for Europe | 22.57 | 28.49 | 26.84 | 11.83 | 1.42 | 0.88 | 0.18 | 3.50 | 0.18 | 4.11 |
| | sodium hypochlorite, 15% in H2O, at plant | RER | - | - | 0 | kg | 5.00E-5 | 1 | 1.13 | (3,1,1,3,1,3); Estimation for Europe | 22.57 | 28.49 | 26.84 | 11.83 | 1.42 | 0.88 | 0.18 | 3.50 | 0.18 | 4.11 |
| | sodium hydroxide, 50% in H2O, production mix, at plant | RER | - | - | 0 | kg | 2.45E-4 | 1 | 1.13 | (3,1,1,3,1,3); Estimation for Europe | - | - | - | - | - | - | - | 100.00 | - | - |
| | sulphuric acid, liquid, at plant | RER | - | - | 0 | kg | 9.69E-6 | 1 | 1.13 | (3,1,1,3,1,3); Estimation for Europe | 22.57 | 28.49 | 26.84 | 11.83 | 1.42 | 0.88 | 0.18 | 3.50 | 0.18 | 4.11 |
| resource, in ground | Rhenium | - | resource | in ground | - | kg | 8.01E-10 | 1 | 1.13 | (3,1,1,3,1,3); Estimation for Europe | 93.84 | - | - | - | - | - | - | 0.77 | - | 5.39 |
| catalysts | molybdenum, at regional storage | RER | - | - | 0 | kg | 4.05E-8 | 1 | 1.13 | (3,1,1,3,1,3); Estimation for Europe | 58.78 | 14.84 | - | - | 3.32 | 2.30 | 0.47 | 9.12 | 0.46 | 10.70 |
| | cobalt, at plant | GLO | - | - | 0 | kg | 1.07E-8 | 1 | 1.13 | (3,1,1,3,1,3); Estimation for Europe | - | 51.50 | 48.50 | - | - | - | - | - | - | - |
| | nickel, 99.5%, at plant | GLO | - | - | 0 | kg | 6.00E-9 | 1 | 1.13 | (3,1,1,3,1,3); Estimation for Europe | 69.36 | - | - | - | 3.99 | 2.71 | 0.55 | 10.76 | - | 12.63 |
| | palladium, at regional storage | RER | - | - | 0 | kg | 2.53E-8 | 1 | 1.13 | (3,1,1,3,1,3); Estimation for Europe | 88.89 | - | - | - | - | 3.48 | 0.71 | 2.98 | - | 3.94 |
| | platinum, at regional storage | RER | - | - | 0 | kg | 8.01E-10 | 1 | 1.13 | (3,1,1,3,1,3); Estimation for Europe | 88.89 | - | - | - | - | 3.48 | 0.71 | 2.98 | - | 3.94 |
| | rhodium, at regional storage | RER | - | - | 0 | kg | 8.01E-10 | 1 | 1.13 | (3,1,1,3,1,3); Estimation for Europe | 88.89 | - | - | - | - | 3.48 | 0.71 | 2.98 | - | 3.94 |
| | zeolite, powder, at plant | RER | - | - | 0 | kg | 9.92E-6 | 1 | 1.13 | (3,1,1,3,1,3); Estimation for Europe | 49.34 | 11.86 | 11.17 | 13.54 | 1.03 | 1.93 | 0.39 | 4.74 | - | 5.99 |
| | zinc, primary, at regional storage | RER | - | - | 0 | kg | 1.07E-7 | 1 | 1.13 | (3,1,1,3,1,3); Estimation for Europe | 49.34 | 11.86 | 11.17 | 13.54 | 1.03 | 1.93 | 0.39 | 4.74 | - | 5.99 |
| transport | transport, lorry >16t, fleet average | RER | - | - | 0 | tkm | 1.99E-4 | 1 | 2.02 | (3,1,1,3,1,3); Estimation for Europe | 22.57 | 28.49 | 26.84 | 11.83 | 1.42 | 0.88 | 0.18 | 3.50 | 0.18 | 4.11 |
| | transport, freight, rail | RER | - | - | 0 | tkm | 1.20E-3 | 1 | 2.02 | (3,1,1,3,1,3); Estimation for Europe | 22.57 | 28.49 | 26.84 | 11.83 | 1.42 | 0.88 | 0.18 | 3.50 | 0.18 | 4.11 |
| | refinery | RER | - | - | 1 | unit | 3.33E-11 | 1 | 3.02 | (3,1,1,3,1,3); Estimation for Europe | 29.47 | 26.58 | 25.03 | 7.72 | 1.32 | 0.49 | 0.10 | 4.90 | 0.16 | 4.22 |
| waste | disposal, municipal solid waste, 22.9% water, to municipal incineration | CH | - | - | 0 | kg | 1.95E-5 | 1 | 1.05 | (1,1,1,1,1,1); Varo 2016 | 22.57 | 28.49 | 26.84 | 11.83 | 1.42 | 0.88 | 0.18 | 3.50 | 0.18 | 4.11 |
| | disposal, refinery sludge, 89.5% water, to hazardous waste incineration | CH | - | - | 0 | kg | 3.96E-4 | 1 | 1.05 | (1,1,1,1,1,1); Varo 2016 | 22.57 | 28.49 | 26.84 | 11.83 | 1.42 | 0.88 | 0.18 | 3.50 | 0.18 | 4.11 |
| | disposal, catalytic converter NOx reduction, 0% water, to underground deposit | DE | - | - | 0 | kg | 1.00E-6 | 1 | 1.13 | (3,1,1,3,1,3); Estimation for Europe | 49.34 | 11.86 | 11.17 | 13.54 | 1.03 | 1.93 | 0.39 | 4.74 | - | 5.99 |

| | Name | Location | Category | SubCategory | InfrastructureProc | Unit | *crude oil, in refinery* | | | | *petrol, at refinery* | *diesel, at refinery* | *light fuel oil, at refinery* | *heavy fuel oil, at refinery* | *kerosene, at refinery* | *benzene, at refinery* | *naphtha, at refinery* | *propane/ butane, at refinery* | *secondary sulphur, at refinery* | *refinery gas, at refinery* |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Location | | | | | | *CH* | | | | *CH* | *CH* | *CH* | *CH* | *CH* | *CH* | *CH* | *CH* | *CH* | *CH* |
| | InfrastructureProcess | | | | | | *0* | | | | *0* | *0* | *0* | *0* | *0* | *0* | *0* | *0* | *0* | *0* |
| | Unit | | | | | | *kg* | | | | *kg* | *kg* | *kg* | *kg* | *kg* | *kg* | *kg* | *kg* | *kg* | *kg* |
| emission air, high population density | Heat, waste | - | air | high population den | - | MJ | 1.53E-1 | 1 | 1.05 | (1,1,1,1,1,1); Calculation | 29.24 | 26.37 | 24.83 | 7.66 | 1.31 | 1.14 | 0.23 | 4.86 | 0.16 | 4.18 |
| | Ammonia | - | air | high population den | - | kg | 1.10E-6 | 1 | 1.24 | (3,1,1,3,1,3); Estimation for Europe | 22.57 | 28.49 | 26.84 | 11.83 | 1.42 | 0.88 | 0.18 | 3.50 | 0.18 | 4.11 |
| | Benzene | - | air | high population den | - | kg | 1.06E-6 | 1 | 3.06 | (3,1,1,1,3,1); Varo 2016 and European NMVOC profile | 22.61 | 28.54 | 26.89 | 11.85 | 1.42 | 0.88 | 0.18 | 3.51 | - | 4.12 |
| | Benzene, ethyl- | - | air | unspecified | - | kg | 1.16E-7 | 1 | 3.06 | (3,1,1,1,3,1); Varo 2016 and European NMVOC profile | 22.61 | 28.54 | 26.89 | 11.85 | 1.42 | 0.88 | 0.18 | 3.51 | - | 4.12 |
| | Butane | - | air | unspecified | - | kg | 4.64E-6 | 1 | 1.58 | (3,1,1,1,3,1); Varo 2016 and European NMVOC profile | 22.61 | 28.54 | 26.89 | 11.85 | 1.42 | 0.88 | 0.18 | 3.51 | - | 4.12 |
| | Butene | - | air | high population den | - | kg | 1.16E-7 | 1 | 1.58 | (3,1,1,1,3,1); Varo 2016 and European NMVOC profile | 22.61 | 28.54 | 26.89 | 11.85 | 1.42 | 0.88 | 0.18 | 3.51 | - | 4.12 |
| | Dinitrogen monoxide | - | air | high population den | - | kg | 0 | 1 | 1.52 | (3,na,na,na,1,na); Not included because covered in fuel emissions | 29.47 | 26.58 | 25.03 | 7.72 | 1.32 | 0.49 | 0.10 | 4.90 | 0.16 | 4.22 |
| | Ethane | - | air | unspecified | - | kg | 1.16E-6 | 1 | 1.58 | (3,1,1,1,3,1); Varo 2016 and European NMVOC profile | 22.61 | 28.54 | 26.89 | 11.85 | 1.42 | 0.88 | 0.18 | 3.51 | - | 4.12 |
| | Ethene | - | air | unspecified | - | kg | 2.32E-7 | 1 | 1.58 | (3,1,1,1,3,1); Varo 2016 and European NMVOC profile | 22.61 | 28.54 | 26.89 | 11.85 | 1.42 | 0.88 | 0.18 | 3.51 | - | 4.12 |
| | Heptane | - | air | high population den | - | kg | 1.16E-6 | 1 | 1.58 | (3,1,1,1,3,1); Varo 2016 and European NMVOC profile | 22.61 | 28.54 | 26.89 | 11.85 | 1.42 | 0.88 | 0.18 | 3.51 | - | 4.12 |
| | Hexane | - | air | high population den | - | kg | 2.32E-6 | 1 | 1.58 | (3,1,1,1,3,1); Varo 2016 and European NMVOC profile | 22.61 | 28.54 | 26.89 | 11.85 | 1.42 | 0.88 | 0.18 | 3.51 | - | 4.12 |
| | Hydrocarbons, aliphatic, alkanes, unspecified | - | air | unspecified | - | kg | 3.87E-12 | 1 | 1.58 | (3,1,1,1,3,1); Varo 2016 and European NMVOC profile | 22.61 | 28.54 | 26.89 | 11.85 | 1.42 | 0.88 | 0.18 | 3.51 | - | 4.12 |
| | Hydrocarbons, aliphatic, unsaturated | - | air | high population den | - | kg | 2.13E-13 | 1 | 1.58 | (3,1,1,1,3,1); Varo 2016 and European NMVOC profile | 22.61 | 28.54 | 26.89 | 11.85 | 1.42 | 0.88 | 0.18 | 3.51 | - | 4.12 |
| | Hydrocarbons, aromatic | - | air | high population den | - | kg | 5.81E-14 | 1 | 1.58 | (3,1,1,1,3,1); Varo 2016 and European NMVOC profile | 22.61 | 28.54 | 26.89 | 11.85 | 1.42 | 0.88 | 0.18 | 3.51 | - | 4.12 |
| | Methane, fossil | - | air | high population den | - | kg | 4.45E-5 | 1 | 1.52 | (1,1,3,1,1,1); Swiss greenhouse gas inventory 2015 | 22.61 | 28.54 | 26.89 | 11.85 | 1.42 | 0.88 | 0.18 | 3.51 | - | 4.12 |
| | Nickel | - | air | high population den | - | kg | 0 | 1 | 5.01 | (2,1,1,1,1,3); Not included because covered in fuel emissions | 22.61 | 28.54 | 26.89 | 11.85 | 1.42 | 0.88 | 0.18 | 3.51 | - | 4.12 |
| | Nitrogen oxides | - | air | high population den | - | kg | 0 | 1 | 1.51 | (2,1,1,1,1,3); Not included because covered in fuel emissions | 29.47 | 26.58 | 25.03 | 7.72 | 1.32 | 0.49 | 0.10 | 4.90 | 0.16 | 4.22 |
| | Particulates, > 10 um | - | air | high population den | - | kg | 1.50E-5 | 1 | 1.52 | (3,1,1,3,1,3); Estimation for Europe | 22.61 | 28.54 | 26.89 | 11.85 | 1.42 | 0.88 | 0.18 | 3.51 | - | 4.12 |
| | Pentane | - | air | high population den | - | kg | 5.79E-6 | 1 | 1.58 | (3,1,1,1,3,1); Varo 2016 and European NMVOC profile | 22.61 | 28.54 | 26.89 | 11.85 | 1.42 | 0.88 | 0.18 | 3.51 | - | 4.12 |
| | Propane | - | air | high population den | - | kg | 4.64E-6 | 1 | 1.58 | (3,1,1,1,3,1); Varo 2016 and European NMVOC profile | 22.61 | 28.54 | 26.89 | 11.85 | 1.42 | 0.88 | 0.18 | 3.51 | - | 4.12 |
| | Propene | - | air | unspecified | - | kg | 2.32E-7 | 1 | 1.58 | (3,1,1,1,3,1); Varo 2016 and European NMVOC profile | 22.61 | 28.54 | 26.89 | 11.85 | 1.42 | 0.88 | 0.18 | 3.51 | - | 4.12 |
| | Sulfur dioxide | - | air | high population den | - | kg | 0 | 1 | 1.09 | (2,1,1,1,1,3); Not included because covered in fuel emissions | 29.52 | 26.62 | 25.07 | 7.74 | 1.32 | 0.50 | 0.10 | 4.91 | - | 4.22 |
| | Toluene | - | air | high population den | - | kg | 6.95E-7 | 1 | 1.58 | (3,1,1,1,3,1); Varo 2016 and European NMVOC profile | 22.61 | 28.54 | 26.89 | 11.85 | 1.42 | 0.88 | 0.18 | 3.51 | - | 4.12 |
| | Xylene | - | air | unspecified | - | kg | 4.64E-7 | 1 | 1.58 | (3,1,1,1,3,1); Varo 2016 and European NMVOC profile | 22.61 | 28.54 | 26.89 | 11.85 | 1.42 | 0.88 | 0.18 | 3.51 | - | 4.12 |

| | Name | Location | Category | SubCategory | InfrastructureProcess | Unit | *crude oil, in refinery* | | | | *petrol, at refinery* | *diesel, at refinery* | *light fuel oil, at refinery* | *heavy fuel oil, at refinery* | *kerosene, at refinery* | *benzene, at refinery* | *naphtha, at refinery* | *propane/ butane, at refinery* | *secondary sulphur, at refinery* | *refinery gas, at refinery* |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Location | | | | | | *CH* | | | | *CH* | *CH* | *CH* | *CH* | *CH* | *CH* | *CH* | *CH* | *CH* | *CH* |
| | InfrastructureProcess | | | | | | *0* | | | | *0* | *0* | *0* | *0* | *0* | *0* | *0* | *0* | *0* | *0* |
| | Unit | | | | | | *kg* | | | | *kg* | *kg* | *kg* | *kg* | *kg* | *kg* | *kg* | *kg* | *kg* | *kg* |
| emission water, river | Aluminium | - | water | river | - | kg | 1.28E-8 | 1 | 5.02 | (3,1,1,3,1,3); Estimation for Europe | 22.57 | 28.49 | 26.84 | 11.83 | 1.42 | 0.88 | 0.18 | 3.50 | 0.18 | 4.11 |
| | Ammonium, ion | - | water | river | - | kg | 1.20E-6 | 1 | 1.52 | (3,1,1,3,1,3); Estimation for Europe | 24.19 | 30.53 | 28.76 | 5.76 | 1.38 | 0.95 | 0.19 | 3.75 | 0.09 | 4.40 |
| | AOX, Adsorbable Organic Halogen as Cl | - | water | river | - | kg | 6.00E-8 | 1 | 1.52 | (3,1,1,3,1,3); Estimation for Europe | 22.85 | 28.84 | 27.16 | 10.78 | 1.43 | 0.89 | 0.18 | 3.55 | 0.16 | 4.16 |
| | Arsenic | - | water | river | - | kg | 7.00E-10 | 1 | 5.02 | (3,1,1,3,1,3); Estimation for Europe | 22.34 | 28.20 | 26.56 | 12.88 | 1.26 | 0.87 | 0.18 | 3.47 | 0.17 | 4.07 |
| | Barium | - | water | river | - | kg | 2.56E-8 | 1 | 5.02 | (3,1,1,3,1,3); Estimation for Europe | 22.57 | 28.49 | 26.84 | 11.83 | 1.42 | 0.88 | 0.18 | 3.50 | 0.18 | 4.11 |
| | Benzene | - | water | river | - | kg | 2.00E-9 | 1 | 3.02 | (3,1,1,3,1,3); Estimation for Europe | 22.85 | 28.84 | 27.16 | 10.78 | 1.43 | 0.89 | 0.18 | 3.55 | 0.16 | 4.16 |
| | Benzene, ethyl- | - | water | river | - | kg | 4.00E-9 | 1 | 3.02 | (3,1,1,3,1,3); Estimation for Europe | 22.33 | 28.20 | 26.56 | 12.88 | 1.26 | 0.87 | 0.18 | 3.47 | 0.19 | 4.07 |
| | BOD5, Biological Oxygen Demand | - | water | river | - | kg | 4.40E-6 | 1 | 1.52 | (3,1,1,3,1,3); Estimation for Europe | 24.19 | 30.54 | 28.76 | 5.76 | 1.38 | 0.95 | 0.19 | 3.75 | 0.07 | 4.40 |
| | Boron | - | water | river | - | kg | 2.64E-12 | 1 | 5.02 | (3,1,1,3,1,3); Estimation for Europe | 22.57 | 28.49 | 26.84 | 11.83 | 1.42 | 0.88 | 0.18 | 3.50 | 0.18 | 4.11 |
| | Cadmium | - | water | river | - | kg | 1.00E-9 | 1 | 3.02 | (3,1,1,3,1,3); Estimation for Europe | 22.34 | 28.20 | 26.56 | 12.88 | 1.26 | 0.87 | 0.18 | 3.47 | 0.17 | 4.07 |
| | Calcium | - | water | river | - | kg | 1.28E-5 | 1 | 3.02 | (3,1,1,3,1,3); Estimation for Europe | 22.57 | 28.49 | 26.84 | 11.83 | 1.42 | 0.88 | 0.18 | 3.50 | 0.18 | 4.11 |
| | Chloride | - | water | river | - | kg | 1.87E-5 | 1 | 3.68 | (3,1,1,1,5,1); Data Cressier in 2003 | 22.57 | 28.49 | 26.84 | 11.83 | 1.42 | 0.88 | 0.18 | 3.50 | 0.18 | 4.11 |
| | Chromium | - | water | river | - | kg | 1.00E-9 | 1 | 3.02 | (3,1,1,3,1,3); Estimation for Europe | 22.34 | 28.20 | 26.56 | 12.88 | 1.26 | 0.87 | 0.18 | 3.47 | 0.17 | 4.07 |
| | Chromium VI | - | water | river | - | kg | 1.00E-9 | 1 | 3.02 | (3,1,1,3,1,3); Estimation for Europe | 22.34 | 28.20 | 26.56 | 12.88 | 1.26 | 0.87 | 0.18 | 3.47 | 0.17 | 4.07 |
| | COD, Chemical Oxygen Demand | - | water | river | - | kg | 2.72E-5 | 1 | 1.52 | (3,1,1,3,1,3); Estimation for Europe | 24.87 | 31.40 | 29.57 | 3.26 | 1.30 | 0.97 | 0.20 | 3.86 | 0.03 | 4.53 |
| | Cobalt | - | water | river | - | kg | 6.60E-15 | 1 | 3.02 | (3,1,1,3,1,3); Estimation for Europe | 22.34 | 28.20 | 26.56 | 12.88 | 1.26 | 0.87 | 0.18 | 3.47 | 0.17 | 4.07 |
| | Copper | - | water | river | - | kg | 2.00E-9 | 1 | 3.02 | (3,1,1,3,1,3); Estimation for Europe | 22.34 | 28.20 | 26.56 | 12.88 | 1.26 | 0.87 | 0.18 | 3.47 | 0.17 | 4.07 |
| | Cyanide | - | water | river | - | kg | 4.00E-9 | 1 | 3.02 | (3,1,1,3,1,3); Estimation for Europe | 22.57 | 28.49 | 26.84 | 11.83 | 1.42 | 0.88 | 0.18 | 3.50 | 0.18 | 4.11 |
| | DOC, Dissolved Organic Carbon | - | water | river | - | kg | 1.58E-8 | 1 | 1.52 | (3,1,1,3,1,3); Estimation for Europe | 24.19 | 30.54 | 28.76 | 5.76 | 1.38 | 0.95 | 0.19 | 3.75 | 0.07 | 4.40 |
| | Fluoride | - | water | river | - | kg | 6.00E-7 | 1 | 1.52 | (3,1,1,3,1,3); Estimation for Europe | 22.57 | 28.49 | 26.84 | 11.83 | 1.42 | 0.88 | 0.18 | 3.50 | 0.18 | 4.11 |
| | Hydrocarbons, aromatic | - | water | river | - | kg | 1.00E-8 | 1 | 1.52 | (3,1,1,3,1,3); Estimation for Europe | 22.57 | 28.49 | 26.84 | 11.83 | 1.42 | 0.88 | 0.18 | 3.50 | 0.18 | 4.11 |
| | Hydrocarbons, unspecified | - | water | river | - | kg | 2.18E-7 | 1 | 1.50 | (1,1,1,1,1,1); Varo 2016 | 38.75 | 12.23 | 11.52 | 20.31 | 2.23 | 1.52 | 0.31 | 6.01 | 0.08 | 7.05 |
| | Iron | - | water | river | - | kg | 1.50E-7 | 1 | 5.02 | (3,1,1,3,1,3); Estimation for Europe | 22.57 | 28.49 | 26.84 | 11.83 | 1.42 | 0.88 | 0.18 | 3.50 | 0.18 | 4.11 |
| | Lead | - | water | river | - | kg | 5.00E-9 | 1 | 5.02 | (3,1,1,3,1,3); Estimation for Europe | 22.34 | 28.20 | 26.56 | 12.88 | 1.26 | 0.87 | 0.18 | 3.47 | 0.17 | 4.07 |
| | Magnesium | - | water | river | - | kg | 6.39E-6 | 1 | 5.02 | (3,1,1,3,1,3); Estimation for Europe | 22.57 | 28.49 | 26.84 | 11.83 | 1.42 | 0.88 | 0.18 | 3.50 | 0.18 | 4.11 |
| | Manganese | - | water | river | - | kg | 4.00E-8 | 1 | 5.02 | (3,1,1,3,1,3); Estimation for Europe | 22.57 | 28.49 | 26.84 | 11.83 | 1.42 | 0.88 | 0.18 | 3.50 | 0.18 | 4.11 |
| | Mercury | - | water | river | - | kg | 1.00E-10 | 1 | 5.02 | (3,1,1,3,1,3); Estimation for Europe | 22.57 | 28.49 | 26.84 | 11.83 | 1.42 | 0.88 | 0.18 | 3.50 | 0.18 | 4.11 |
| | Molybdenum | - | water | river | - | kg | 6.60E-14 | 1 | 5.02 | (3,1,1,3,1,3); Estimation for Europe | 22.57 | 28.49 | 26.84 | 11.83 | 1.42 | 0.88 | 0.18 | 3.50 | 0.18 | 4.11 |
| | Nickel | - | water | river | - | kg | 3.11E-9 | 1 | 5.78 | (3,1,1,1,5,1); Data Cressier in 2003 | 22.34 | 28.20 | 26.56 | 12.88 | 1.26 | 0.87 | 0.18 | 3.47 | 0.17 | 4.07 |
| | Nitrate | - | water | river | - | kg | 6.20E-6 | 1 | 1.52 | (3,1,1,3,1,3); Estimation for Europe | 22.57 | 28.49 | 26.84 | 11.83 | 1.42 | 0.88 | 0.18 | 3.50 | 0.18 | 4.11 |
| | Nitrite | - | water | river | - | kg | 1.00E-7 | 1 | 1.52 | (3,1,1,3,1,3); Estimation for Europe | 22.57 | 28.49 | 26.84 | 11.83 | 1.42 | 0.88 | 0.18 | 3.50 | 0.18 | 4.11 |
| | Nitrogen, organic bound | - | water | river | - | kg | 4.00E-6 | 1 | 1.52 | (3,1,1,3,1,3); Estimation for Europe | 38.75 | 12.23 | 11.52 | 20.31 | 2.23 | 1.52 | 0.31 | 6.01 | 0.08 | 7.05 |
| | Oils, unspecified | - | water | river | - | kg | 2.08E-7 | 1 | 2.24 | (3,1,1,1,5,1); Data Cressier in 2003 | 38.75 | 12.23 | 11.52 | 20.31 | 2.23 | 1.52 | 0.31 | 6.01 | 0.08 | 7.05 |
| | PAH, polycyclic aromatic hydrocarbons | - | water | river | - | kg | 3.00E-10 | 1 | 3.02 | (3,1,1,3,1,3); Estimation for Europe | 22.85 | 28.84 | 27.16 | 10.78 | 1.43 | 0.89 | 0.18 | 3.55 | 0.16 | 4.16 |
| | Phenol | - | water | river | - | kg | 1.92E-8 | 1 | 3.00 | (1,1,1,1,1,1); Varo 2016 | 20.49 | 25.87 | 24.37 | 20.29 | 0.86 | 0.80 | 0.16 | 3.18 | 0.25 | 3.73 |
| | Phosphate | - | water | river | - | kg | 1.30E-7 | 1 | 1.52 | (3,1,1,3,1,3); Estimation for Europe | 22.57 | 28.49 | 26.84 | 11.83 | 1.42 | 0.88 | 0.18 | 3.50 | 0.18 | 4.11 |
| | Phosphorus | - | water | river | - | kg | 3.00E-7 | 1 | 1.52 | (3,1,1,3,1,3); Estimation for Europe | 22.57 | 28.49 | 26.84 | 11.83 | 1.42 | 0.88 | 0.18 | 3.50 | 0.18 | 4.11 |
| | Potassium | - | water | river | - | kg | 2.56E-6 | 1 | 5.02 | (3,1,1,3,1,3); Estimation for Europe | 22.57 | 28.49 | 26.84 | 11.83 | 1.42 | 0.88 | 0.18 | 3.50 | 0.18 | 4.11 |
| | Selenium | - | water | river | - | kg | 2.64E-13 | 1 | 5.02 | (3,1,1,3,1,3); Estimation for Europe | 22.57 | 28.49 | 26.84 | 11.83 | 1.42 | 0.88 | 0.18 | 3.50 | 0.18 | 4.11 |
| | Silver | - | water | river | - | kg | 1.28E-8 | 1 | 5.02 | (3,1,1,3,1,3); Estimation for Europe | 22.57 | 28.49 | 26.84 | 11.83 | 1.42 | 0.88 | 0.18 | 3.50 | 0.18 | 4.11 |
| | Sodium | - | water | river | - | kg | 7.67E-5 | 1 | 5.02 | (3,1,1,3,1,3); Estimation for Europe | 22.57 | 28.49 | 26.84 | 11.83 | 1.42 | 0.88 | 0.18 | 3.50 | 0.18 | 4.11 |
| | Strontium | - | water | river | - | kg | 1.79E-7 | 1 | 5.02 | (3,1,1,3,1,3); Estimation for Europe | 22.34 | 28.20 | 26.56 | 12.88 | 1.26 | 0.87 | 0.18 | 3.47 | 0.17 | 4.07 |
| | Sulfate | - | water | river | - | kg | 5.11E-5 | 1 | 1.52 | (3,1,1,3,1,3); Estimation for Europe | 22.85 | 28.84 | 27.16 | 10.78 | 1.43 | 0.89 | 0.18 | 3.55 | 0.16 | 4.16 |
| | Sulfide | - | water | river | - | kg | 2.50E-8 | 1 | 1.52 | (3,1,1,3,1,3); Estimation for Europe | 22.57 | 28.49 | 26.84 | 11.83 | 1.42 | 0.88 | 0.18 | 3.50 | 0.18 | 4.11 |
| | Suspended solids, unspecified | - | water | fossil- | - | kg | 6.30E-6 | 1 | 1.52 | (3,1,1,3,1,3); Estimation for Europe | 22.57 | 28.49 | 26.84 | 11.83 | 1.42 | 0.88 | 0.18 | 3.50 | 0.18 | 4.11 |
| | t-Butyl methyl ether | - | water | river | - | kg | 5.00E-9 | 1 | 3.02 | (3,1,1,3,1,3); Estimation for Europe | 100.00 | - | - | - | - | - | - | - | - | - |
| | Tin | - | water | river | - | kg | 4.00E-9 | 1 | 5.02 | (3,1,1,3,1,3); Estimation for Europe | 22.34 | 28.20 | 26.56 | 12.88 | 1.26 | 0.87 | 0.18 | 3.47 | 0.17 | 4.07 |
| | TOC, Total Organic Carbon | - | water | river | - | kg | 5.50E-6 | 1 | 1.52 | (3,1,1,3,1,3); Estimation for Europe | 24.19 | 30.54 | 28.76 | 5.76 | 1.38 | 0.95 | 0.19 | 3.75 | 0.07 | 4.40 |
| | Toluene | - | water | river | - | kg | 4.00E-9 | 1 | 3.02 | (3,1,1,3,1,3); Estimation for Europe | 22.57 | 28.49 | 26.84 | 11.83 | 1.42 | 0.88 | 0.18 | 3.50 | 0.18 | 4.11 |
| | Vanadium | - | water | river | - | kg | 3.00E-9 | 1 | 5.02 | (3,1,1,3,1,3); Estimation for Europe | 22.34 | 28.20 | 26.56 | 12.88 | 1.26 | 0.87 | 0.18 | 3.47 | 0.17 | 4.07 |
| | Xylene | - | water | river | - | kg | 4.00E-9 | 1 | 3.02 | (3,1,1,3,1,3); Estimation for Europe | 22.57 | 28.49 | 26.84 | 11.83 | 1.42 | 0.88 | 0.18 | 3.50 | 0.18 | 4.11 |
| | Zinc | - | water | river | - | kg | 4.06E-8 | 1 | 5.78 | (3,1,1,1,5,1); Data Cressier in 2003 | 22.34 | 28.20 | 26.56 | 12.88 | 1.26 | 0.87 | 0.18 | 3.47 | 0.17 | 4.07 |
| Total products | | | | | | | 1.0242 | | | | 23.1% | 29.2% | 27.5% | 12.1% | 1.5% | 0.9% | 0.2% | 3.6% | 0.2% | 4.2% |
| Total crude oil | | | | | | | 1.0000 | | | | | | | | | | | | | |
| Total additives | | | | | | | 0.0004 | | | | | | | | | | | | | |
| Total add on products | | | | | | | 0.0238 | | | | | | | | | | | | | |
| | *Literature* | | | *river* | | | | | | | | | | | | | | | | |

| | Name | Location | Category | SubCategory | InfrastructureProcess | Unit | mean values | crude oil, in refinery | crude oil, in refinery Cressier | crude oil, in refinery | crude oil, in refinery | crude oil, in refinery | refinery operation, Cressier | crude oil, in refinery Cressier | crude oil, in refinery | crude oil, in refinery Cressier | crude oil, in refinery | refinery operation, Cressier | refinery operation | crude oil, in refinery | crude oil, in refinery Cressier | crude oil in refinery | crude oil, in refinery Collombey | crude oil, in refinery Collombey |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Location | | | | | | CH | CH | CH | CH | RER | CH | CH | CH | CH | CH | CH | CH | CH | CH | CH | CH | CH | CH |
| | InfrastructureProcess | | | | | | 2007 | 2016 | 2016 | 2016 | 2016 | 2015 | 2015 | 2006 | 2016 | 2016 | 2016 | 2015 | 2015 | 2006 | 2006 | 2006 | 2006 | 2006 |
| | Unit | | | | | | kg, mg/l | kg | kg | kg | kg | kg | kg | kg | a | a | a | a | a | a | a | kg, mg/l | kg, mg/l | a |
| products | petrol, at refinery | CH | - | - | 0 | kg | | 2.31E-1 | 2.53E-1 | 2.52E-1 | | | | 2.25E-1 | 6.77E+8 | 7.28E+8 | 7.23E+8 | | | | 6.30E+8 | 2.34E-1 | 2.71E-1 | 4.90E+8 |
| | diesel, at refinery | CH | - | - | 0 | kg | | 2.92E-1 | 3.01E-1 | 3.04E-1 | | | | 4.29E-2 | 8.55E+8 | 8.64E+8 | 8.74E+8 | | | | 1.20E+8 | 1.08E-1 | - | - |
| | light fuel oil, at refinery | CH | - | - | 0 | kg | | 2.75E-1 | 2.80E-1 | 2.85E-1 | | | | - | 8.05E+8 | 8.05E+8 | 8.19E+8 | | | | | 2.88E-1 | 4.02E-1 | 7.26E+8 |
| | heavy fuel oil, at refinery | CH | - | - | 0 | kg | | 1.21E-1 | 1.23E-1 | 1.20E-1 | | | | 4.29E-1 | 3.55E+8 | 3.55E+8 | 3.44E+8 | | | | 1.20E+9 | 1.70E-1 | - | - |
| | kerosene, at refinery | CH | - | - | 0 | kg | | 1.45E-2 | 1.48E-2 | 1.57E-2 | | | | 1.34E-1 | 4.25E+7 | 4.25E+7 | 4.52E+7 | | | | 3.75E+8 | 9.85E-2 | 1.73E-1 | 3.13E+8 |
| | benzene, at refinery | CH | - | - | 0 | kg | | 9.05E-3 | 9.22E-3 | 9.50E-3 | | | | 1.39E-1 | 2.65E+7 | 2.65E+7 | 2.73E+7 | | | | 3.90E+8 | 9.85E-2 | 5.32E-2 | 9.61E+7 |
| | naphtha, at refinery | CH | - | - | 0 | kg | | 1.84E-3 | 1.88E-3 | 2.56E-3 | | | | - | 5.40E+6 | 5.40E+6 | 7.35E+6 | | | | | 8.39E-3 | - | |
| | propane/ butane, at refinery | CH | - | - | 0 | kg | | 3.59E-2 | 3.66E-2 | 3.67E-2 | | | | 4.29E-2 | 1.05E+8 | 1.05E+8 | 1.05E+8 | | | | 1.20E+8 | 4.14E-2 | - | - |
| | secondary sulphur, at refinery | CH | - | - | 0 | kg | | 1.81E-3 | 1.84E-3 | 1.83E-3 | | | | - | 5.30E+6 | 5.30E+6 | 5.27E+6 | | | | | 7.69E-4 | 4.94E-2 | 8.92E+7 |
| | petroleum coke, at refinery | CH | - | - | 0 | kg | | - | - | - | | | | | - | - | | | | | 1.17E+4 | | - | |
| | refinery gas, at refinery | CH | - | - | 0 | kg | | 4.21E-2 | 4.29E-2 | - | | | | 2.81E-2 | 1.23E+8 | 1.23E+8 | - | | | | 7.86E+7 | 3.64E-2 | 2.85E-2 | 5.14E+7 |
| | bitumen, at refinery | CH | - | - | 0 | kg | | - | - | - | | | | - | - | - | - | | | | | 2.79E-2 | 2.71E-4 | 4.90E+5 |
| | electricity, at refinery | CH | - | - | 0 | kWh | | - | - | - | | | | - | - | - | - | | | | | - | 1.12E-1 | 2.02E+8 |
| resource, in water | Water, unspecified natural origin, CH | - | resource | in water | - | m3 | | 1.38E-4 | 1.38E-4 | - | 6.60E-3 | | | 2.35E-4 | | 3.97E+5 | | | | | 6.59E+5 | | 8.96E-4 | 1.62E+6 |
| | Water, cooling, unspecified natural origin, CH | - | resource | in water | - | m3 | | 3.69E-4 | 3.69E-4 | - | 7.69E-3 | | | | | 1.06E+6 | | | | | | | | |
| water discharge | Water, CH | - | water | river | - | m3 | | 5.22E-4 | 1.38E-4 | - | 1.43E-2 | | | 3.96E-5 | | 3.97E+5 | | | | | 1.11E+5 | | 8.96E-4 | 1.62E+6 |
| crude input | crude oil, import mix, at long distance transport | CH | - | - | 0 | kg | 1.82E+9 | 1.00E+0 | 1.00E+0 | 1.00E+0 | 1.00E+0 | | 2.92E+9 | | 2.88E+9 | 2.88E+9 | 2.88E+9 | | 2.92E+9 | 4.61E+9 | 2.80E+9 | 1.00E+0 | 1.00E+0 | 1.81E+9 |
| energy | electricity, medium voltage, at grid | CH | - | - | 0 | kWh | | 4.24E-2 | 4.24E-2 | - | 6.13E-2 | | | 3.57E-2 | | 1.22E+8 | | | | | 1.00E+8 | | 1.57E-4 | 2.83E+5 |
| | natural gas, burned in industrial furnace low-NOx >100kW | RER | - | - | 0 | MJ | | - | - | - | 5.20E-1 | | | | | | | | | | | | | |
| | refinery gas, burned in furnace | CH | - | - | 0 | MJ | | 2.09E+0 | 2.09E+0 | 2.12E+0 | 1.48E+0 | 2.08E+0 | | 1.37E+0 | | 6.00E+9 | 6.09E+9 | | 6.09E+09 | 8.17E+09 | 3.83E+9 | 1.77E+0 | 2.40E+0 | 4.34E+9 |
| | heavy fuel oil, burned in refinery furnace | CH | - | - | 0 | MJ | | 7.81E-2 | 7.81E-2 | 2.11E-1 | 3.87E-1 | 2.12E-1 | | 1.79E-1 | | 2.25E+8 | 6.08E+8 | | 6.18E+08 | 1.95E+09 | 5.01E+8 | 4.24E-1 | 8.03E-1 | 1.45E+9 |
| | petroleum coke, burned in refinery furnace | CH | - | - | 0 | MJ | | - | - | 1.22E-1 | 4.20E-1 | 1.20E-1 | | 1.32E-4 | | - | 3.50E+8 | | 3.50E+08 | 3.71E+05 | 3.71E+5 | 8.05E-5 | - | |
| | refinery gas, burned in flare | GLO | - | - | 0 | MJ | | - | - | - | - | | | | | | | | 0.00E+00 | | | | 5.52E-2 | 9.98E+7 |
| | tap water, unspecified natural origin CH, at user | CH | - | - | 0 | kg | | 1.52E-2 | - | - | 1.52E-2 | | | | | | | | | | | - | - | |
| chemicals | ammonia, liquid, at regional storehouse | RER | - | - | 0 | kg | | 2.00E-6 | - | - | 2.00E-6 | | | | | | | | | | | - | - | |
| | calcium chloride, CaCl2, at plant | RER | - | - | 0 | kg | | 1.62E-5 | - | - | 1.62E-5 | | | | | | | | | | | - | - | |
| | chlorine, liquid, production mix, at plant | RER | - | - | 0 | kg | | 4.20E-5 | - | - | 4.20E-5 | | | | | | | | | | | - | - | |
| | chemicals organic, at plant | GLO | - | - | 0 | kg | | 3.00E-4 | - | - | 3.00E-4 | | | | | | | | | | | - | - | |
| | hydrochloric acid, 30% in H2O, at plant | RER | - | - | 0 | kg | | 8.90E-5 | - | - | 8.90E-5 | | | | | | | | | | | - | - | |
| | iron sulphate, at plant | RER | - | - | 0 | kg | | 5.00E-5 | - | - | 5.00E-5 | | | | | | | | | | | - | - | |
| | lime, hydrated, packed, at plant | CH | - | - | 0 | kg | | 3.50E-5 | - | - | 3.50E-5 | | | | | | | | | | | - | - | |
| | lubricating oil, at plant | RER | - | - | 0 | kg | | 1.23E-5 | - | - | 1.23E-5 | | | | | | | | | | | - | - | |
| | naphtha, at refinery | RER | - | - | 0 | kg | | | 2.43E-2 | - | - | | | | | 7.00E+7 | | | | | | - | - | |
| | nitrogen, liquid, at plant | RER | - | - | 0 | kg | | 1.13E-3 | - | - | 1.13E-3 | | | | | | | | | | | - | - | |
| | propylene glycol, liquid, at plant | RER | - | - | 0 | kg | | 6.00E-6 | - | - | 6.00E-6 | | | | | | | | | | | - | - | |
| | soap, at plant | RER | - | - | 0 | kg | | 2.68E-6 | - | - | 2.68E-6 | | | | | | | | | | | - | - | |
| | sodium hypochlorite, 15% in H2O, at plant | RER | - | - | 0 | kg | | 5.00E-5 | - | - | 5.00E-5 | | | | | | | | | | | - | - | |
| | sodium hydroxide, 50% in H2O, production mix, at plant | RER | - | - | 0 | kg | | 2.45E-4 | - | - | 2.45E-4 | | | | | | | | | | | - | - | |
| | sulphuric acid, liquid, at plant | RER | - | - | 0 | kg | | 9.69E-6 | - | - | 9.69E-6 | | | | | | | | | | | - | - | |
| resource, in ground | Rhenium | - | resource | in ground | - | kg | | 8.01E-10 | - | - | 8.01E-10 | | | | | | | | | | | - | - | |
| catalysts | molybdenum, at regional storage | RER | - | - | 0 | kg | | 4.05E-8 | - | - | 4.05E-8 | | | | | | | | | | | - | - | |
| | cobalt, at plant | GLO | - | - | 0 | kg | | 1.07E-8 | - | - | 1.07E-8 | | | | | | | | | | | - | - | |
| | nickel, 99.5%, at plant | GLO | - | - | 0 | kg | | 6.00E-9 | - | - | 6.00E-9 | | | | | | | | | | | - | - | |
| | palladium, at regional storage | RER | - | - | 0 | kg | | 2.53E-8 | - | - | 2.53E-8 | | | | | | | | | | | - | - | |
| | platinum, at regional storage | RER | - | - | 0 | kg | | 8.01E-10 | - | - | 8.01E-10 | | | | | | | | | | | - | - | |
| | rhodium, at regional storage | RER | - | - | 0 | kg | | 8.01E-10 | - | - | 8.01E-10 | | | | | | | | | | | - | - | |
| | zeolite, powder, at plant | RER | - | - | 0 | kg | | 9.92E-6 | - | - | 9.92E-6 | | | | | | | | | | | - | - | |
| | zinc, primary, at regional storage | RER | - | - | 0 | kg | | 1.07E-7 | - | - | 1.07E-7 | | | | | | | | | | | - | - | |
| transport | transport, lorry >16t, fleet average | RER | - | - | 0 | tkm | | 1.99E-4 | - | - | 1.99E-4 | | | | | | | | | | | - | - | |
| | transport, freight, rail | RER | - | - | 0 | tkm | | 1.20E-3 | - | - | 1.20E-3 | | | | | | | | | | | - | - | |
| | refinery | RER | - | - | 1 | unit | | 3.33E-11 | - | - | 3.33E-11 | | | | | | | | | | | - | - | |
| waste | disposal, municipal solid waste, 22.9% water, to municipal incineration | CH | - | - | 0 | kg | | 1.95E-5 | 1.95E-5 | - | 1.45E-3 | | | | | 5.60E+4 | | | | | | - | - | |
| | disposal, refinery sludge, 89.5% water, to hazardous waste incineration | CH | - | - | 0 | kg | | 3.96E-4 | 3.96E-4 | - | 1.07E-3 | | 7.42E-5 | | | 1.14E+6 | | 2.17E+5 | | | | - | 1.22E-4 | 2.20E+5 |
| | disposal, catalytic converter NOx reduction, 0% water, to underground deposit | DE | - | - | 0 | kg | | 1.00E-6 | - | - | 1.00E-6 | | | | | | | | | | | - | - | |

| | Name | Location | Category | SubCategory | InfrastructureProc | Unit | mean values | crude oil, in refinery | crude oil, in refinery Cressier | crude oil, in refinery | crude oil, in refinery | crude oil, in refinery | refinery operation, Cressier | crude oil, in refinery Cressier | crude oil, in refinery | crude oil, in refinery Cressier | crude oil, in refinery | refinery operation, Cressier | refinery operation | crude oil, in refinery | crude oil, in refinery Cressier | crude oil in refinery | crude oil, in refinery Collombey | crude oil, in refinery Collombey |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Location | | | | | | CH | CH | CH | CH | RER | CH | CH | CH | CH | CH | CH | CH | CH | CH | CH | CH | CH | CH |
| | InfrastructureProcess | | | | | | 2007 | 2016 | 2016 | 2016 | 2016 | 2015 | 2015 | 2006 | 2016 | 2016 | 2016 | 2015 | 2015 | 2006 | 2006 | 2006 | 2006 | 2006 |
| | Unit | | | | | | kg, mg/l | kg | kg | kg | kg | kg | kg | kg | a | a | a | a | a | a | a | kg, mg/l | kg, mg/l | a |
| emission air, high population density | Heat, waste | - | air | high population den | - | MJ | 6.00E+7 | 1.53E-1 | - | - | 2.21E-1 | | | 1.29E-1 | - | | | | | - | 3.60E+8 | 1.29E-1 | 5.64E-4 | 1.02E+6 |
| | Ammonia | - | air | high population den | - | kg | -1.10E-6 | 1.10E-6 | - | - | 1.10E-6 | | | | | | | | | | | - | - | |
| | Benzene | - | air | high population den | - | kg | 3.10E+3 | 1.06E-6 | 2.84E-7 | - | 2.50E-6 | | 1.06E-6 | | | | | 3.10E+3 | | | | - | - | |
| | Benzene, ethyl- | - | air | unspecified | - | kg | -6.26E-7 | 1.16E-7 | 1.16E-7 | - | 1.02E-6 | | | | | | | | | | | - | - | |
| | Butane | - | air | unspecified | - | kg | -2.51E-5 | 4.64E-6 | 4.64E-6 | - | 4.08E-5 | | | | | | | | | | | - | - | |
| | Butene | - | air | high population den | - | kg | -6.26E-7 | 1.16E-7 | 1.16E-7 | - | 1.02E-6 | | | | | | | | | | | - | - | |
| | Dinitrogen monoxide | - | air | high population den | - | kg | | - | - | - | - | | | 3.39E-7 | | | | | | | 9.50E+2 | 3.39E-7 | - | |
| | Ethane | - | air | unspecified | - | kg | -6.26E-6 | 1.16E-6 | 1.16E-6 | - | 1.02E-5 | | | | | | | | | | | - | - | |
| | Ethene | - | air | unspecified | - | kg | -1.25E-6 | 2.32E-7 | 2.32E-7 | - | 2.04E-6 | | | | | | | | | | | - | - | |
| | Heptane | - | air | high population den | - | kg | -6.26E-6 | 1.16E-6 | 1.16E-6 | - | 1.02E-5 | | | | | | | | | | | - | - | |
| | Hexane | - | air | high population den | - | kg | -1.25E-5 | 2.32E-6 | 2.32E-6 | - | 2.04E-5 | | | | | | | | | | | - | - | |
| | Hydrocarbons, aliphatic, alkanes, unspecified | - | air | unspecified | - | kg | -2.09E-11 | 3.87E-12 | 3.87E-12 | - | 3.41E-11 | | | | | | | | | | | - | - | |
| | Hydrocarbons, aliphatic, unsaturated | - | air | high population den | - | kg | -1.15E-12 | 2.13E-13 | 2.13E-13 | - | 1.88E-12 | | | | | | | | | | | - | - | |
| | Hydrocarbons, aromatic | - | air | high population den | - | kg | -3.14E-13 | 5.81E-14 | 5.81E-14 | - | 5.12E-13 | | | | | | | | | | | - | - | |
| | Methane, fossil | - | air | high population den | - | kg | 4.45E-5 | 4.45E-5 | - | - | 8.50E-6 | 4.45E-5 | | 1.65E-5 | | | | | 1.30E+05 | | 4.62E+4 | 1.65E-5 | - | |
| | Nickel | - | air | high population den | - | kg | 1.31E+2 | - | - | - | - | | 9.00E-8 | | | | | 2.63E+2 | | | | - | 3.01E-4 | 5.44E+5 |
| | Nitrogen oxides | - | air | high population den | - | kg | 1.61E+5 | - | 1.21E-4 | - | - | | 1.04E-4 | | | 3.49E+5 | | 3.04E+5 | | | 3.11E+5 | 1.11E-4 | 3.01E-4 | 5.44E+5 |
| | Particulates, > 10 um | - | air | high population den | - | kg | -1.50E-5 | 1.50E-5 | - | - | 1.50E-5 | | | | | | | | | | | - | - | |
| | Pentane | - | air | high population den | - | kg | -3.13E-5 | 5.79E-6 | 5.79E-6 | - | 5.11E-5 | | | | | | | | | | | - | - | |
| | Propane | - | air | high population den | - | kg | -2.51E-5 | 4.64E-6 | 4.64E-6 | - | 4.08E-5 | | | | | | | | | | | - | - | |
| | Propene | - | air | unspecified | - | kg | -1.25E-6 | 2.32E-7 | 2.32E-7 | - | 2.04E-6 | | | | | | | | | | | - | - | |
| | Sulfur dioxide | - | air | high population den | - | kg | 7.16E+4 | - | 8.04E-5 | - | - | | 7.53E-5 | | | 2.31E+5 | | 2.20E+5 | | | 2.66E+5 | 9.48E-5 | 2.21E-4 | 3.99E+5 |
| | Toluene | - | air | high population den | - | kg | -3.76E-6 | 6.95E-7 | 6.95E-7 | - | 6.13E-6 | | | | | | | | | | | - | - | |
| | Xylene | - | air | unspecified | - | kg | -2.51E-6 | 4.64E-7 | 4.64E-7 | - | 4.08E-6 | | | | | | | | | | | - | - | |

| | Name | Location | Category | SubCategory | InfrastructureProcess | Unit | mean values | crude oil, in refinery | crude oil, in refinery Cressier | crude oil, in refinery | crude oil, in refinery | crude oil, in refinery | refinery operation, Cressier | crude oil, in refinery Cressier | crude oil, in refinery | crude oil, in refinery Cressier | crude oil, in refinery | refinery operation, Cressier | refinery operation | crude oil, in refinery | crude oil, in refinery Cressier | crude oil in refinery | crude oil, in refinery Collombey | crude oil, in refinery Collombey |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Location | | | | | | CH | CH | CH | CH | RER | CH | CH | CH | CH | CH | CH | CH | CH | CH | CH | CH | CH | CH |
| | InfrastructureProcess | | | | | | 2007 | 2016 | 2016 | 2016 | 2016 | 2015 | 2015 | 2006 | 2016 | 2016 | 2016 | 2015 | 2015 | 2006 | 2006 | 2006 | 2006 | 2006 |
| | Unit | | | | | | kg, mg/l | kg | kg | kg | kg | kg | kg | kg | a | a | a | a | a | a | a | kg, mg/l | kg, mg/l | a |
| emission water, river | Aluminium | - | water | river | - | kg | 5.00E-2 | 1.28E-8 | - | - | 1.28E-8 | | | | | | | | | | | na | - | |
| | Ammonium, ion | - | water | river | - | kg | 6.00E+0 | 1.20E-6 | - | - | 1.20E-6 | | | | | | | | | | | na | - | |
| | AOX, Adsorbable Organic Halogen as Cl | - | water | river | - | kg | 1.58E-2 | 6.00E-8 | - | - | 6.00E-8 | | | | | | | | | | | na | - | |
| | Arsenic | - | water | river | - | kg | 1.00E-2 | 7.00E-10 | - | - | 7.00E-10 | | | | | | | | | | | na | - | |
| | Barium | - | water | river | - | kg | 1.00E-1 | 2.56E-8 | - | - | 2.56E-8 | | | | | | | | | | | na | - | |
| | Benzene | - | water | river | - | kg | 2.24E-2 | 2.00E-9 | - | - | 2.00E-9 | | | | | | | | | | | na | - | |
| | Benzene, ethyl- | - | water | river | - | kg | 2.00E-4 | 4.00E-9 | - | - | 4.00E-9 | | | | | | | | | | | na | - | |
| | BOD5, Biological Oxygen Demand | - | water | river | - | kg | 6.32E+0 | 4.40E-6 | - | - | 4.40E-6 | | | | | | | | | | | na | - | |
| | Boron | - | water | river | - | kg | 4.00E-1 | 2.64E-12 | - | - | 2.64E-12 | | | | | | | | | | | na | - | |
| | Cadmium | - | water | river | - | kg | 1.00E-2 | 1.00E-9 | - | - | 1.00E-9 | | | | | | | | | | | na | - | |
| | Calcium | - | water | river | - | kg | 5.00E+1 | 1.28E-5 | - | - | 1.28E-5 | | | | | | | | | | | na | - | |
| | Chloride | - | water | river | - | kg | 1.87E-5 | 1.87E-5 | - | - | 1.47E-4 | | | 1.87E-5 | | | | | | | 5.24E+4 | 7.95E+1 | - | |
| | Chromium | - | water | river | - | kg | 2.24E-1 | 1.00E-9 | - | - | 1.00E-9 | | | | | | | | | | | na | - | |
| | Chromium VI | - | water | river | - | kg | 1.00E-2 | 1.00E-9 | - | - | 1.00E-9 | | | | | | | | | | | na | - | |
| | COD, Chemical Oxygen Demand | - | water | river | - | kg | 6.12E+1 | 2.72E-5 | - | - | 2.72E-5 | | | | | | | | | | | na | - | |
| | Cobalt | - | water | river | - | kg | 3.30E+1 | 6.60E-15 | - | - | 6.60E-15 | | | | | | | | | | | na | - | |
| | Copper | - | water | river | - | kg | 1.00E-2 | 2.00E-9 | - | - | 2.00E-9 | | | | | | | | | | | na | - | |
| | Cyanide | - | water | river | - | kg | 1.73E-1 | 4.00E-9 | - | - | 4.00E-9 | | | | | | | | | | | na | - | |
| | DOC, Dissolved Organic Carbon | - | water | river | - | kg | 1.58E-8 | 1.58E-8 | - | - | 1.58E-8 | | | | | | | | | | | 6.17E-2 | 6.17E-2 | 1.00E+2 |
| | Fluoride | - | water | river | - | kg | 4.47E+0 | 6.00E-7 | - | - | 6.00E-7 | | | | | | | | | | | na | - | |
| | Hydrocarbons, aromatic | - | water | river | - | kg | 7.19E-1 | 1.00E-8 | - | - | 1.00E-8 | | | | | | | | | | | na | - | |
| | Hydrocarbons, unspecified | - | water | river | - | kg | 2.74E-1 | 2.18E-7 | 2.18E-7 | - | 5.00E-7 | | | | | 6.26E+2 | | | | | | na | - | |
| | Iron | - | water | river | - | kg | 5.00E-1 | 1.50E-7 | - | - | 1.50E-7 | | | | | | | | | | | na | - | |
| | Lead | - | water | river | - | kg | 3.16E-1 | 5.00E-9 | - | - | 5.00E-9 | | | | | | | | | | | na | - | |
| | Magnesium | - | water | river | - | kg | 2.50E+1 | 6.39E-6 | - | - | 6.39E-6 | | | | | | | | | | | na | - | |
| | Manganese | - | water | river | - | kg | 2.00E-1 | 4.00E-8 | - | - | 4.00E-8 | | | | | | | | | | | na | - | |
| | Mercury | - | water | river | - | kg | 1.00E-4 | 1.00E-10 | - | - | 1.00E-10 | | | | | | | | | | | na | - | |
| | Molybdenum | - | water | river | - | kg | 1.00E-2 | 6.60E-14 | - | - | 6.60E-14 | | | | | | | | | | | na | - | |
| | Nickel | - | water | river | - | kg | 3.11E-9 | 3.11E-9 | - | - | 6.00E-9 | | | 3.11E-9 | | | | | | | 8.70E+0 | 1.32E-2 | - | |
| | Nitrate | - | water | river | - | kg | 8.22E+0 | 6.20E-6 | - | - | 6.20E-6 | | | | | | | | | | | na | - | |
| | Nitrite | - | water | river | - | kg | 0 | 1.00E-7 | - | - | 1.00E-7 | | | | | | | | | | | na | - | |
| | Nitrogen, organic bound | - | water | river | - | kg | 1.32E+1 | 4.00E-6 | - | - | 4.00E-6 | | | | | | | | | | | na | - | |
| | Oils, unspecified | - | water | river | - | kg | 7.00E-1 | 2.08E-7 | - | - | 6.79E-7 | | | 2.08E-7 | | | | | | | 5.81E+2 | 7.19E-1 | 5.56E-1 | 9.00E+2 |
| | PAH, polycyclic aromatic hydrocarbons | - | water | river | - | kg | 1.58E-2 | 3.00E-10 | - | - | 3.00E-10 | | | | | | | | | | | na | - | |
| | Phenol | - | water | river | - | kg | 1.92E-8 | 1.92E-8 | 1.92E-8 | - | 2.00E-8 | | 2.19E-8 | | | 5.52E+1 | | 6.41E+1 | | | 1.33E+2 | 2.02E-1 | - | |
| | Phosphate | - | water | river | - | kg | 1.73E-1 | 1.30E-7 | - | - | 1.30E-7 | | | | | | | | | | | na | - | |
| | Phosphorus | - | water | river | - | kg | 3.87E-1 | 3.00E-7 | - | - | 3.00E-7 | | | | | | | | | | | na | - | |
| | Potassium | - | water | river | - | kg | 1.00E+1 | 2.56E-6 | - | - | 2.56E-6 | | | | | | | | | | | na | - | |
| | Selenium | - | water | river | - | kg | 1.50E-2 | 2.64E-13 | - | - | 2.64E-13 | | | | | | | | | | | na | - | |
| | Silver | - | water | river | - | kg | 5.00E-2 | 1.28E-8 | - | - | 1.28E-8 | | | | | | | | | | | na | - | |
| | Sodium | - | water | river | - | kg | 3.00E+2 | 7.67E-5 | - | - | 7.67E-5 | | | | | | | | | | | na | - | |
| | Strontium | - | water | river | - | kg | 7.00E-1 | 1.79E-7 | - | - | 1.79E-7 | | | | | | | | | | | na | - | |
| | Sulfate | - | water | river | - | kg | 2.00E+2 | 5.11E-5 | - | - | 5.11E-5 | | | | | | | | | | | na | - | |
| | Sulfide | - | water | river | - | kg | 1.00E-1 | 2.50E-8 | - | - | 2.50E-8 | | | | | | | | | | | na | - | |
| | Suspended solids, unspecified | - | water | fossil- | - | kg | 1.00E+1 | 6.30E-6 | - | - | 6.30E-6 | | | | | | | | | | | na | - | |
| | t-Butyl methyl ether | - | water | river | - | kg | 3.16E-1 | 5.00E-9 | - | - | 5.00E-9 | | | | | | | | | | | na | - | |
| | Tin | - | water | river | - | kg | 3.16E-1 | 4.00E-9 | - | - | 4.00E-9 | | | | | | | | | | | na | - | |
| | TOC, Total Organic Carbon | - | water | river | - | kg | 2.50E+1 | 5.50E-6 | - | - | 5.50E-6 | | | | | | | | | | | na | - | |
| | Toluene | - | water | river | - | kg | 1.00E+0 | 4.00E-9 | - | - | 4.00E-9 | | | | | | | | | | | na | - | |
| | Vanadium | - | water | river | - | kg | 3.00E-2 | 3.00E-9 | - | - | 3.00E-9 | | | | | | | | | | | na | - | |
| | Xylene | - | water | river | - | kg | 1.00E-1 | 4.00E-9 | - | - | 4.00E-9 | | | | | | | | | | | na | - | |
| | Zinc | - | water | river | - | kg | 4.06E-8 | 4.06E-8 | - | - | 1.50E-8 | | | 4.06E-8 | | | | | | | 1.14E+2 | 1.72E-1 | - | |
| Total products | | | | | | | 2.83E+9 | 1.0242 | | | | | | | 3.00E+9 | 3.06E+9 | 2.96E+9 | | | 4.97E+9 | 3.00E+9 | 1.07E+0 | 1.09E+0 | 1.97E+9 |
| Total crude oil | | | | | | | | 1.00E+0 | | | | | | | 2.93E+9 | 2.93E+9 | 2.88E+9 | | | | | | | |
| Total additives | | | | | | | 0 | 4.07E-4 | 0 | 0 | 4.07E-4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Total add on products | | | | | | | | | | | | | | | | | | | | | | | | |
| | Literature | | | river | | | | This report | Varo 2018 | Erdölvereinigung - Jahresberi | This report | greenhouse gas inventory | PRTR 2015 | Jungbluth 2007 | This study | Marc Veuve, VARO, | Erdölvereinigung - Jahresber | PRTR 2015 | greenhouse gas inventory | This report - Jungbluth | Jungbluth 2007 | Jungbluth 2007 | Jungbluth 2007 | |

| | Name | Location | Category | SubCategory | InfrastructureProcess | Unit | sum product | Controll allocation | petrol, at refinery | diesel, at refinery | light fuel oil, at refinery | heavy fuel oil, at refinery | kerosene, at refinery | benzene, at refinery | distillates, at refinery | naphtha, at refinery | propane/ butane, at refinery | secondary sulphur, at refinery | refinery gas, at refinery | petroleum coke, at refinery | bitumen, at refinery | electricity, at refinery |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Location | | | | | | CH | | | | | | | | | | | | | | | 0 |
| | InfrastructureProcess | | | | | | 0 | | | | | | | | | | | | | | | 0 |
| | Unit | | | | | | | | kg | kg | kg | kg | kg | kg | kg | kg | kg | kg | kg | kg | kg | kWh |
| products | petrol, at refinery | CH | - | - | 0 | kg | 23.117 | 100 | 100 | - | - | - | - | - | - | - | - | - | - | - | - | - |
| | diesel, at refinery | CH | - | - | 0 | kg | 29.184 | 100 | - | 100 | - | - | - | - | - | - | - | - | - | - | - | - |
| | light fuel oil, at refinery | CH | - | - | 0 | kg | 27.487 | 100 | - | - | 100 | - | - | - | - | - | - | - | - | - | - | - |
| | heavy fuel oil, at refinery | CH | - | - | 0 | kg | 12.115 | 100 | - | - | - | 100 | - | - | - | - | - | - | - | - | - | - |
| | kerosene, at refinery | CH | - | - | 0 | kg | 1.451 | 100 | - | - | - | - | 100 | - | - | - | - | - | - | - | - | - |
| | benzene, at refinery | CH | - | - | 0 | kg | 0.905 | 100 | - | - | - | - | - | 100 | - | - | - | - | - | - | - | - |
| | naphtha, at refinery | CH | - | - | 0 | kg | 0.184 | 100 | - | - | - | - | - | - | - | 100 | - | - | - | - | - | - |
| | propane/ butane, at refinery | CH | - | - | 0 | kg | 3.587 | 100 | - | - | - | - | - | - | - | - | 100 | - | - | - | - | - |
| | secondary sulphur, at refinery | CH | - | - | 0 | kg | 0.181 | 100 | - | - | - | - | - | - | - | - | - | 100 | - | - | - | - |
| | petroleum coke, at refinery | CH | - | - | 0 | kg | - | - | - | - | - | - | - | - | - | - | - | - | - | 100 | - | - |
| | refinery gas, at refinery | CH | - | - | 0 | kg | 4.209 | 100 | - | - | - | - | - | - | - | - | - | - | 100 | - | - | - |
| | bitumen, at refinery | CH | - | - | 0 | kg | - | - | - | - | - | - | - | - | - | - | - | - | - | - | 100 | - |
| | electricity, at refinery | CH | - | - | 0 | kWh | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | 100 |
| resource, in water | Water, unspecified natural origin, CH | - | resource | in water | - | m3 | 1.024 | 100 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 |
| | Water, cooling, unspecified natural origin, CH | - | resource | in water | - | m3 | 1.024 | 100 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 |
| water discharge | Water, CH | - | water | river | - | m3 | 1.024 | 100 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 |
| crude input | crude oil, import mix, at long distance transport | CH | - | - | 0 | kg | 44.031 | 100 | 42.6 | 43 | 42.9 | 41.2 | 43.2 | 45 | 45 | 45 | 46 | 19.1 | 48.7 | 31.8 | 40.7 | 0 |
| energy | electricity, medium voltage, at grid | CH | - | - | 0 | kWh | 0.992 | 100 | 1.59 | 0.7 | 0.7 | 0.9 | 0.6 | 1.59 | 1.59 | 1.59 | 1.41 | 1 | 0.95 | 1.11 | 1.11 | 0 |
| | natural gas, burned in industrial furnace low-NOx >100kW | RER | - | - | 0 | MJ | 1.098 | 100 | 1.4 | 1 | 1 | 0.7 | 1 | 0.6 | 0.6 | 0.6 | 1.5 | 1 | 1.1 | 0.7 | 0.7 | 0 |
| | refinery gas, burned in furnace | CH | - | - | 0 | MJ | 1.098 | 100 | 1.4 | 1 | 1 | 0.7 | 1 | 0.6 | 0.6 | 0.6 | 1.5 | 1 | 1.1 | 0.7 | 0.7 | 0 |
| | heavy fuel oil, burned in refinery furnace | CH | - | - | 0 | MJ | 1.098 | 100 | 1.4 | 1 | 1 | 0.7 | 1 | 0.6 | 0.6 | 0.6 | 1.5 | 1 | 1.1 | 0.7 | 0.7 | 0 |
| | petroleum coke, burned in refinery furnace | CH | - | - | 0 | MJ | 1.098 | 100 | 1.4 | 1 | 1 | 0.7 | 1 | 0.6 | 0.6 | 0.6 | 1.5 | 1 | 1.1 | 0.7 | 0.7 | 0 |
| | refinery gas, burned in flare | GLO | - | - | 0 | MJ | 1.098 | 100 | 1.4 | 1 | 1 | 0.7 | 1 | 0.6 | 0.6 | 0.6 | 1.5 | 1 | 1.1 | 0.7 | 0.7 | 0 |
| | tap water, unspecified natural origin CH, at user | CH | - | - | 0 | kg | 1.024 | 100 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 |
| chemicals | ammonia, liquid, at regional storehouse | RER | - | - | 0 | kg | 1.022 | 100 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 0 |
| | calcium chloride, CaCl2, at plant | RER | - | - | 0 | kg | 1.024 | 100 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 |
| | chlorine, liquid, production mix, at plant | RER | - | - | 0 | kg | 0.978 | 100 | 3.8 | 0 | 0 | 0 | 0 | 3.8 | 3.8 | 3.8 | 0.2 | 0 | 1.2 | 0 | 0 | 0 |
| | chemicals organic, at plant | GLO | - | - | 0 | kg | 0.001 | 100 | 3.01E-4 | 7.01E-4 | 7.34E-4 | 3.01E-4 | 3.22E-4 | 0.000601 | 0.000601 | 6.01E-4 | 3.01E-4 | 3.01E-4 | 3.01E-4 | 3.01E-4 | 1.80E-3 | 0 |
| | hydrochloric acid, 30% in H2O, at plant | RER | - | - | 0 | kg | 1.024 | 100 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 |
| | iron sulphate, at plant | RER | - | - | 0 | kg | 1.024 | 100 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 |
| | lime, hydrated, packed, at plant | CH | - | - | 0 | kg | 1.024 | 100 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 |
| | lubricating oil, at plant | RER | - | - | 0 | kg | 1.024 | 100 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 |
| | naphtha, at refinery | RER | - | - | 0 | kg | 44.031 | 100 | 42.6 | 43 | 42.9 | 41.2 | 43.2 | 45 | 45 | 45 | 46 | 19.1 | 48.7 | 31.8 | 40.7 | 0 |
| | nitrogen, liquid, at plant | RER | - | - | 0 | kg | 1.024 | 100 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 |
| | propylene glycol, liquid, at plant | RER | - | - | 0 | kg | 0.000 | 100 | 0.000216 | 0.000006 | 0.000006 | 0.000006 | 0.000006 | 0.000216 | 0.000216 | 0.000216 | 0.000006 | 0.000006 | 0.000006 | 0.000006 | 0.000006 | 0 |
| | soap, at plant | RER | - | - | 0 | kg | 1.024 | 100 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 |
| | sodium hypochlorite, 15% in H2O, at plant | RER | - | - | 0 | kg | 1.024 | 100 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 |
| | sodium hydroxide, 50% in H2O, production mix, at plant | RER | - | - | 0 | kg | 0.036 | 100 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 |
| | sulphuric acid, liquid, at plant | RER | - | - | 0 | kg | 1.024 | 100 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 |
| resource, in ground | Rhenium | - | resource | in ground | - | kg | 0.936 | 100 | 3.8 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.2 | 0 | 1.2 | 0 | 0 | 0 |
| catalysts | molybdenum, at regional storage | RER | - | - | 0 | kg | 0.787 | 100 | 2 | 0.4 | 0 | 0 | 1.8 | 2 | 2 | 2 | 2 | 2 | 2 | 0 | 0 | 0 |
| | cobalt, at plant | GLO | - | - | 0 | kg | 1.417 | 100 | 0 | 2.5 | 2.5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | nickel, 99.5%, at plant | GLO | - | - | 0 | kg | 0.800 | 100 | 2.4 | 0 | 0 | 0 | 2.2 | 2.4 | 2.4 | 2.4 | 2.4 | 0 | 2.4 | 0 | 0 | 0 |
| | palladium, at regional storage | RER | - | - | 0 | kg | 0.962 | 100 | 3.7 | 0 | 0 | 0 | 0 | 3.7 | 3.7 | 3.7 | 0.8 | 0 | 0.9 | 0 | 0 | 0 |
| | platinum, at regional storage | RER | - | - | 0 | kg | 0.962 | 100 | 3.7 | 0 | 0 | 0 | 0 | 3.7 | 3.7 | 3.7 | 0.8 | 0 | 0.9 | 0 | 0 | 0 |
| | rhodium, at regional storage | RER | - | - | 0 | kg | 0.962 | 100 | 3.7 | 0 | 0 | 0 | 0 | 3.7 | 3.7 | 3.7 | 0.8 | 0 | 0.9 | 0 | 0 | 0 |
| | zeolite, powder, at plant | RER | - | - | 0 | kg | 0.984 | 100 | 2.1 | 0.4 | 0.4 | 1.1 | 0.7 | 2.1 | 2.1 | 2.1 | 1.3 | 0 | 1.4 | 0 | 0 | 0 |
| | zinc, primary, at regional storage | RER | - | - | 0 | kg | 0.984 | 100 | 2.1 | 0.4 | 0.4 | 1.1 | 0.7 | 2.1 | 2.1 | 2.1 | 1.3 | 0 | 1.4 | 0 | 0 | 0 |
| transport | transport, lorry >16t, fleet average | RER | - | - | 0 | tkm | 1.024 | 100 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 |
| | transport, freight, rail | RER | - | - | 0 | tkm | 1.024 | 100 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 |
| | refinery | RER | - | - | 1 | unit | 1.098 | 100 | 1.4 | 1 | 1 | 0.7 | 1 | 0.6 | 0.6 | 0.6 | 1.5 | 1 | 1.1 | 0.7 | 0.7 | 0 |
| waste | disposal, municipal solid waste, 22.9% water, to municipal incineration | CH | - | - | 0 | kg | 1.024 | 100 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 |
| | disposal, refinery sludge, 89.5% water, to hazardous waste incineration | CH | - | - | 0 | kg | 1.024 | 100 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 |
| | disposal, catalytic converter NOx reduction, 0% water, to underground deposit | DE | - | - | 0 | kg | 0.984 | 100 | 2.1 | 0.4 | 0.4 | 1.1 | 0.7 | 2.1 | 2.1 | 2.1 | 1.3 | 0 | 1.4 | 0 | 0 | 0 |

| | Name | Location | Category | SubCategory | InfrastructureProcess | Unit | sum product | Controll allokation | petrol, at refinery | diesel, at refinery | light fuel oil, at refinery | heavy fuel oil, at refinery | kerosene, at refinery | benzene, at refinery | distillates, at refinery | naphtha, at refinery | propane/ butane, at refinery | secondary sulphur, at refinery | refinery gas, at refinery | petroleum coke, at refinery | bitumen, at refinery | electricity, at refinery |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Location | | | | | | CH | | | | | | | | | | | | | | | 0 |
| | InfrastructureProcess | | | | | | 0 | | | | | | | | | | | | | | | 0 |
| | Unit | | | | | | | | kg | kg | kg | kg | kg | kg | kg | kg | kg | kg | kg | kg | kg | kWh |
| emission air, high population density | Heat, waste | - | air | high population den | - | MJ | 1.107 | 100 | 1.4 | 1 | 1 | 0.7 | 1 | 1.4 | 1.4 | 1.4 | 1.5 | 1 | 1.1 | 0.7 | 0.7 | 0 |
| | Ammonia | - | air | high population den | - | kg | 1.024 | 100 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 |
| | Benzene | - | air | high population den | - | kg | 1.022 | 100 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 0 |
| | Benzene, ethyl- | - | air | unspecified | - | kg | 1.022 | 100 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 0 |
| | Butane | - | air | unspecified | - | kg | 1.022 | 100 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 0 |
| | Butene | - | air | high population den | - | kg | 1.022 | 100 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 0 |
| | Dinitrogen monoxide | - | air | high population den | - | kg | 1.098 | 100 | 1.4 | 1 | 1 | 0.7 | 1 | 0.6 | 0.6 | 0.6 | 1.5 | 1 | 1.1 | 0.7 | 0.7 | 0 |
| | Ethane | - | air | unspecified | - | kg | 1.022 | 100 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 0 |
| | Ethene | - | air | unspecified | - | kg | 1.022 | 100 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 0 |
| | Heptane | - | air | high population den | - | kg | 1.022 | 100 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 0 |
| | Hexane | - | air | high population den | - | kg | 1.022 | 100 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 0 |
| | Hydrocarbons, aliphatic, alkanes, unspecified | - | air | unspecified | - | kg | 1.022 | 100 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 0 |
| | Hydrocarbons, aliphatic, unsaturated | - | air | high population den | - | kg | 1.022 | 100 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 0 |
| | Hydrocarbons, aromatic | - | air | high population den | - | kg | 1.022 | 100 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 0 |
| | Methane, fossil | - | air | high population den | - | kg | 1.022 | 100 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 0 |
| | Nickel | - | air | high population den | - | kg | 1.022 | 100 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 0 |
| | Nitrogen oxides | - | air | high population den | - | kg | 1.098 | 100 | 1.4 | 1 | 1 | 0.7 | 1 | 0.6 | 0.6 | 0.6 | 1.5 | 1 | 1.1 | 0.7 | 0.7 | 0 |
| | Particulates, > 10 um | - | air | high population den | - | kg | 1.022 | 100 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 0 |
| | Pentane | - | air | high population den | - | kg | 1.022 | 100 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 0 |
| | Propane | - | air | high population den | - | kg | 1.022 | 100 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 0 |
| | Propene | - | air | unspecified | - | kg | 1.022 | 100 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 0 |
| | Sulfur dioxide | - | air | high population den | - | kg | 1.096 | 100 | 1.4 | 1 | 1 | 0.7 | 1 | 0.6 | 0.6 | 0.6 | 1.5 | 0 | 1.1 | 0.7 | 0.7 | 0 |
| | Toluene | - | air | high population den | - | kg | 1.022 | 100 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 0 |
| | Xylene | - | air | unspecified | - | kg | 1.022 | 100 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 0 |

| | Name | Location | Category | SubCategory | InfrastructureProcess | Unit | sum product | Controll allokation | petrol, at refinery | diesel, at refinery | light fuel oil, at refinery | heavy fuel oil, at refinery | kerosene, at refinery | benzene, at refinery | distillates, at refinery | naphtha, at refinery | propane/ butane, at refinery | secondary sulphur, at refinery | refinery gas, at refinery | petroleum coke, at refinery | bitumen, at refinery | electricity, at refinery |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Location | | | | | | CH | | | | | | | | | | | | | | | 0 |
| | InfrastructureProcess | | | | | | 0 | | | | | | | | | | | | | | | 0 |
| | Unit | | | | | | | | kg | kg | kg | kg | kg | kg | kg | kg | kg | kg | kg | kg | kg | kWh |
| emission water, river | Aluminium | - | water | river | - | kg | 1.024 | 100 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 |
| | Ammonium, ion | - | water | river | - | kg | 1.051 | 100 | 1.1 | 1.1 | 1.1 | 0.5 | 1 | 1.1 | 1.1 | 1.1 | 1.1 | 0.5 | 1.1 | 0.5 | 0.5 | 0 |
| | AOX, Adsorbable Organic Halogen as Cl | - | water | river | - | kg | 1.012 | 100 | 1 | 1 | 1 | 0.9 | 1 | 1 | 1 | 1 | 1 | 0.9 | 1 | 0.9 | 0.9 | 0 |
| | Arsenic | - | water | river | - | kg | 1.035 | 100 | 1 | 1 | 1 | 1.1 | 0.9 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 |
| | Barium | - | water | river | - | kg | 1.024 | 100 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 |
| | Benzene | - | water | river | - | kg | 1.012 | 100 | 1 | 1 | 1 | 0.9 | 1 | 1 | 1 | 1 | 1 | 0.9 | 1 | 0.9 | 0.9 | 0 |
| | Benzene, ethyl- | - | water | river | - | kg | 1.035 | 100 | 1 | 1 | 1 | 1.1 | 0.9 | 1 | 1 | 1 | 1 | 1.1 | 1 | 1.1 | 1.1 | 0 |
| | BOD5, Biological Oxygen Demand | - | water | river | - | kg | 1.051 | 100 | 1.1 | 1.1 | 1.1 | 0.5 | 1 | 1.1 | 1.1 | 1.1 | 1.1 | 0.4 | 1.1 | 0.4 | 0.4 | 0 |
| | Boron | - | water | river | - | kg | 1.024 | 100 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 |
| | Cadmium | - | water | river | - | kg | 1.035 | 100 | 1 | 1 | 1 | 1.1 | 0.9 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 |
| | Calcium | - | water | river | - | kg | 1.024 | 100 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 |
| | Chloride | - | water | river | - | kg | 1.024 | 100 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 |
| | Chromium | - | water | river | - | kg | 1.035 | 100 | 1 | 1 | 1 | 1.1 | 0.9 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 |
| | Chromium VI | - | water | river | - | kg | 1.035 | 100 | 1 | 1 | 1 | 1.1 | 0.9 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 |
| | COD, Chemical Oxygen Demand | - | water | river | - | kg | 1.115 | 100 | 1.2 | 1.2 | 1.2 | 0.3 | 1 | 1.2 | 1.2 | 1.2 | 1.2 | 0.2 | 1.2 | 0.2 | 0.2 | 0 |
| | Cobalt | - | water | river | - | kg | 1.035 | 100 | 1 | 1 | 1 | 1.1 | 0.9 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 |
| | Copper | - | water | river | - | kg | 1.035 | 100 | 1 | 1 | 1 | 1.1 | 0.9 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 |
| | Cyanide | - | water | river | - | kg | 1.024 | 100 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 |
| | DOC, Dissolved Organic Carbon | - | water | river | - | kg | 1.051 | 100 | 1.1 | 1.1 | 1.1 | 0.5 | 1 | 1.1 | 1.1 | 1.1 | 1.1 | 0.4 | 1.1 | 0.4 | 0.4 | 0 |
| | Fluoride | - | water | river | - | kg | 1.024 | 100 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 |
| | Hydrocarbons, aromatic | - | water | river | - | kg | 1.024 | 100 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 |
| | Hydrocarbons, unspecified | - | water | river | - | kg | 0.716 | 100 | 1.2 | 0.3 | 0.3 | 1.2 | 1.1 | 1.2 | 1.2 | 1.2 | 1.2 | 0.3 | 1.2 | 0.3 | 0.3 | 0 |
| | Iron | - | water | river | - | kg | 1.024 | 100 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 |
| | Lead | - | water | river | - | kg | 1.035 | 100 | 1 | 1 | 1 | 1.1 | 0.9 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 |
| | Magnesium | - | water | river | - | kg | 1.024 | 100 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 |
| | Manganese | - | water | river | - | kg | 1.024 | 100 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 |
| | Mercury | - | water | river | - | kg | 1.024 | 100 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 |
| | Molybdenum | - | water | river | - | kg | 1.024 | 100 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 |
| | Nickel | - | water | river | - | kg | 1.035 | 100 | 1 | 1 | 1 | 1.1 | 0.9 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 |
| | Nitrate | - | water | river | - | kg | 1.024 | 100 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 |
| | Nitrite | - | water | river | - | kg | 1.024 | 100 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 |
| | Nitrogen, organic bound | - | water | river | - | kg | 0.716 | 100 | 1.2 | 0.3 | 0.3 | 1.2 | 1.1 | 1.2 | 1.2 | 1.2 | 1.2 | 0.3 | 1.2 | 0.3 | 0.3 | 0 |
| | Oils, unspecified | - | water | river | - | kg | 0.716 | 100 | 1.2 | 0.3 | 0.3 | 1.2 | 1.1 | 1.2 | 1.2 | 1.2 | 1.2 | 0.3 | 1.2 | 0.3 | 0.3 | 0 |
| | PAH, polycyclic aromatic hydrocarbons | - | water | river | - | kg | 1.012 | 100 | 1 | 1 | 1 | 0.9 | 1 | 1 | 1 | 1 | 1 | 0.9 | 1 | 0.9 | 0.9 | 0 |
| | Phenol | - | water | river | - | kg | 1.015 | 100 | 0.9 | 0.9 | 0.9 | 1.7 | 0.6 | 0.9 | 0.9 | 0.9 | 0.9 | 1.4 | 0.9 | 1.4 | 1.4 | 0 |
| | Phosphate | - | water | river | - | kg | 1.024 | 100 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 |
| | Phosphorus | - | water | river | - | kg | 1.024 | 100 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 |
| | Potassium | - | water | river | - | kg | 1.024 | 100 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 |
| | Selenium | - | water | river | - | kg | 1.024 | 100 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 |
| | Silver | - | water | river | - | kg | 1.024 | 100 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 |
| | Sodium | - | water | river | - | kg | 1.024 | 100 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 |
| | Strontium | - | water | river | - | kg | 1.035 | 100 | 1 | 1 | 1 | 1.1 | 0.9 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 |
| | Sulfate | - | water | river | - | kg | 1.012 | 100 | 1 | 1 | 1 | 0.9 | 1 | 1 | 1 | 1 | 1 | 0.9 | 1 | 0.9 | 0.9 | 0 |
| | Sulfide | - | water | river | - | kg | 1.024 | 100 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 |
| | Suspended solids, unspecified | - | water | fossil- | - | kg | 1.024 | 100 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 |
| | t-Butyl methyl ether | - | water | river | - | kg | 0.231 | 100 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | Tin | - | water | river | - | kg | 1.035 | 100 | 1 | 1 | 1 | 1.1 | 0.9 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 |
| | TOC, Total Organic Carbon | - | water | river | - | kg | 1.051 | 100 | 1.1 | 1.1 | 1.1 | 0.5 | 1 | 1.1 | 1.1 | 1.1 | 1.1 | 0.4 | 1.1 | 0.4 | 0.4 | 0 |
| | Toluene | - | water | river | - | kg | 1.024 | 100 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 |
| | Vanadium | - | water | river | - | kg | 1.035 | 100 | 1 | 1 | 1 | 1.1 | 0.9 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 |
| | Xylene | - | water | river | - | kg | 1.024 | 100 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 |
| | Zinc | - | water | river | - | kg | 1.035 | 100 | 1 | 1 | 1 | 1.1 | 0.9 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 |
| Total products | | | | | | | #BEZUG! | 1 | 23.1% | 29.2% | 27.5% | 12.1% | 1.5% | 0.9% | 0.0% | 0.2% | 3.6% | 0.2% | 4.2% | 0.0% | 0.0% | 0.0% |
| Total crude oil | | | | | | | 0 | - | | | | | | | | | | | | | | |
| Total additives | | | | | | | | | | | | | | | | | | | | | | |
| Total add on products | | | | | | | | | | | | | | | | | | | | | | |
| | *Literature* | | | *river* | | | | | | | | | | | | | | | | | | |

| | Name | Location | Unit | crude oil, in refinery | UncertaintyType | StandardDeviation95% | GeneralComment | petrol, unleaded, at refinery | bitumen, at refinery | diesel, at refinery | light fuel oil, at refinery | heavy fuel oil, at refinery | kerosene, at refinery | naphtha, at refinery | propane/ butane, at refinery | refinery gas, at refinery | secondary sulphur, at refinery | petroleum coke, at refinery | electricity, at refinery | sum product | Controll allokation |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Location | | | RER | | | | RER | RER | RER | RER | RER | RER | RER | RER | RER | RER | RER | RER | RER | |
| | InfrastructureProcess | | | 0 | | | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 9.87E-1 | |
| | Unit | | | kg | | | | kg | kg | kg | kg | kg | kg | kg | kg | kg | kg | kg | kWh | | |
| product | petrol, at refinery | RER | kg | 1.83E-1 | | | statista.com | 100 | - | - | - | - | - | - | - | - | - | - | - | 1.83E-1 | 100 |
| | bitumen, at refinery | RER | kg | 7.34E-4 | | | statista.com | - | 100 | - | - | - | - | - | - | - | - | - | - | 7.34E-4 | 100 |
| | diesel, at refinery | RER | kg | 3.84E-1 | | | statista.com | - | - | 100 | - | - | - | - | - | - | - | - | - | 3.84E-1 | 100 |
| | light fuel oil, at refinery | RER | kg | 1.09E-1 | | | statista.com | - | - | - | 100 | - | - | - | - | - | - | - | - | 1.09E-1 | 100 |
| | heavy fuel oil, at refinery | RER | kg | 1.18E-1 | | | statista.com | - | - | - | - | 100 | - | - | - | - | - | - | - | 1.18E-1 | 100 |
| | kerosene, at refinery | RER | kg | 7.18E-2 | | | statista.com | - | - | - | - | - | 100 | - | - | - | - | - | - | 7.18E-2 | 100 |
| | naphtha, at refinery | RER | kg | 6.22E-2 | | | statista.com | - | - | - | - | - | - | 100 | - | - | - | - | - | 6.22E-2 | 100 |
| | propane/ butane, at refinery | RER | kg | 2.49E-2 | | | statista.com | - | - | - | - | - | - | - | 100 | - | - | - | - | 2.49E-2 | 100 |
| | refinery gas, at refinery | RER | kg | 3.04E-2 | | | Calculated from consumption | - | - | - | - | - | - | - | - | 100 | - | - | - | 3.04E-2 | 100.0 |
| | secondary sulphur, at refinery | RER | kg | 3.71E-3 | | | statista.com | - | - | - | - | - | - | - | - | - | 100 | - | - | 3.71E-3 | 100.0 |
| | petroleum coke, at refinery | RER | kg | 1.32E-2 | | | statista.com | - | - | - | - | - | - | - | - | - | - | 100 | - | 1.32E-2 | 100.0 |
| | electricity, at refinery | RER | kWh | 2.15E-2 | | | Average of plant data | | | | | | | | | | | | 100 | 2.15E-2 | 100.0 |
| resource, in water | Water, unspecified natural origin, RER | - | m3 | 6.60E-3 | 1 | 1.07 | (1,2,1,1,1,3); Barthe et al 2015 | 18.2679 | 0.0734 | 38.3531 | 10.9034 | 11.7980 | 7.1733 | 6.2168 | 2.4867 | 3.0352 | 0.3710 | 1.3213 | - | 1.00E+0 | 100.0 |
| | Water, cooling, unspecified natural origin, RER | - | m3 | 7.69E-3 | 1 | 1.07 | (1,2,1,1,1,3); Barthe et al 2015 | 18.2679 | 0.0734 | 38.3531 | 10.9034 | 11.7980 | 7.1733 | 6.2168 | 2.4867 | 3.0352 | 0.3710 | 1.3213 | - | 1.00E+0 | 100.0 |
| water discharge | Water, RER | - | m3 | 1.43E-2 | 1 | 1.51 | (1,2,1,1,1,3); Barthe et al 2015 | 18.2679 | 0.0734 | 38.3531 | 10.9034 | 11.7980 | 7.1733 | 6.2168 | 2.4867 | 3.0352 | 0.3710 | 1.3213 | - | 1.00E+0 | 100.0 |
| technosphere | crude oil, import mix, at long distance transport | RER | kg | 1.00E+0 | 1 | 1.07 | (1,1,1,1,1,3); Reference flow of mulit-output proces | 18.1607 | 0.0697 | 38.4859 | 10.9157 | 11.3432 | 7.2316 | 6.5285 | 2.6694 | 3.4494 | 0.1654 | 0.9805 | - | 4.29E+1 | 100.0 |
| energy | electricity, medium voltage, production ENTSO, at grid | :NTS | kWh | 6.13E-2 | 1 | 1.06 | (1,1,2,1,1,1); Concawe data for 2010 | 30.0555 | 0.0843 | 27.7802 | 7.8976 | 10.9872 | 4.4535 | 10.2283 | 3.6282 | 2.9836 | 0.3839 | 1.5176 | - | 9.67E-1 | 100.0 |
| | natural gas, burned in industrial furnace low-NOx >100kW | RER | MJ | 5.20E-1 | 1 | 1.06 | (1,1,2,1,1,1); Concawe data for 2010 | 24.9733 | 0.0502 | 37.4507 | 10.6468 | 8.0643 | 7.0045 | 3.6423 | 3.6423 | 3.2601 | 0.3623 | 0.9031 | - | 1.02E+0 | 100.0 |
| | refinery gas, burned in furnace | RER | MJ | 1.48E+0 | 1 | 1.06 | (1,1,2,1,1,1); Concawe data for 2010 | 23.5 | 0.0 | 35.2 | 10.0 | 7.6 | 6.6 | 3.4 | 3.4 | 3.1 | 0.3 | 0.9 | 5.9 | 1.02E+0 | 100.0 |
| | heavy fuel oil, burned in refinery furnace | RER | MJ | 3.87E-1 | 1 | 1.06 | (1,1,2,1,1,1); Concawe data for 2010 | 23.5 | 0.0 | 35.2 | 10.0 | 7.6 | 6.6 | 3.4 | 3.4 | 3.1 | 0.3 | 0.9 | 5.9 | 1.02E+0 | 100.0 |
| | petroleum coke, burned in refinery furnace | RER | MJ | 4.20E-1 | 1 | 1.06 | (1,1,2,1,1,1); Concawe data for 2010 | 23.5 | 0.0 | 35.2 | 10.0 | 7.6 | 6.6 | 3.4 | 3.4 | 3.1 | 0.3 | 0.9 | 5.9 | 1.02E+0 | 100.0 |
| | refinery gas, burned in flare | GLO | MJ | 0 | 1 | 1.11 | (1,1,3,1,1,1); Concawe data for 2010 | 24.9733 | 0.0502 | 37.4507 | 10.6468 | 8.0643 | 7.0045 | 3.6423 | 3.6423 | 3.2601 | 0.3623 | 0.9031 | - | 1.02E+0 | 100.0 |
| | tap water, unspecified natural origin RER, at user | RER | kg | 1.52E-2 | 1 | 1.10 | (2,3,1,3,1,3); Average of plant data | 18.2679 | 0.0734 | 38.3531 | 10.9034 | 11.7980 | 7.1733 | 6.2168 | 2.4867 | 3.0352 | 0.3710 | 1.3213 | - | 1.00E+0 | 100.0 |
| chemicals | ammonia, liquid, at regional storehouse | RER | kg | 2.00E-6 | 1 | 1.60 | (3,4,5,3,3,na); Literature before 2003 | 18.3359 | 0.0737 | 38.4959 | 10.9440 | 11.8419 | 7.2000 | 6.2400 | 2.4960 | 3.0465 | - | 1.3262 | - | 9.97E-1 | 100.0 |
| | calcium chloride, CaCl2, at plant | RER | kg | 1.62E-5 | 1 | 1.60 | (3,4,5,3,3,na); Average of plant data | 18.2679 | 0.0734 | 38.3531 | 10.9034 | 11.7980 | 7.1733 | 6.2168 | 2.4867 | 3.0352 | 0.3710 | 1.3213 | - | 1.00E+0 | 100.0 |
| | chlorine, liquid, production mix, at plant | RER | kg | 4.20E-5 | 1 | 1.60 | (3,4,5,3,3,na); Env. reports DE | 71.4313 | - | - | - | - | - | 24.3091 | 0.5118 | 3.7478 | - | - | - | 9.72E-1 | 100.0 |
| | chemicals organic, at plant | GLO | kg | 3.00E-4 | 1 | 1.60 | (3,4,5,3,3,na); IPPC European plant data | 10.5160 | 0.2528 | 51.4179 | 15.3057 | 6.7916 | 4.4174 | 7.1456 | 1.4315 | 1.7472 | 0.2136 | 0.7606 | - | 5.23E-4 | 100 |
| | hydrochloric acid, 30% in H2O, at plant | RER | kg | 8.90E-5 | 1 | 1.60 | (3,4,5,3,3,na); Env. reports DE | 18.2679 | 0.0734 | 38.3531 | 10.9034 | 11.7980 | 7.1733 | 6.2168 | 2.4867 | 3.0352 | 0.3710 | 1.3213 | - | 1.00E+0 | 100 |
| | iron sulphate, at plant | RER | kg | 5.00E-5 | 1 | 1.60 | (3,4,5,3,3,na); Literature, waste water treatment | 18.2679 | 0.0734 | 38.3531 | 10.9034 | 11.7980 | 7.1733 | 6.2168 | 2.4867 | 3.0352 | 0.3710 | 1.3213 | - | 1.00E+0 | 100 |
| | lime, hydrated, packed, at plant | CH | kg | 3.50E-5 | 1 | 1.60 | (3,4,5,3,3,na); Estimation based on literature | 18.2679 | 0.0734 | 38.3531 | 10.9034 | 11.7980 | 7.1733 | 6.2168 | 2.4867 | 3.0352 | 0.3710 | 1.3213 | - | 1.00E+0 | 100 |
| | lubricating oil, at plant | RER | kg | 1.23E-5 | 1 | 1.14 | (2,4,1,3,1,3); Env. reports DE | 18.2679 | 0.0734 | 38.3531 | 10.9034 | 11.7980 | 7.1733 | 6.2168 | 2.4867 | 3.0352 | 0.3710 | 1.3213 | - | 1.00E+0 | 100 |
| | naphtha, at refinery | RER | kg | 0 | 1 | 1.60 | (3,4,5,3,3,na); Calculation as input-output balance, | 18.1607 | 0.0697 | 38.4859 | 10.9157 | 11.3432 | 7.2316 | 6.5285 | 2.6694 | 3.4494 | 0.1654 | 0.9805 | - | 4.29E+1 | 100 |
| | nitrogen, liquid, at plant | RER | kg | 1.13E-3 | 1 | 1.14 | (2,4,1,3,1,3); Env. reports DE | 18.2679 | 0.0734 | 38.3531 | 10.9034 | 11.7980 | 7.1733 | 6.2168 | 2.4867 | 3.0352 | 0.3710 | 1.3213 | - | 1.00E+0 | 100 |
| | propylene glycol, liquid, at plant | RER | kg | 6.00E-6 | 1 | 1.60 | (3,4,5,3,3,na); Literature | 68.7219 | 0.0077 | 4.0078 | 1.1394 | 1.2329 | 0.7496 | 23.3870 | 0.2599 | 0.3172 | 0.0388 | 0.1381 | - | 5.74E-5 | 100 |
| | soap, at plant | RER | kg | 2.68E-6 | 1 | 1.60 | (3,4,5,3,3,na); Average of plant data | 18.2679 | 0.0734 | 38.3531 | 10.9034 | 11.7980 | 7.1733 | 6.2168 | 2.4867 | 3.0352 | 0.3710 | 1.3213 | - | 1.00E+0 | 100 |
| | sodium hypochlorite, 15% in H2O, at plant | RER | kg | 5.00E-5 | 1 | 1.60 | (3,4,5,3,3,na); Literature, waste water treatment | 18.2679 | 0.0734 | 38.3531 | 10.9034 | 11.7980 | 7.1733 | 6.2168 | 2.4867 | 3.0352 | 0.3710 | 1.3213 | - | 1.00E+0 | 100 |
| | sodium hydroxide, 50% in H2O, production mix, at plant | RER | kg | 2.45E-4 | 1 | 1.60 | (3,4,5,3,3,na); Average of plant data | - | - | - | - | - | - | - | ####### | - | - | - | - | 2.49E-2 | 100 |
| | sulphuric acid, liquid, at plant | RER | kg | 9.69E-6 | 1 | 1.14 | (2,4,1,3,1,3); Env. reports DE | 18.2679 | 0.0734 | 38.3531 | 10.9034 | 11.7980 | 7.1733 | 6.2168 | 2.4867 | 3.0352 | 0.3710 | 1.3213 | - | 1.00E+0 | 100 |
| resource, in ground | Rhenium | - | kg | 8.01E-10 | 1 | 1.60 | (3,4,5,3,3,na); Range for RER refineries, Reformei | 94.3724 | - | - | - | - | - | - | 0.6761 | 4.9515 | - | - | - | 7.36E-1 | 100.0 |
| catalysts | molybdenum, at regional storage | RER | kg | 4.05E-8 | 1 | 1.60 | (3,4,5,3,3,na); Range for RER refineries, Co/Mo C | 41.0476 | - | 17.2357 | - | - | 14.5064 | 13.9691 | 5.5876 | 6.8200 | 0.8336 | - | - | 8.90E-1 | 100 |
| | cobalt, at plant | GLO | kg | 1.07E-8 | 1 | 1.60 | (3,4,5,3,3,na); Range for RER refineries, Co/Mo C | - | - | 77.8641 | 22.1359 | - | - | - | - | - | - | - | - | 1.23E+0 | 100.0 |
| | nickel, 99.5%, at plant | GLO | kg | 6.00E-9 | 1 | 1.60 | (3,4,5,3,3,na); Range for RER refineries, Ni/Mo Ca | 49.9367 | - | - | - | - | 17.9746 | 16.9942 | 6.7977 | 8.2969 | - | - | - | 8.78E-1 | 100 |
| | palladium, at regional storage | RER | kg | 2.53E-8 | 1 | 1.60 | (3,4,5,3,3,na); Range for RER refineries, Vanadiur | 70.9139 | - | - | - | - | - | 24.1330 | 2.0872 | 2.8659 | - | - | - | 9.54E-1 | 100 |
| | platinum, at regional storage | RER | kg | 8.01E-10 | 1 | 1.60 | (3,4,5,3,3,na); Range for RER refineries, Reformei | 70.9139 | - | - | - | - | - | 24.1330 | 2.0872 | 2.8659 | - | - | - | 9.54E-1 | 100 |
| | rhodium, at regional storage | RER | kg | 8.01E-10 | 1 | 1.60 | (3,4,5,3,3,na); Range for RER refineries, Reformei | 70.9139 | - | - | - | - | - | 24.1330 | 2.0872 | 2.8659 | - | - | - | 9.54E-1 | 100 |
| | zeolite, powder, at plant | RER | kg | 9.92E-6 | 1 | 1.60 | (3,4,5,3,3,na); Range for RER refineries | 39.7122 | - | 15.8809 | 4.5148 | 13.4343 | 5.1979 | 13.5146 | 3.3465 | 4.3987 | - | - | - | 9.66E-1 | 100 |
| | zinc, primary, at regional storage | RER | kg | 1.07E-7 | 1 | 1.60 | (3,4,5,3,3,na); Range for RER refineries, Zn Catal | 39.7122 | - | 15.8809 | 4.5148 | 13.4343 | 5.1979 | 13.5146 | 3.3465 | 4.3987 | - | - | - | 9.66E-1 | 100 |
| transport | transport, lorry >16t, fleet average | RER | tkm | 1.99E-4 | 1 | 2.09 | (4,5,na,na,na,na); Standard distance 100km | 18.2679 | 0.0734 | 38.3531 | 10.9034 | 11.7980 | 7.1733 | 6.2168 | 2.4867 | 3.0352 | 0.3710 | 1.3213 | - | 1.00E+0 | 100 |
| | transport, freight, rail | RER | tkm | 1.20E-3 | 1 | 2.09 | (4,5,na,na,na,na); Standard distance 600km | 18.2679 | 0.0734 | 38.3531 | 10.9034 | 11.7980 | 7.1733 | 6.2168 | 2.4867 | 3.0352 | 0.3710 | 1.3213 | - | 1.00E+0 | 100 |
| | refinery | RER | unit | 3.33E-11 | 1 | 3.30 | (3,4,5,3,3,na); Estimation | 24.9733 | 0.0502 | 37.4507 | 10.6468 | 8.0643 | 7.0045 | 3.6423 | 3.6423 | 3.2601 | 0.3623 | 0.9031 | - | 1.02E+0 | 100 |
| waste | disposal, municipal solid waste, 22.9% water, to municipal incineration | CH | kg | 1.45E-3 | 1 | 1.06 | (1,1,2,1,1,1); Concawe data for 2010 | 18.2679 | 0.0734 | 38.3531 | 10.9034 | 11.7980 | 7.1733 | 6.2168 | 2.4867 | 3.0352 | 0.3710 | 1.3213 | - | 1.00E+0 | 100 |
| | disposal, refinery sludge, 89.5% water, to hazardous waste incineration | CH | kg | 1.07E-3 | 1 | 1.06 | (1,1,2,1,1,1); Concawe data for 2010 | 18.2679 | 0.0734 | 38.3531 | 10.9034 | 11.7980 | 7.1733 | 6.2168 | 2.4867 | 3.0352 | 0.3710 | 1.3213 | - | 1.00E+0 | 100 |
| | disposal, catalytic converter NOx reduction, 0% water, to underground deposit | DE | kg | 1.00E-6 | 1 | 1.60 | (3,4,5,3,3,na); Estimation based on literature data | 39.7122 | - | 15.8809 | 4.5148 | 13.4343 | 5.1979 | 13.5146 | 3.3465 | 4.3987 | - | - | - | 9.66E-1 | 100 |
| emission air, high population density | Heat, waste | - | MJ | 2.21E-1 | 1 | 1.10 | (2,3,1,3,1,3); Calculation | 23.8167 | 0.0479 | 35.7161 | 10.1537 | 7.6908 | 6.6801 | 8.1052 | 3.4736 | 3.1092 | 0.3455 | 0.8613 | - | 1.07E+0 | 100 |
| | Ammonia | - | kg | 1.10E-6 | 1 | 1.21 | (1,2,1,1,1,3); Barthe et al 2015 | 18.2679 | 0.0734 | 38.3531 | 10.9034 | 11.7980 | 7.1733 | 6.2168 | 2.4867 | 3.0352 | 0.3710 | 1.3213 | - | 1.00E+0 | 100 |
| | Benzene | - | kg | 2.50E-6 | 1 | 3.00 | (1,2,1,1,1,3); Barthe et al 2015 | 18.3359 | 0.0737 | 38.4959 | 10.9440 | 11.8419 | 7.2000 | 6.2400 | 2.4960 | 3.0465 | - | 1.3262 | - | 9.97E-1 | 100 |
| | Benzene, ethyl- | - | kg | 1.02E-6 | 1 | 3.30 | (3,4,5,3,3,na); Literature | 18.3359 | 0.0737 | 38.4959 | 10.9440 | 11.8419 | 7.2000 | 6.2400 | 2.4960 | 3.0465 | - | 1.3262 | - | 9.97E-1 | 100 |
| | Butane | - | kg | 4.08E-5 | 1 | 1.85 | (3,4,5,3,3,na); Literature | 18.3359 | 0.0737 | 38.4959 | 10.9440 | 11.8419 | 7.2000 | 6.2400 | 2.4960 | 3.0465 | - | 1.3262 | - | 9.97E-1 | 100 |
| | Butene | - | kg | 1.02E-6 | 1 | 1.85 | (3,4,5,3,3,na); Literature | 18.3359 | 0.0737 | 38.4959 | 10.9440 | 11.8419 | 7.2000 | 6.2400 | 2.4960 | 3.0465 | - | 1.3262 | - | 9.97E-1 | 100 |
| | Dinitrogen monoxide | - | kg | 0 | 1 | 1.51 | (2,3,1,3,1,3); Not included because covered in fuel | 23.9 | 0.0 | 35.9 | 10.2 | 7.7 | 6.7 | 3.5 | 3.5 | 3.1 | 0.3 | 0.9 | 4.3 | 1.02E+0 | 100 |
| | Ethane | - | kg | 1.02E-5 | 1 | 1.85 | (3,4,5,3,3,na); Literature | 18.3359 | 0.0737 | 38.4959 | 10.9440 | 11.8419 | 7.2000 | 6.2400 | 2.4960 | 3.0465 | - | 1.3262 | - | 9.97E-1 | 100 |
| | Ethene | - | kg | 2.04E-6 | 1 | 1.85 | (3,4,5,3,3,na); Literature | 18.3359 | 0.0737 | 38.4959 | 10.9440 | 11.8419 | 7.2000 | 6.2400 | 2.4960 | 3.0465 | - | 1.3262 | - | 9.97E-1 | 100 |
| | Heptane | - | kg | 1.02E-5 | 1 | 1.85 | (3,4,5,3,3,na); Literature | 18.3359 | 0.0737 | 38.4959 | 10.9440 | 11.8419 | 7.2000 | 6.2400 | 2.4960 | 3.0465 | - | 1.3262 | - | 9.97E-1 | 100 |
| | Hexane | - | kg | 2.04E-5 | 1 | 1.85 | (3,4,5,3,3,na); Literature | 18.3359 | 0.0737 | 38.4959 | 10.9440 | 11.8419 | 7.2000 | 6.2400 | 2.4960 | 3.0465 | - | 1.3262 | - | 9.97E-1 | 100 |
| | Hydrocarbons, aliphatic, alkanes, unspecified | - | kg | 3.41E-11 | 1 | 1.85 | (3,4,5,3,3,na); Average of plant data | 18.3359 | 0.0737 | 38.4959 | 10.9440 | 11.8419 | 7.2000 | 6.2400 | 2.4960 | 3.0465 | - | 1.3262 | - | 9.97E-1 | 100 |
| | Hydrocarbons, aliphatic, unsaturated | - | kg | 1.88E-12 | 1 | 1.85 | (3,4,5,3,3,na); Average of plant data | 18.3359 | 0.0737 | 38.4959 | 10.9440 | 11.8419 | 7.2000 | 6.2400 | 2.4960 | 3.0465 | - | 1.3262 | - | 9.97E-1 | 100 |
| | Hydrocarbons, aromatic | - | kg | 5.12E-13 | 1 | 1.85 | (3,4,5,3,3,na); Average of plant data | 18.3359 | 0.0737 | 38.4959 | 10.9440 | 11.8419 | 7.2000 | 6.2400 | 2.4960 | 3.0465 | - | 1.3262 | - | 9.97E-1 | 100 |
| | Methane, fossil | - | kg | 8.50E-6 | 1 | 1.51 | (1,2,1,1,1,3); Barthe et al 2015 | 18.3359 | 0.0737 | 38.4959 | 10.9440 | 11.8419 | 7.2000 | 6.2400 | 2.4960 | 3.0465 | - | 1.3262 | - | 9.97E-1 | 100 |
| | Nickel | - | kg | 0 | 1 | 5.34 | (3,4,5,3,3,na); Not included because covered in fu | 18.3359 | 0.0737 | 38.4959 | 10.9440 | 11.8419 | 7.2000 | 6.2400 | 2.4960 | 3.0465 | - | 1.3262 | - | 9.97E-1 | 100 |
| | Nitrogen oxides | - | kg | 0 | 1 | 1.50 | (,,,,,); Not included because covered in fuel emissic | 23.9 | 0.0 | 35.9 | 10.2 | 7.7 | 6.7 | 3.5 | 3.5 | 3.1 | 0.3 | 0.9 | 4.3 | 1.02E+0 | 100 |
| | Particulates, > 10 um | - | kg | 1.50E-5 | 1 | 1.51 | (1,2,1,1,1,3); Barthe et al 2015 | 18.3359 | 0.0737 | 38.4959 | 10.9440 | 11.8419 | 7.2000 | 6.2400 | 2.4960 | 3.0465 | - | 1.3262 | - | 9.97E-1 | 100 |
| | Pentane | - | kg | 5.11E-5 | 1 | 1.85 | (3,4,5,3,3,na); Literature | 18.3359 | 0.0737 | 38.4959 | 10.9440 | 11.8419 | 7.2000 | 6.2400 | 2.4960 | 3.0465 | - | 1.3262 | - | 9.97E-1 | 100 |
| | Propane | - | kg | 4.08E-5 | 1 | 1.85 | (3,4,5,3,3,na); Literature | 18.3359 | 0.0737 | 38.4959 | 10.9440 | 11.8419 | 7.2000 | 6.2400 | 2.4960 | 3.0465 | - | 1.3262 | - | 9.97E-1 | 100 |
| | Propene | - | kg | 2.04E-6 | 1 | 1.85 | (3,4,5,3,3,na); Literature | 18.3359 | 0.0737 | 38.4959 | 10.9440 | 11.8419 | 7.2000 | 6.2400 | 2.4960 | 3.0465 | - | 1.3262 | - | 9.97E-1 | 100 |
| | Sulfur dioxide | - | kg | 0 | 1 | 1.05 | (,,,,,); Not included because covered in fuel emissic | 13.7 | 0.0 | 20.5 | 5.8 | 4.4 | 3.8 | 2.0 | 2.0 | 1.8 | 45.5 | 0.5 | - | 1.02E+0 | 99.982 |
| | Toluene | - | kg | 6.13E-6 | 1 | 1.85 | (3,4,5,3,3,na); Literature | 18.3359 | 0.0737 | 38.4959 | 10.9440 | 11.8419 | 7.2000 | 6.2400 | 2.4960 | 3.0465 | - | 1.3262 | - | 9.97E-1 | 100 |
| | Xylene | - | kg | 4.08E-6 | 1 | 1.85 | (3,4,5,3,3,na); Literature | 18.3359 | 0.0737 | 38.4959 | 10.9440 | 11.8419 | 7.2000 | 6.2400 | 2.4960 | 3.0465 | - | 1.3262 | - | 9.97E-1 | 100 |

| | Name | Location | Unit | crude oil, in refinery | UncertaintyType | StandardDeviation95% | GeneralComment | petrol, unleaded, at refinery | bitumen, at refinery | diesel, at refinery | light fuel oil, at refinery | heavy fuel oil, at refinery | kerosene, at refinery | naphtha, at refinery | propane/ butane, at refinery | refinery gas, at refinery | secondary sulphur, at refinery | petroleum coke, at refinery | electricity, at refinery | sum product | Controll allokation |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Location | | | RER | | | | RER | RER | RER | RER | RER | RER | RER | RER | RER | RER | RER | RER | RER | |
| | InfrastructureProcess | | | 0 | | | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 9.87E-1 | |
| | Unit | | | kg | | | | kg | kg | kg | kg | kg | kg | kg | kg | kg | kg | kg | kWh | | |
| emission water, river | Aluminium | - | kg | 4.67E-9 | 1 | 5.34 | (3,4,5,3,3,na); Literature | 18.2679 | 0.0734 | 38.3531 | 10.9034 | 11.7980 | 7.1733 | 6.2168 | 2.4867 | 3.0352 | 0.3710 | 1.3213 | - | 1.00E+0 | 100 |
| | Ammonium, ion | - | kg | 4.38E-7 | 1 | 1.51 | (1,2,1,1,1,3); Barthe et al 2015 | 19.8673 | 0.0363 | 41.7110 | 11.8580 | 5.8322 | 7.0921 | 6.7611 | 2.7045 | 3.3009 | 0.1834 | 0.6532 | - | 1.01E+0 | 100 |
| | AOX, Adsorbable Organic Halogen as Cl | - | kg | 2.19E-8 | 1 | 1.51 | (1,2,1,1,1,3); Barthe et al 2015 | 18.5191 | 0.0670 | 38.8804 | 11.0533 | 10.7642 | 7.2719 | 6.3023 | 2.5209 | 3.0769 | 0.3385 | 1.2055 | - | 9.87E-1 | 100 |
| | Arsenic | - | kg | 2.56E-10 | 1 | 5.00 | (1,2,1,1,1,3); Barthe et al 2015 | 18.1838 | 0.0731 | 38.1765 | 10.8532 | 12.9180 | 6.4262 | 6.1882 | 2.4753 | 3.0212 | 0.3693 | 1.3152 | - | 1.01E+0 | 100 |
| | Barium | - | kg | 9.34E-9 | 1 | 5.34 | (3,4,5,3,3,na); Literature | 18.2679 | 0.0734 | 38.3531 | 10.9034 | 11.7980 | 7.1733 | 6.2168 | 2.4867 | 3.0352 | 0.3710 | 1.3213 | - | 1.00E+0 | 100 |
| | Benzene | - | kg | 7.30E-10 | 1 | 3.00 | (1,2,1,1,1,3); Barthe et al 2015 | 18.5191 | 0.0670 | 38.8804 | 11.0533 | 10.7642 | 7.2719 | 6.3023 | 2.5209 | 3.0769 | 0.3385 | 1.2055 | - | 9.87E-1 | 100 |
| | Benzene, ethyl- | - | kg | 1.46E-9 | 1 | 3.00 | (1,2,1,1,1,3); Barthe et al 2015 | 18.1519 | 0.0802 | 38.1095 | 10.8341 | 12.8954 | 6.4149 | 6.1774 | 2.4709 | 3.0159 | 0.4055 | 1.4442 | - | 1.01E+0 | 100 |
| | BOD5, Biological Oxygen Demand | - | kg | 1.61E-6 | 1 | 1.51 | (1,2,1,1,1,3); Barthe et al 2015 | 19.9021 | 0.0291 | 41.7839 | 11.8787 | 5.8424 | 7.1045 | 6.7730 | 2.7092 | 3.3067 | 0.1470 | 0.5234 | - | 1.01E+0 | 100 |
| | Boron | - | kg | 9.64E-13 | 1 | 5.00 | (1,2,1,1,1,3); Barthe et al 2015 | 18.2679 | 0.0734 | 38.3531 | 10.9034 | 11.7980 | 7.1733 | 6.2168 | 2.4867 | 3.0352 | 0.3710 | 1.3213 | - | 1.00E+0 | 100 |
| | Cadmium | - | kg | 3.65E-10 | 1 | 3.00 | (1,2,1,1,1,3); Barthe et al 2015 | 18.1838 | 0.0731 | 38.1765 | 10.8532 | 12.9180 | 6.4262 | 6.1882 | 2.4753 | 3.0212 | 0.3693 | 1.3152 | - | 1.01E+0 | 100 |
| | Calcium | - | kg | 4.67E-6 | 1 | 3.30 | (3,4,5,3,3,na); Literature | 18.2679 | 0.0734 | 38.3531 | 10.9034 | 11.7980 | 7.1733 | 6.2168 | 2.4867 | 3.0352 | 0.3710 | 1.3213 | - | 1.00E+0 | 100 |
| | Chloride | - | kg | 5.36E-5 | 1 | 3.02 | (2,4,1,3,1,3); Env. reports DE | 18.2679 | 0.0734 | 38.3531 | 10.9034 | 11.7980 | 7.1733 | 6.2168 | 2.4867 | 3.0352 | 0.3710 | 1.3213 | - | 1.00E+0 | 100 |
| | Chromium | - | kg | 3.65E-10 | 1 | 3.00 | (1,2,1,1,1,3); Barthe et al 2015 | 18.1838 | 0.0731 | 38.1765 | 10.8532 | 12.9180 | 6.4262 | 6.1882 | 2.4753 | 3.0212 | 0.3693 | 1.3152 | - | 1.01E+0 | 100 |
| | Chromium VI | - | kg | 3.65E-10 | 1 | 3.00 | (1,2,1,1,1,3); Barthe et al 2015 | 18.1838 | 0.0731 | 38.1765 | 10.8532 | 12.9180 | 6.4262 | 6.1882 | 2.4753 | 3.0212 | 0.3693 | 1.3152 | - | 1.01E+0 | 100 |
| | COD, Chemical Oxygen Demand | - | kg | 9.93E-6 | 1 | 1.51 | (1,2,1,1,1,3); Barthe et al 2015 | 20.6453 | 0.0138 | 43.3443 | 12.3223 | 3.3333 | 6.7557 | 7.0259 | 2.8104 | 3.4302 | 0.0699 | 0.2489 | - | 1.06E+0 | 100 |
| | Cobalt | - | kg | 2.41E-15 | 1 | 3.00 | (1,2,1,1,1,3); Barthe et al 2015 | 18.1838 | 0.0731 | 38.1765 | 10.8532 | 12.9180 | 6.4262 | 6.1882 | 2.4753 | 3.0212 | 0.3693 | 1.3152 | - | 1.01E+0 | 100 |
| | Copper | - | kg | 7.30E-10 | 1 | 3.00 | (1,2,1,1,1,3); Barthe et al 2015 | 18.1838 | 0.0731 | 38.1765 | 10.8532 | 12.9180 | 6.4262 | 6.1882 | 2.4753 | 3.0212 | 0.3693 | 1.3152 | - | 1.01E+0 | 100 |
| | Cyanide | - | kg | 1.46E-9 | 1 | 3.00 | (1,2,1,1,1,3); Barthe et al 2015 | 18.2679 | 0.0734 | 38.3531 | 10.9034 | 11.7980 | 7.1733 | 6.2168 | 2.4867 | 3.0352 | 0.3710 | 1.3213 | - | 1.00E+0 | 100 |
| | DOC, Dissolved Organic Carbon | - | kg | 5.77E-9 | 1 | 1.85 | (3,4,5,3,3,na); Average of CH plant | 19.9021 | 0.0291 | 41.7839 | 11.8787 | 5.8424 | 7.1045 | 6.7730 | 2.7092 | 3.3067 | 0.1470 | 0.5234 | - | 1.01E+0 | 100 |
| | Fluoride | - | kg | 2.19E-7 | 1 | 1.51 | (1,2,1,1,1,3); Barthe et al 2015 | 18.2679 | 0.0734 | 38.3531 | 10.9034 | 11.7980 | 7.1733 | 6.2168 | 2.4867 | 3.0352 | 0.3710 | 1.3213 | - | 1.00E+0 | 100 |
| | Hydrocarbons, aromatic | - | kg | 3.65E-9 | 1 | 1.51 | (1,2,1,1,1,3); Barthe et al 2015 | 18.2679 | 0.0734 | 38.3531 | 10.9034 | 11.7980 | 7.1733 | 6.2168 | 2.4867 | 3.0352 | 0.3710 | 1.3213 | - | 1.00E+0 | 100 |
| | Hydrocarbons, unspecified | - | kg | 1.83E-7 | 1 | 1.51 | (1,2,1,1,1,3); Barthe et al 2015 | 29.8810 | 0.0300 | 15.6836 | 4.4587 | 19.2980 | 10.7556 | 10.1689 | 4.0676 | 4.9647 | 0.1517 | 0.5403 | - | 7.34E-1 | 100 |
| | Iron | - | kg | 5.48E-8 | 1 | 5.00 | (1,2,1,1,1,3); Barthe et al 2015 | 18.2679 | 0.0734 | 38.3531 | 10.9034 | 11.7980 | 7.1733 | 6.2168 | 2.4867 | 3.0352 | 0.3710 | 1.3213 | - | 1.00E+0 | 100 |
| | Lead | - | kg | 1.83E-9 | 1 | 5.00 | (1,2,1,1,1,3); Barthe et al 2015 | 18.1838 | 0.0731 | 38.1765 | 10.8532 | 12.9180 | 6.4262 | 6.1882 | 2.4753 | 3.0212 | 0.3693 | 1.3152 | - | 1.01E+0 | 100 |
| | Magnesium | - | kg | 2.33E-6 | 1 | 5.34 | (3,4,5,3,3,na); Literature | 18.2679 | 0.0734 | 38.3531 | 10.9034 | 11.7980 | 7.1733 | 6.2168 | 2.4867 | 3.0352 | 0.3710 | 1.3213 | - | 1.00E+0 | 100 |
| | Manganese | - | kg | 1.46E-8 | 1 | 5.00 | (1,2,1,1,1,3); Barthe et al 2015 | 18.2679 | 0.0734 | 38.3531 | 10.9034 | 11.7980 | 7.1733 | 6.2168 | 2.4867 | 3.0352 | 0.3710 | 1.3213 | - | 1.00E+0 | 100 |
| | Mercury | - | kg | 3.65E-11 | 1 | 5.00 | (1,2,1,1,1,3); Barthe et al 2015 | 18.2679 | 0.0734 | 38.3531 | 10.9034 | 11.7980 | 7.1733 | 6.2168 | 2.4867 | 3.0352 | 0.3710 | 1.3213 | - | 1.00E+0 | 100 |
| | Molybdenum | - | kg | 2.41E-14 | 1 | 5.00 | (1,2,1,1,1,3); Barthe et al 2015 | 18.2679 | 0.0734 | 38.3531 | 10.9034 | 11.7980 | 7.1733 | 6.2168 | 2.4867 | 3.0352 | 0.3710 | 1.3213 | - | 1.00E+0 | 100 |
| | Nickel | - | kg | 2.19E-9 | 1 | 5.00 | (1,2,1,1,1,3); Barthe et al 2015 | 18.1838 | 0.0731 | 38.1765 | 10.8532 | 12.9180 | 6.4262 | 6.1882 | 2.4753 | 3.0212 | 0.3693 | 1.3152 | - | 1.01E+0 | 100 |
| | Nitrate | - | kg | 2.26E-6 | 1 | 1.51 | (1,2,1,1,1,3); Barthe et al 2015 | 18.2679 | 0.0734 | 38.3531 | 10.9034 | 11.7980 | 7.1733 | 6.2168 | 2.4867 | 3.0352 | 0.3710 | 1.3213 | - | 1.00E+0 | 100 |
| | Nitrite | - | kg | 3.65E-8 | 1 | 1.51 | (1,2,1,1,1,3); Barthe et al 2015 | 18.2679 | 0.0734 | 38.3531 | 10.9034 | 11.7980 | 7.1733 | 6.2168 | 2.4867 | 3.0352 | 0.3710 | 1.3213 | - | 1.00E+0 | 100 |
| | Nitrogen, organic bound | - | kg | 1.46E-6 | 1 | 1.51 | (1,2,1,1,1,3); Barthe et al 2015 | 29.8810 | 0.0300 | 15.6836 | 4.4587 | 19.2980 | 10.7556 | 10.1689 | 4.0676 | 4.9647 | 0.1517 | 0.5403 | - | 7.34E-1 | 100 |
| | Oils, unspecified | - | kg | 2.48E-7 | 1 | 1.85 | (3,4,5,3,3,na); Literature before 2003 | 29.8810 | 0.0300 | 15.6836 | 4.4587 | 19.2980 | 10.7556 | 10.1689 | 4.0676 | 4.9647 | 0.1517 | 0.5403 | - | 7.34E-1 | 100 |
| | PAH, polycyclic aromatic hydrocarbons | - | kg | 1.10E-10 | 1 | 3.00 | (1,2,1,1,1,3); Barthe et al 2015 | 18.5191 | 0.0670 | 38.8804 | 11.0533 | 10.7642 | 7.2719 | 6.3023 | 2.5209 | 3.0769 | 0.3385 | 1.2055 | - | 9.87E-1 | 100 |
| | Phenol | - | kg | 7.30E-9 | 1 | 3.00 | (1,2,1,1,1,3); Barthe et al 2015 | 16.7477 | 0.1047 | 35.1615 | 9.9960 | 20.4306 | 4.3842 | 5.6995 | 2.2798 | 2.7826 | 0.5291 | 1.8843 | - | 9.82E-1 | 100 |
| | Phosphate | - | kg | 4.75E-8 | 1 | 1.51 | (1,2,1,1,1,3); Barthe et al 2015 | 18.2679 | 0.0734 | 38.3531 | 10.9034 | 11.7980 | 7.1733 | 6.2168 | 2.4867 | 3.0352 | 0.3710 | 1.3213 | - | 1.00E+0 | 100 |
| | Phosphorus | - | kg | 1.10E-7 | 1 | 1.51 | (1,2,1,1,1,3); Barthe et al 2015 | 18.2679 | 0.0734 | 38.3531 | 10.9034 | 11.7980 | 7.1733 | 6.2168 | 2.4867 | 3.0352 | 0.3710 | 1.3213 | - | 1.00E+0 | 100 |
| | Potassium | - | kg | 9.34E-7 | 1 | 5.34 | (3,4,5,3,3,na); Literature | 18.2679 | 0.0734 | 38.3531 | 10.9034 | 11.7980 | 7.1733 | 6.2168 | 2.4867 | 3.0352 | 0.3710 | 1.3213 | - | 1.00E+0 | 100 |
| | Selenium | - | kg | 9.64E-14 | 1 | 5.00 | (1,2,1,1,1,3); Barthe et al 2015 | 18.2679 | 0.0734 | 38.3531 | 10.9034 | 11.7980 | 7.1733 | 6.2168 | 2.4867 | 3.0352 | 0.3710 | 1.3213 | - | 1.00E+0 | 100 |
| | Silver | - | kg | 4.67E-9 | 1 | 5.34 | (3,4,5,3,3,na); Literature | 18.2679 | 0.0734 | 38.3531 | 10.9034 | 11.7980 | 7.1733 | 6.2168 | 2.4867 | 3.0352 | 0.3710 | 1.3213 | - | 1.00E+0 | 100 |
| | Sodium | - | kg | 2.80E-5 | 1 | 5.34 | (3,4,5,3,3,na); Literature | 18.2679 | 0.0734 | 38.3531 | 10.9034 | 11.7980 | 7.1733 | 6.2168 | 2.4867 | 3.0352 | 0.3710 | 1.3213 | - | 1.00E+0 | 100 |
| | Strontium | - | kg | 6.53E-8 | 1 | 5.34 | (3,4,5,3,3,na); Literature | 18.1838 | 0.0731 | 38.1765 | 10.8532 | 12.9180 | 6.4262 | 6.1882 | 2.4753 | 3.0212 | 0.3693 | 1.3152 | - | 1.01E+0 | 100 |
| | Sulfate | - | kg | 1.87E-5 | 1 | 1.85 | (3,4,5,3,3,na); Literature | 18.5191 | 0.0670 | 38.8804 | 11.0533 | 10.7642 | 7.2719 | 6.3023 | 2.5209 | 3.0769 | 0.3385 | 1.2055 | - | 9.87E-1 | 100 |
| | Sulfide | - | kg | 9.13E-9 | 1 | 1.51 | (1,2,1,1,1,3); Barthe et al 2015 | 18.2679 | 0.0734 | 38.3531 | 10.9034 | 11.7980 | 7.1733 | 6.2168 | 2.4867 | 3.0352 | 0.3710 | 1.3213 | - | 1.00E+0 | 100 |
| | Suspended solids, unspecified | - | kg | 2.30E-6 | 1 | 1.51 | (1,2,1,1,1,3); Barthe et al 2015 | 18.2679 | 0.0734 | 38.3531 | 10.9034 | 11.7980 | 7.1733 | 6.2168 | 2.4867 | 3.0352 | 0.3710 | 1.3213 | - | 1.00E+0 | 100 |
| | t-Butyl methyl ether | - | kg | 1.83E-9 | 1 | 3.00 | (1,2,1,1,1,3); Barthe et al 2015 | ####### | - | - | - | - | - | - | - | - | - | - | - | 1.83E-1 | 100 |
| | Tin | - | kg | 1.46E-9 | 1 | 5.00 | (1,2,1,1,1,3); Barthe et al 2015 | 18.1838 | 0.0731 | 38.1765 | 10.8532 | 12.9180 | 6.4262 | 6.1882 | 2.4753 | 3.0212 | 0.3693 | 1.3152 | - | 1.01E+0 | 100 |
| | TOC, Total Organic Carbon | - | kg | 2.01E-6 | 1 | 1.51 | (1,2,1,1,1,3); Barthe et al 2015 | 19.9021 | 0.0291 | 41.7839 | 11.8787 | 5.8424 | 7.1045 | 6.7730 | 2.7092 | 3.3067 | 0.1470 | 0.5234 | - | 1.01E+0 | 100 |
| | Toluene | - | kg | 1.46E-9 | 1 | 3.00 | (1,2,1,1,1,3); Barthe et al 2015 | 18.2679 | 0.0734 | 38.3531 | 10.9034 | 11.7980 | 7.1733 | 6.2168 | 2.4867 | 3.0352 | 0.3710 | 1.3213 | - | 1.00E+0 | 100 |
| | Vanadium | - | kg | 1.10E-9 | 1 | 5.00 | (1,2,1,1,1,3); Barthe et al 2015 | 18.1838 | 0.0731 | 38.1765 | 10.8532 | 12.9180 | 6.4262 | 6.1882 | 2.4753 | 3.0212 | 0.3693 | 1.3152 | - | 1.01E+0 | 100 |
| | Xylene | - | kg | 1.46E-9 | 1 | 3.00 | (1,2,1,1,1,3); Barthe et al 2015 | 18.2679 | 0.0734 | 38.3531 | 10.9034 | 11.7980 | 7.1733 | 6.2168 | 2.4867 | 3.0352 | 0.3710 | 1.3213 | - | 1.00E+0 | 100 |
| | Zinc | - | kg | 5.48E-9 | 1 | 5.00 | (1,2,1,1,1,3); Barthe et al 2015 | 18.1838 | 0.0731 | 38.1765 | 10.8532 | 12.9180 | 6.4262 | 6.1882 | 2.4753 | 3.0212 | 0.3693 | 1.3152 | - | 1.01E+0 | 100 |

| | Name | Location | Unit | crude oil, in refinery | UncertaintyType | StandardDeviation95% | GeneralComment | petrol, unleaded, at refinery | bitumen, at refinery | diesel, at refinery | light fuel oil, at refinery | heavy fuel oil, at refinery | kerosene, at refinery | naphtha, at refinery | propane/ butane, at refinery | refinery gas, at refinery | secondary sulphur, at refinery | petroleum coke, at refinery | electricity, at refinery | sum product | Controll allocation |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Location<br>InfrastructureProcess<br>Unit | | | RER<br>0<br>kg | | | | RER<br>0<br>kg | RER<br>0<br>kg | RER<br>0<br>kg | RER<br>0<br>kg | RER<br>0<br>kg | RER<br>0<br>kg | RER<br>0<br>kg | RER<br>0<br>kg | RER<br>0<br>kg | RER<br>0<br>kg | RER<br>0<br>kg | RER<br>0<br>kWh | RER<br>9.87E-1 | |
| emission water, ocean | Aluminium | - | kg | 8.13E-9 | 1 | 5.34 | (3,4,5,3,3,na); Literature | 18.3 | 0.07 | 38.4 | 10.9 | 11.8 | 7.2 | 6.2 | 2.5 | 3.0 | 0.4 | 1.3 | - | | |
| | Ammonium, ion | - | kg | 7.62E-7 | 1 | 1.51 | (1,2,1,1,1,3); Barthe et al 2015 | 19.9 | 0.04 | 41.7 | 11.9 | 5.8 | 7.1 | 6.8 | 2.7 | 3.3 | 0.2 | 0.7 | - | | |
| | AOX, Adsorbable Organic Halogen as Cl | - | kg | 3.81E-8 | 1 | 1.51 | (1,2,1,1,1,3); Barthe et al 2015 | 18.5 | 0.07 | 38.9 | 11.1 | 10.8 | 7.3 | 6.3 | 2.5 | 3.1 | 0.3 | 1.2 | 1.0 | | |
| | Arsenic | - | kg | 4.45E-10 | 1 | 5.00 | (1,2,1,1,1,3); Barthe et al 2015 | 18.2 | 0.07 | 38.2 | 10.9 | 12.9 | 6.4 | 6.2 | 2.5 | 3.0 | 0.4 | 1.3 | 2.0 | | |
| | Barium | - | kg | 1.63E-8 | 1 | 5.34 | (3,4,5,3,3,na); Literature | 18.3 | 0.07 | 38.4 | 10.9 | 11.8 | 7.2 | 6.2 | 2.5 | 3.0 | 0.4 | 1.3 | 3.0 | | |
| | Benzene | - | kg | 1.27E-9 | 1 | 3.00 | (1,2,1,1,1,3); Barthe et al 2015 | 18.5 | 0.07 | 38.9 | 11.1 | 10.8 | 7.3 | 6.3 | 2.5 | 3.1 | 0.3 | 1.2 | 4.0 | | |
| | Benzene, ethyl- | - | kg | 2.54E-9 | 1 | 3.00 | (1,2,1,1,1,3); Barthe et al 2015 | 18.2 | 0.08 | 38.1 | 10.8 | 12.9 | 6.4 | 6.2 | 2.5 | 3.0 | 0.4 | 1.4 | 5.0 | | |
| | BOD5, Biological Oxygen Demand | - | kg | 2.79E-6 | 1 | 1.51 | (1,2,1,1,1,3); Barthe et al 2015 | 19.9 | 0.03 | 41.8 | 11.9 | 5.8 | 7.1 | 6.8 | 2.7 | 3.3 | 0.1 | 0.5 | 6.0 | | |
| | Boron | - | kg | 1.68E-12 | 1 | 5.00 | (1,2,1,1,1,3); Barthe et al 2015 | 18.3 | 0.07 | 38.4 | 10.9 | 11.8 | 7.2 | 6.2 | 2.5 | 3.0 | 0.4 | 1.3 | 7.0 | | |
| | Cadmium | - | kg | 6.35E-10 | 1 | 3.00 | (1,2,1,1,1,3); Barthe et al 2015 | 18.2 | 0.07 | 38.2 | 10.9 | 12.9 | 6.4 | 6.2 | 2.5 | 3.0 | 0.4 | 1.3 | 8.0 | | |
| | Calcium | - | kg | 8.13E-6 | 1 | 3.30 | (3,4,5,3,3,na); Literature | 18.3 | 0.07 | 38.4 | 10.9 | 11.8 | 7.2 | 6.2 | 2.5 | 3.0 | 0.4 | 1.3 | 9.0 | | |
| | Chloride | - | kg | 9.33E-5 | 1 | 3.02 | (2,4,1,3,1,3); Env. reports DE | 18.3 | 0.07 | 38.4 | 10.9 | 11.8 | 7.2 | 6.2 | 2.5 | 3.0 | 0.4 | 1.3 | 10.0 | | |
| | Chromium | - | kg | 6.35E-10 | 1 | 3.00 | (1,2,1,1,1,3); Barthe et al 2015 | 18.2 | 0.07 | 38.2 | 10.9 | 12.9 | 6.4 | 6.2 | 2.5 | 3.0 | 0.4 | 1.3 | 11.0 | | |
| | Chromium VI | - | kg | 6.35E-10 | 1 | 3.00 | (1,2,1,1,1,3); Barthe et al 2015 | 18.2 | 0.07 | 38.2 | 10.9 | 12.9 | 6.4 | 6.2 | 2.5 | 3.0 | 0.4 | 1.3 | 12.0 | | |
| | COD, Chemical Oxygen Demand | - | kg | 1.73E-5 | 1 | 1.51 | (1,2,1,1,1,3); Barthe et al 2015 | 20.6 | 0.01 | 43.3 | 12.3 | 3.3 | 6.8 | 7.0 | 2.8 | 3.4 | 0.1 | 0.2 | 13.0 | | |
| | Cobalt | - | kg | 4.19E-15 | 1 | 3.00 | (1,2,1,1,1,3); Barthe et al 2015 | 18.2 | 0.07 | 38.2 | 10.9 | 12.9 | 6.4 | 6.2 | 2.5 | 3.0 | 0.4 | 1.3 | 14.0 | | |
| | Copper | - | kg | 1.27E-9 | 1 | 3.00 | (1,2,1,1,1,3); Barthe et al 2015 | 18.2 | 0.07 | 38.2 | 10.9 | 12.9 | 6.4 | 6.2 | 2.5 | 3.0 | 0.4 | 1.3 | 15.0 | | |
| | Cyanide | - | kg | 2.54E-9 | 1 | 3.00 | (1,2,1,1,1,3); Barthe et al 2015 | 18.3 | 0.07 | 38.4 | 10.9 | 11.8 | 7.2 | 6.2 | 2.5 | 3.0 | 0.4 | 1.3 | 16.0 | | |
| | DOC, Dissolved Organic Carbon | - | kg | 1.00E-8 | 1 | 1.85 | (3,4,5,3,3,na); Average of CH plant | 19.9 | 0.03 | 41.8 | 11.9 | 5.8 | 7.1 | 6.8 | 2.7 | 3.3 | 0.1 | 0.5 | 17.0 | | |
| | Fluoride | - | kg | 3.81E-7 | 1 | 1.51 | (1,2,1,1,1,3); Barthe et al 2015 | 18.3 | 0.07 | 38.4 | 10.9 | 11.8 | 7.2 | 6.2 | 2.5 | 3.0 | 0.4 | 1.3 | 18.0 | | |
| | Hydrocarbons, aromatic | - | kg | 6.35E-9 | 1 | 1.51 | (1,2,1,1,1,3); Barthe et al 2015 | 18.3 | 0.07 | 38.4 | 10.9 | 11.8 | 7.2 | 6.2 | 2.5 | 3.0 | 0.4 | 1.3 | 19.0 | | |
| | Hydrocarbons, unspecified | - | kg | 3.18E-7 | 1 | 1.51 | (1,2,1,1,1,3); Barthe et al 2015 | 29.9 | 0.03 | 15.7 | 4.5 | 19.3 | 10.8 | 10.2 | 4.1 | 5.0 | 0.2 | 0.5 | 20.0 | | |
| | Iron | - | kg | 9.53E-8 | 1 | 5.00 | (1,2,1,1,1,3); Barthe et al 2015 | 18.3 | 0.07 | 38.4 | 10.9 | 11.8 | 7.2 | 6.2 | 2.5 | 3.0 | 0.4 | 1.3 | 21.0 | | |
| | Lead | - | kg | 3.18E-9 | 1 | 5.00 | (1,2,1,1,1,3); Barthe et al 2015 | 18.2 | 0.07 | 38.2 | 10.9 | 12.9 | 6.4 | 6.2 | 2.5 | 3.0 | 0.4 | 1.3 | 22.0 | | |
| | Magnesium | - | kg | 4.06E-6 | 1 | 5.34 | (3,4,5,3,3,na); Literature | 18.3 | 0.07 | 38.4 | 10.9 | 11.8 | 7.2 | 6.2 | 2.5 | 3.0 | 0.4 | 1.3 | 23.0 | | |
| | Manganese | - | kg | 2.54E-8 | 1 | 5.00 | (1,2,1,1,1,3); Barthe et al 2015 | 18.3 | 0.07 | 38.4 | 10.9 | 11.8 | 7.2 | 6.2 | 2.5 | 3.0 | 0.4 | 1.3 | 24.0 | | |
| | Mercury | - | kg | 6.35E-11 | 1 | 5.00 | (1,2,1,1,1,3); Barthe et al 2015 | 18.3 | 0.07 | 38.4 | 10.9 | 11.8 | 7.2 | 6.2 | 2.5 | 3.0 | 0.4 | 1.3 | 25.0 | | |
| | Molybdenum | - | kg | 4.19E-14 | 1 | 5.00 | (1,2,1,1,1,3); Barthe et al 2015 | 18.3 | 0.07 | 38.4 | 10.9 | 11.8 | 7.2 | 6.2 | 2.5 | 3.0 | 0.4 | 1.3 | 26.0 | | |
| | Nickel | - | kg | 3.81E-9 | 1 | 5.00 | (1,2,1,1,1,3); Barthe et al 2015 | 18.2 | 0.07 | 38.2 | 10.9 | 12.9 | 6.4 | 6.2 | 2.5 | 3.0 | 0.4 | 1.3 | 27.0 | | |
| | Nitrate | - | kg | 3.94E-6 | 1 | 1.51 | (1,2,1,1,1,3); Barthe et al 2015 | 18.3 | 0.07 | 38.4 | 10.9 | 11.8 | 7.2 | 6.2 | 2.5 | 3.0 | 0.4 | 1.3 | 28.0 | | |
| | Nitrite | - | kg | 6.35E-8 | 1 | 1.51 | (1,2,1,1,1,3); Barthe et al 2015 | 18.3 | 0.07 | 38.4 | 10.9 | 11.8 | 7.2 | 6.2 | 2.5 | 3.0 | 0.4 | 1.3 | 29.0 | | |
| | Nitrogen, organic bound | - | kg | 2.54E-6 | 1 | 1.51 | (1,2,1,1,1,3); Barthe et al 2015 | 29.9 | 0.03 | 15.7 | 4.5 | 19.3 | 10.8 | 10.2 | 4.1 | 5.0 | 0.2 | 0.5 | 30.0 | | |
| | Oils, unspecified | - | kg | 4.31E-7 | 1 | 1.85 | (3,4,5,3,3,na); Literature before 2003 | 29.9 | 0.03 | 15.7 | 4.5 | 19.3 | 10.8 | 10.2 | 4.1 | 5.0 | 0.2 | 0.5 | 31.0 | | |
| | PAH, polycyclic aromatic hydrocarbons | - | kg | 1.91E-10 | 1 | 3.00 | (1,2,1,1,1,3); Barthe et al 2015 | 18.5 | 0.07 | 38.9 | 11.1 | 10.8 | 7.3 | 6.3 | 2.5 | 3.1 | 0.3 | 1.2 | 32.0 | | |
| | Phenol | - | kg | 1.27E-8 | 1 | 3.00 | (1,2,1,1,1,3); Barthe et al 2015 | 16.7 | 0.10 | 35.2 | 10.0 | 20.4 | 4.4 | 5.7 | 2.3 | 2.8 | 0.5 | 1.9 | 33.0 | | |
| | Phosphate | - | kg | 8.26E-8 | 1 | 1.51 | (1,2,1,1,1,3); Barthe et al 2015 | 18.3 | 0.07 | 38.4 | 10.9 | 11.8 | 7.2 | 6.2 | 2.5 | 3.0 | 0.4 | 1.3 | 34.0 | | |
| | Phosphorus | - | kg | 1.91E-7 | 1 | 1.51 | (1,2,1,1,1,3); Barthe et al 2015 | 18.3 | 0.07 | 38.4 | 10.9 | 11.8 | 7.2 | 6.2 | 2.5 | 3.0 | 0.4 | 1.3 | 35.0 | | |
| | Potassium | - | kg | 1.63E-6 | 1 | 5.34 | (3,4,5,3,3,na); Literature | 18.3 | 0.07 | 38.4 | 10.9 | 11.8 | 7.2 | 6.2 | 2.5 | 3.0 | 0.4 | 1.3 | 36.0 | | |
| | Selenium | - | kg | 1.68E-13 | 1 | 5.00 | (1,2,1,1,1,3); Barthe et al 2015 | 18.3 | 0.07 | 38.4 | 10.9 | 11.8 | 7.2 | 6.2 | 2.5 | 3.0 | 0.4 | 1.3 | 37.0 | | |
| | Silver | - | kg | 8.13E-9 | 1 | 5.34 | (3,4,5,3,3,na); Literature | 18.3 | 0.07 | 38.4 | 10.9 | 11.8 | 7.2 | 6.2 | 2.5 | 3.0 | 0.4 | 1.3 | 38.0 | | |
| | Sodium | - | kg | 4.87E-5 | 1 | 5.34 | (3,4,5,3,3,na); Literature | 18.3 | 0.07 | 38.4 | 10.9 | 11.8 | 7.2 | 6.2 | 2.5 | 3.0 | 0.4 | 1.3 | 39.0 | | |
| | Strontium | - | kg | 1.14E-7 | 1 | 5.34 | (3,4,5,3,3,na); Literature | 18.2 | 0.07 | 38.2 | 10.9 | 12.9 | 6.4 | 6.2 | 2.5 | 3.0 | 0.4 | 1.3 | 40.0 | | |
| | Sulfate | - | kg | 3.24E-5 | 1 | 1.85 | (3,4,5,3,3,na); Literature | 18.5 | 0.07 | 38.9 | 11.1 | 10.8 | 7.3 | 6.3 | 2.5 | 3.1 | 0.3 | 1.2 | 41.0 | | |
| | Sulfide | - | kg | 1.59E-8 | 1 | 1.51 | (1,2,1,1,1,3); Barthe et al 2015 | 18.3 | 0.07 | 38.4 | 10.9 | 11.8 | 7.2 | 6.2 | 2.5 | 3.0 | 0.4 | 1.3 | 42.0 | | |
| | Suspended solids, unspecified | - | kg | 4.00E-6 | 1 | 1.51 | (1,2,1,1,1,3); Barthe et al 2015 | 18.3 | 0.07 | 38.4 | 10.9 | 11.8 | 7.2 | 6.2 | 2.5 | 3.0 | 0.4 | 1.3 | 43.0 | | |
| | t-Butyl methyl ether | - | kg | 3.18E-9 | 1 | 3.00 | (1,2,1,1,1,3); Barthe et al 2015 | 100.0 | - | - | - | - | - | - | - | - | - | - | 44.0 | | |
| | Tin | - | kg | 2.54E-9 | 1 | 5.00 | (1,2,1,1,1,3); Barthe et al 2015 | 18.2 | 0.07 | 38.2 | 10.9 | 12.9 | 6.4 | 6.2 | 2.5 | 3.0 | 0.4 | 1.3 | 45.0 | | |
| | TOC, Total Organic Carbon | - | kg | 3.49E-6 | 1 | 1.51 | (1,2,1,1,1,3); Barthe et al 2015 | 19.9 | 0.03 | 41.8 | 11.9 | 5.8 | 7.1 | 6.8 | 2.7 | 3.3 | 0.1 | 0.5 | 46.0 | | |
| | Toluene | - | kg | 2.54E-9 | 1 | 3.00 | (1,2,1,1,1,3); Barthe et al 2015 | 18.3 | 0.07 | 38.4 | 10.9 | 11.8 | 7.2 | 6.2 | 2.5 | 3.0 | 0.4 | 1.3 | 47.0 | | |
| | Vanadium | - | kg | 1.91E-9 | 1 | 5.00 | (1,2,1,1,1,3); Barthe et al 2015 | 18.2 | 0.07 | 38.2 | 10.9 | 12.9 | 6.4 | 6.2 | 2.5 | 3.0 | 0.4 | 1.3 | 48.0 | | |
| | Xylene | - | kg | 2.54E-9 | 1 | 3.00 | (1,2,1,1,1,3); Barthe et al 2015 | 18.3 | 0.07 | 38.4 | 10.9 | 11.8 | 7.2 | 6.2 | 2.5 | 3.0 | 0.4 | 1.3 | 49.0 | | |
| | Zinc | - | kg | 9.53E-9 | 1 | 5.00 | (1,2,1,1,1,3); Barthe et al 2015 | 18.2 | 0.07 | 38.2 | 10.9 | 12.9 | 6.4 | 6.2 | 2.5 | 3.0 | 0.4 | 1.3 | 50.0 | | |
| | | | | | | | | | | | | | | | | | | | - | | |
| Total products | | | | 1.000 | | | | 18.1840 | 0.0730 | | | | | | | | | | - | | |
| Total crude oil | | | | 1.000 | | | | | | | | | | | | | | | - | | |
| Total additives | | | | 4.07E-4 | | | | | | | | | | | | | | | | | |

| Name | petrol, unleaded, at refinery | bitumen, at refinery | diesel, at refinery | light fuel oil, at refinery | heavy fuel oil, at refinery | kerosene, at refinery | naphtha, at refinery | propane/ butane, at refinery | refinery gas, at refinery | secondary sulphur, at refinery | petroleum coke, at refinery | electricity, at refinery | | Tab. 9.61 | mean values | estimation water emmissions | crude oil, in refinery | crude oil, in refinery Godorf | crude oil, in refinery Harburg | crude oil, in refinery | crude oil, in refinery, Naantali | crude oil, in refinery, Porvoo | crude oil, in refinery | crude oil, in refinery, Concawe, IEA |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Location | | | | | | | | | | | | | | 0 | RER | RER | RER | DE | DE | FR | FI | FI | SE | RER |
| InfrastructureProcess | | | | | | | | | | | | | | 0 | 0 | 2007 | 1996 | 2000 | 2000 | 2001 | 2002 | 2002 | 1999 | 1998 |
| Unit | kg | kg | kg | kg | kg | kg | kg | kg | kg | kg | kg | kWh | | 0 | kg, mg/l | mg/l | kg | kg | kg | kg | kg | kg | kg | kg |
| petrol, at refinery | 1 | | | | | | | | | | | | petrol, at refinery | kg | 2.77E-1 | | | 2.13E-1 | 2.94E-1 | 1.93E-1 | 2.89E-1 | 4.04E-1 | 2.69E-1 | 2.15E-1 |
| bitumen, at refinery | | 1 | | | | | | | | | | | bitumen, at refinery | kg | 7.08E-3 | | | - | - | 4.23E-2 | 1.11E-4 | 1.93E-6 | - | 1.09E-3 |
| diesel, at refinery | | | 1 | | | | | | | | | | diesel, at refinery | kg | 1.21E-1 | | | 2.13E-1 | 2.61E-1 | 2.50E-1 | - | - | - | 1.00E-1 |
| light fuel oil, at refinery | | | | 1 | | | | | | | | | light fuel oil, at refinery | kg | 3.22E-1 | | | 1.88E-1 | 2.06E-1 | 1.42E-1 | 4.33E-1 | 5.91E-1 | 3.74E-1 | 2.68E-1 |
| heavy fuel oil, at refinery | | | | | 1 | | | | | | | | heavy fuel oil, at refinery | kg | 3.83E-1 | | | 8.06E-1 | 9.58E-1 | 1.20E-1 | 1.44E-1 | 1.29E-4 | 2.69E-1 | 1.76E-1 |
| kerosene, at refinery | | | | | | 1 | | | | | | | kerosene, at refinery | kg | 2.04E-2 | | | 1.10E-1 | 1.17E-2 | 7.88E-4 | - | - | - | 6.68E-2 |
| naphtha, at refinery | | | | | | | 1 | | | | | | naphtha, at refinery | kg | 1.01E-1 | | | 2.85E-1 | 5.70E-2 | 2.62E-1 | 5.78E-5 | - | - | 6.79E-2 |
| propane/ butane, at refinery | | | | | | | | 1 | | | | | propane/ butane, at refinery | kg | 1.07E-2 | | | 1.63E-2 | 1.23E-2 | 2.61E-2 | 1.23E-5 | 2.68E-5 | 9.60E-3 | 2.83E-2 |
| refinery gas, at refinery | | | | | | | | | 1 | | | | refinery gas, at refinery | kg | 7.57E-1 | | | 2.44E+0 | 2.04E+0 | 2.89E-2 | - | - | 3.84E-2 | 1.17E-1 |
| secondary sulphur, at refinery | | | | | | | | | | 1 | | | secondary sulphur, at refinery | kg | 3.35E-3 | | | 2.94E-3 | 2.78E-3 | 2.66E-3 | 4.23E-3 | 4.30E-3 | 3.18E-3 | 5.53E-3 |
| petroleum coke, at refinery | | | | | | | | | | | 1 | | petroleum coke, at refinery | kg | 1.80E-3 | | | - | - | 1.08E-2 | - | - | - | 2.78E-4 |
| electricity, at refinery | | | | | | | | | | | | 1 | electricity, at refinery | kWh | 2.07E-2 | | | 1.43E-2 | 2.67E-3 | - | - | 6.58E-2 | - | - |
| Water, unspecified natural origin, RER | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | Water, unspecified natural origin, RER | m3 | 3.95E-4 | | 4.10E-3 | 4.96E-4 | 3.60E-4 | - | 3.32E-4 | 7.52E-4 | 2.53E-4 | 4.70E-4 |
| Water, cooling, unspecified natural origin, RER | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | Water, cooling, unspecified natural origin, RER | m3 | 9.69E-3 | | | 7.81E-5 | 3.16E-3 | - | 8.46E-4 | 5.80E-2 | 6.64E-4 | 4.23E-3 |
| Water, RER | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | Water, RER | m3 | 4.53E-4 | | 4.10E-3 | 4.96E-4 | 3.60E-4 | - | 3.32E-4 | 7.52E-4 | 6.64E-4 | 4.70E-4 |
| crude oil, import mix, at long distance transport | 42.6 | 40.7 | 43 | 42.9 | 41.2 | 43.2 | 45 | 46 | 48.7 | 19.1 | 31.8 | 0 | crude oil, import mix, at long distance transport | kg | 1.16E-1 | | 1.06E+0 | 1.00E+0 | 1.00E+0 | - | 1.00E+0 | 1.00E+0 | 1.00E+0 | 1.00E+0 |
| electricity, medium voltage, production ENTSO, at grid | 1.59 | 1.11 | 0.7 | 0.7 | 0.9 | 0.6 | 1.59 | 1.41 | 0.95 | 1 | 1.11 | 0 | electricity, medium voltage, production ENTSO, at grid | kWh | 3.71E-2 | | 3.89E-2 | 1.06E-4 | 4.37E-3 | - | 7.11E-2 | 7.27E-2 | - | - |
| natural gas, burned in industrial furnace low-NOx >100kW | 1.4 | 0.7 | 1 | 1 | 0.7 | 1 | 0.6 | 1.5 | 1.1 | 1 | 0.7 | 0 | natural gas, burned in industrial furnace low-NOx >100kW | MJ | na | | | | | | | | | |
| refinery gas, burned in furnace | 1.4 | 0.7 | 1 | 1 | 0.7 | 1 | 0.6 | 1.5 | 1.1 | 1 | 0.7 | 0 | refinery gas, burned in furnace | MJ | 1.90E+0 | | 1.95E+0 | 2.43E+0 | 2.04E+0 | 1.33E+0 | - | 1.08E+0 | 1.79E+0 | 1.86E+0 |
| heavy fuel oil, burned in refinery furnace | 1.4 | 0.7 | 1 | 1 | 0.7 | 1 | 0.6 | 1.5 | 1.1 | 1 | 0.7 | 0 | heavy fuel oil, burned in refinery furnace | MJ | 7.97E-1 | | 9.72E-1 | 7.35E-1 | 7.38E-1 | 9.71E-1 | - | 4.63E-1 | - | 6.76E-1 |
| petroleum coke, burned in refinery furnace | 1.4 | 0.7 | 1 | 1 | 0.7 | 1 | 0.6 | 1.5 | 1.1 | 1 | 0.7 | 0 | petroleum coke, burned in refinery furnace | MJ | 6.85E-1 | | 9.72E-1 | 7.35E-1 | 7.38E-1 | 9.71E-1 | - | 4.63E-1 | - | - |
| refinery gas, burned in flare | 1.4 | 0.7 | 1 | 1 | 0.7 | 1 | 0.6 | 1.5 | 1.1 | 1 | 0.7 | 0 | refinery gas, burned in flare | MJ | na | | 1.51E-1 | - | - | - | - | - | - | - |
| tap water, unspecified natural origin RER, at user | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | | tap water, unspecified natural origin RER, at user | kg | 1.52E-2 | | | 9.66E-2 | 2.50E-2 | - | - | - | - | - |
| ammonia, liquid, at regional storehouse | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | | 1 | | ammonia, liquid, at regional storehouse | kg | na | | 2.00E-6 | - | - | - | - | - | - | - |
| calcium chloride, CaCl2, at plant | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | | calcium chloride, CaCl2, at plant | kg | 1.62E-5 | | | 2.91E-5 | 3.37E-6 | - | - | - | - | - |
| chlorine, liquid, production mix, at plant | 3.8 | | | | | | 3.8 | 0.2 | 1.2 | | | | chlorine, liquid, production mix, at plant | kg | 4.20E-5 | | 1.50E-6 | 7.52E-5 | 8.80E-6 | - | - | - | - | - |
| chemicals organic, at plant | 3.01E-4 | 1.80E-03 | 7.01E-04 | 7.34E-04 | 3.01E-4 | 3.22E-4 | 6.01E-4 | 3.01E-4 | 3.01E-4 | 3.01E-4 | 3.01E-4 | | chemicals organic, at plant | kg | 6.92E-3 | | 6.50E-6 | 6.90E-3 | 6.95E-3 | - | - | - | - | - |
| hydrochloric acid, 30% in H2O, at plant | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | | hydrochloric acid, 30% in H2O, at plant | kg | 8.90E-5 | | | 9.23E-5 | 8.57E-5 | - | - | - | - | - |
| iron sulphate, at plant | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | | iron sulphate, at plant | kg | na | | 5.00E-5 | - | - | - | - | - | - | - |
| lime, hydrated, packed, at plant | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | | lime, hydrated, packed, at plant | kg | 2.84E-5 | | 4.00E-5 | 2.84E-5 | - | - | - | - | - | - |
| lubricating oil, at plant | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | | lubricating oil, at plant | kg | 2.48E-5 | | | 2.99E-5 | 1.97E-5 | - | - | - | - | - |
| naphtha, at refinery | 42.6 | 40.7 | 43.0 | 42.9 | 41.2 | 43.2 | 45.0 | 46.0 | 48.7 | 19.1 | 31.8 | 0.0 | naphtha, at refinery | kg | 1.15E-1 | | | 1.55E-1 | 9.57E-2 | - | 1.04E-1 | 1.04E-1 | - | - |
| nitrogen, liquid, at plant | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | | nitrogen, liquid, at plant | kg | 8.24E-4 | | 9.00E-5 | 1.24E-3 | 4.10E-4 | - | - | - | - | - |
| propylene glycol, liquid, at plant | 0.000216 | 0.000006 | 0.000006 | 0.000006 | 0.000006 | 0.000006 | 0.000216 | 0.000006 | 0.000006 | 0.000006 | 0.000006 | | propylene glycol, liquid, at plant | kg | na | | 6.00E-6 | - | - | - | - | - | - | - |
| soap, at plant | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | | soap, at plant | kg | 2.68E-6 | | | 3.17E-6 | 2.18E-6 | - | - | - | - | - |
| sodium hypochlorite, 15% in H2O, at plant | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | | sodium hypochlorite, 15% in H2O, at plant | kg | na | | 5.00E-5 | - | - | - | - | - | - | - |
| sodium hydroxide, 50% in H2O, production mix, at plant | | | | | | | | 1 | | | | | sodium hydroxide, 50% in H2O, production mix, at plant | kg | 2.45E-4 | | 1.60E-4 | 1.09E-4 | 3.81E-4 | - | - | - | - | - |
| sulphuric acid, liquid, at plant | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | | sulphuric acid, liquid, at plant | kg | 1.19E-5 | | | 1.55E-5 | 8.34E-6 | - | - | - | - | - |
| Rhenium | 3.8 | | | | | | | 0.2 | 1.2 | | | | Rhenium | kg | 2.24E-8 | | 3.68E-9 | - | - | - | - | - | - | - |
| molybdenum, at regional storage | 2 | | 0.4 | | | 1.8 | 2 | 2 | 2 | 2 | | | molybdenum, at regional storage | kg | 1.13E-6 | | 2.76E-9 | - | - | - | - | - | - | - |
| cobalt, at plant | | | 2.5 | 2.5 | | | | | | | | | cobalt, at plant | kg | 3.00E-7 | | | - | - | - | - | - | - | - |
| nickel, 99.5%, at plant | 2.4 | | | | | 2.2 | 2.4 | 2.4 | 2.4 | | | | nickel, 99.5%, at plant | kg | 1.68E-7 | | 0 | - | - | - | - | - | - | - |
| palladium, at regional storage | 3.7 | | | | | | 3.7 | 0.8 | 0.9 | | | | palladium, at regional storage | kg | 7.07E-7 | | 3.44E-9 | - | - | - | - | - | - | - |
| platinum, at regional storage | 3.7 | | | | | | 3.7 | 0.8 | 0.9 | | | | platinum, at regional storage | kg | 2.24E-8 | | 3.87E-9 | - | - | - | - | - | - | - |
| rhodium, at regional storage | 3.7 | | | | | | 3.7 | 0.8 | 0.9 | | | | rhodium, at regional storage | kg | 2.24E-8 | | 3.65E-9 | - | - | - | - | - | - | - |
| zeolite, powder, at plant | 2.1 | | 0.4 | 0.4 | 1.1 | 0.7 | 2.1 | 1.3 | 1.4 | | | | zeolite, powder, at plant | kg | 2.77E-4 | | 9.66E-5 | - | - | - | - | - | - | - |
| zinc, primary, at regional storage | 2.1 | 0 | 0.4 | 0.4 | 1.1 | 0.7 | 2.1 | 1.3 | 1.4 | 0 | 0 | | zinc, primary, at regional storage | kg | 3.00E-6 | | | - | - | - | - | - | - | - |
| transport, lorry >16t, fleet average | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | | transport, lorry >16t, fleet average | tkm | 1.23E-2 | | | - | - | - | - | - | - | - |
| transport, freight, rail | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | | transport, freight, rail | tkm | 7.40E-2 | | | - | - | - | - | - | - | - |
| refinery | 1.4 | 0.7 | 1 | 1 | 0.7 | 1 | 0.6 | 1.5 | 1.1 | 1 | 0.7 | 0 | refinery | unit | na | | | - | - | - | - | - | - | - |
| disposal, municipal solid waste, 22.9% water, to municipal incineration | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | | disposal, municipal solid waste, 22.9% water, to municipal incineration | kg | 1.88E-4 | | 2.10E-4 | 4.06E-5 | 3.97E-7 | - | 3.14E-4 | 3.97E-4 | - | - |
| disposal, refinery sludge, 89.5% water, to hazardous waste incineration | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | | disposal, refinery sludge, 89.5% water, to hazardous waste incineration | kg | 1.74E-3 | | 3.50E-4 | 2.46E-4 | 2.10E-4 | - | 6.29E-3 | 2.16E-4 | - | - |
| disposal, catalytic converter NOx reduction, 0% water, to underground deposit | 2.1 | 0 | 0.4 | 0.4 | 1.1 | 0.7 | 2.1 | 1.3 | 1.4 | | 0 | | disposal, catalytic converter NOx reduction, 0% water, to underground deposit | kg | 1.61E-5 | | 6.90E-5 | 2.01E-5 | 4.43E-5 | - | - | - | - | - |
| Heat, waste | 1.4 | 0.7 | 1 | 1 | 0.7 | 1 | 1.4 | 1.5 | 1.1 | 1 | 0.7 | 0 | Heat, waste | MJ | 6.68E-2 | | 2.75E-1 | 3.82E-4 | 1.57E-2 | - | 2.56E-1 | 2.62E-1 | - | - |
| Ammonia | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | | Ammonia | kg | 7.35E-8 | | | - | - | - | - | - | - | - |
| Benzene | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 0 | Benzene | kg | na | | 7.20E-6 | - | - | - | - | - | - | - |
| Benzene, ethyl- | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 0 | Benzene, ethyl- | kg | na | | 1.80E-6 | - | - | - | - | - | - | - |
| Butane | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 0 | Butane | kg | na | | 7.20E-5 | - | - | - | - | - | - | - |
| Butene | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 0 | Butene | kg | na | | 1.80E-6 | - | - | - | - | - | - | - |
| Dinitrogen monoxide | 1.4 | 0.7 | 1 | 1 | 0.7 | 1 | 0.6 | 1.5 | 1.1 | 1 | 0.7 | 0 | Dinitrogen monoxide | kg | 2.03E-6 | | | - | - | - | - | - | - | - |
| Ethane | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 0 | Ethane | kg | na | | 1.80E-5 | - | - | - | - | - | - | - |
| Ethene | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 0 | Ethene | kg | na | | 3.60E-6 | - | - | - | - | - | - | - |
| Heptane | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 0 | Heptane | kg | na | | 1.80E-5 | - | - | - | - | - | - | - |
| Hexane | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 0 | Hexane | kg | na | | 3.60E-5 | - | - | - | - | - | - | - |
| Hydrocarbons, aliphatic, alkanes, unspecified | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 0 | Hydrocarbons, aliphatic, alkanes, unspecified | kg | 4.48E-11 | | 1.80E-5 | - | - | - | - | - | 4.48E-11 | - |
| Hydrocarbons, aliphatic, unsaturated | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 0 | Hydrocarbons, aliphatic, unsaturated | kg | 2.46E-12 | | | - | - | - | - | - | 2.46E-12 | - |
| Hydrocarbons, aromatic | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 0 | Hydrocarbons, aromatic | kg | 6.72E-13 | | | - | - | - | - | - | 6.72E-13 | - |
| Methane, fossil | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 0 | Methane, fossil | kg | na | | 4.00E-5 | - | - | - | - | - | - | - |
| Nickel | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 0 | Nickel | kg | na | | | | | | | | | |
| Nitrogen oxides | 1.4 | 0.7 | 1 | 1 | 0.7 | 1 | 0.6 | 1.5 | 1.1 | 1 | 0.7 | 0 | Nitrogen oxides | kg | 2.53E-4 | | 2.80E-5 | 2.66E-4 | 2.28E-4 | - | 1.74E-4 | 3.96E-4 | 1.05E-4 | - |
| Particulates, > 10 um | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 0 | Particulates, > 10 um | kg | 4.98E-5 | | 1.00E-5 | 1.61E-5 | 5.72E-6 | - | 1.75E-4 | 4.23E-5 | - | - |
| Pentane | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 0 | Pentane | kg | na | | 9.00E-5 | - | - | - | - | - | - | - |
| Propane | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 0 | Propane | kg | na | | 7.20E-5 | - | - | - | - | - | - | - |
| Propene | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 0 | Propene | kg | na | | 3.60E-6 | - | - | - | - | - | - | - |
| Sulfur dioxide | 1.4 | 0.7 | 1 | 1 | 0.7 | 1 | 0.6 | 1.5 | 1.1 | 0 | 0.7 | 0 | Sulfur dioxide | kg | 3.86E-4 | | 4.70E-4 | 5.88E-4 | 1.97E-4 | - | 5.97E-4 | 4.53E-4 | 8.80E-5 | - |
| Toluene | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 0 | Toluene | kg | na | | 1.08E-5 | - | - | - | - | - | - | - |
| Xylene | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 0 | Xylene | kg | na | this study | 7.20E-6 | - | - | - | - | - | - | - |

| Name | petrol, unleaded, at refinery | bitumen, at refinery | diesel, at refinery | light fuel oil, at refinery | heavy fuel oil, at refinery | kerosene, at refinery | naphtha, at refinery | propane/ butane, at refinery | refinery gas, at refinery | secondary sulphur, at refinery | petroleum coke, at refinery | electricity, at refinery |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Location | | | | | | | | | | | | |
| InfrastructureProcess | | | | | | | | | | | | |
| Unit | kg | kg | kg | kg | kg | kg | kg | kg | kg | kg | kg | kWh |
| Aluminium | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 |
| Ammonium, ion | 1.1 | 0.5 | 1.1 | 1.1 | 0.5 | 1 | 1.1 | 1.1 | 1.1 | 0.5 | 0.5 | 0 |
| AOX, Adsorbable Organic Halogen as Cl | 1 | 0.9 | 1 | 1 | 0.9 | 1 | 1 | 1 | 1 | 0.9 | 0.9 | 0 |
| Arsenic | 1 | 1 | 1 | 1 | 1.1 | 0.9 | 1 | 1 | 1 | 1 | 1 | 0 |
| Barium | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 |
| Benzene | 1 | 0.9 | 1 | 1 | 0.9 | 1 | 1 | 1 | 1 | 0.9 | 0.9 | 0 |
| Benzene, ethyl- | 1 | 1.1 | 1 | 1 | 1.1 | 0.9 | 1 | 1 | 1 | 1.1 | 1.1 | 0 |
| BOD5, Biological Oxygen Demand | 1.1 | 0.4 | 1.1 | 1.1 | 0.5 | 1 | 1.1 | 1.1 | 1.1 | 0.4 | 0.4 | 0 |
| Boron | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 |
| Cadmium | 1 | 1 | 1 | 1 | 1.1 | 0.9 | 1 | 1 | 1 | 1 | 1 | 0 |
| Calcium | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 |
| Chloride | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 |
| Chromium | 1 | 1 | 1 | 1 | 1.1 | 0.9 | 1 | 1 | 1 | 1 | 1 | 0 |
| Chromium VI | 1 | 1 | 1 | 1 | 1.1 | 0.9 | 1 | 1 | 1 | 1 | 1 | 0 |
| COD, Chemical Oxygen Demand | 1.2 | 0.2 | 1.2 | 1.2 | 0.3 | 1 | 1.2 | 1.2 | 1.2 | 0.2 | 0.2 | 0 |
| Cobalt | 1 | 1 | 1 | 1 | 1.1 | 0.9 | 1 | 1 | 1 | 1 | 1 | 0 |
| Copper | 1 | 1 | 1 | 1 | 1.1 | 0.9 | 1 | 1 | 1 | 1 | 1 | 0 |
| Cyanide | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 |
| DOC, Dissolved Organic Carbon | 1.1 | 0.4 | 1.1 | 1.1 | 0.5 | 1 | 1.1 | 1.1 | 1.1 | 0.4 | 0.4 | 0 |
| Fluoride | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 |
| Hydrocarbons, aromatic | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 |
| Hydrocarbons, unspecified | 1.2 | 0.3 | 0.3 | 0.3 | 1.2 | 1.1 | 1.2 | 1.2 | 1.2 | 0.3 | 0.3 | 0 |
| Iron | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 |
| Lead | 1 | 1 | 1 | 1 | 1.1 | 0.9 | 1 | 1 | 1 | 1 | 1 | 0 |
| Magnesium | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 |
| Manganese | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 |
| Mercury | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 |
| Molybdenum | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 |
| Nickel | 1 | 1 | 1 | 1 | 1.1 | 0.9 | 1 | 1 | 1 | 1 | 1 | 0 |
| Nitrate | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 |
| Nitrite | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 |
| Nitrogen, organic bound | 1.2 | 0.3 | 0.3 | 0.3 | 1.2 | 1.1 | 1.2 | 1.2 | 1.2 | 0.3 | 0.3 | 0 |
| Oils, unspecified | 1.2 | 0.3 | 0.3 | 0.3 | 1.2 | 1.1 | 1.2 | 1.2 | 1.2 | 0.3 | 0.3 | 0 |
| PAH, polycyclic aromatic hydrocarbons | 1 | 0.9 | 1 | 1 | 0.9 | 1 | 1 | 1 | 1 | 0.9 | 0.9 | 0 |
| Phenol | 0.9 | 1.4 | 0.9 | 0.9 | 1.7 | 0.6 | 0.9 | 0.9 | 0.9 | 1.4 | 1.4 | 0 |
| Phosphate | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 |
| Phosphorus | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 |
| Potassium | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 |
| Selenium | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 |
| Silver | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 |
| Sodium | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 |
| Strontium | 1 | 1 | 1 | 1 | 1.1 | 0.9 | 1 | 1 | 1 | 1 | 1 | 0 |
| Sulfate | 1 | 0.9 | 1 | 1 | 0.9 | 1 | 1 | 1 | 1 | 0.9 | 0.9 | 0 |
| Sulfide | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 |
| Suspended solids, unspecified | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 |
| t-Butyl methyl ether | 1 | | 0 | | | | | | | 0 | 0 | 0 |
| Tin | 1 | 1 | 1 | 1 | 1.1 | 0.9 | 1 | 1 | 1 | 1 | 1 | 0 |
| TOC, Total Organic Carbon | 1.1 | 0.4 | 1.1 | 1.1 | 0.5 | 1 | 1.1 | 1.1 | 1.1 | 0.4 | 0.4 | 0 |
| Toluene | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 |
| Vanadium | 1 | 1 | 1 | 1 | 1.1 | 0.9 | 1 | 1 | 1 | 1 | 1 | 0 |
| Xylene | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 |
| Zinc | 1 | 1 | 1 | 1 | 1.1 | 0.9 | 1 | 1 | 1 | 1 | 1 | 0 |

| | Tab. 9.61 | mean values | estimation water emmissions | crude oil, in refinery | crude oil, in refinery Godorf | crude oil, in refinery Harburg | crude oil, in refinery | crude oil, in refinery, Naantali | crude oil, in refinery, Porvoo | crude oil, in refinery | crude oil, in refinery, Concawe, IEA |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | 0 | RER | RER | RER | DE | DE | FR | FI | FI | SE | RER |
| | 0 | 0 | 2007 | 1996 | 2000 | 2000 | 2001 | 2002 | 2002 | 1999 | 1998 |
| | 0 | kg, mg/l | mg/l | kg | kg | kg | kg | kg | kg | kg | kg |
| Aluminium | kg | na | 5.00E-2 | 5.00E-2 | - | - | - | - | - | - | - |
| Ammonium, ion | kg | 1.70E+1 | 6.00E+0 | 2.06E+1 | - | - | - | - | - | - | 1.70E+1 |
| AOX, Adsorbable Organic Halogen as Cl | kg | 4.61E-2 | 1.58E-2 | 5.00E-2 | - | - | - | - | - | 4.61E-2 | - |
| Arsenic | kg | na | 1.00E-2 | 1.00E-2 | - | - | - | - | - | - | - |
| Barium | kg | na | 1.00E-1 | 1.00E-1 | - | - | - | - | - | - | - |
| Benzene | kg | 2.00E-1 | 2.24E-2 | 1.00E-3 | - | - | - | - | - | - | - |
| Benzene, ethyl- | kg | 1.50E-2 | 2.00E-4 | 2.00E-4 | - | - | - | - | - | - | - |
| BOD5, Biological Oxygen Demand | kg | 4.01E+1 | 6.32E+0 | 1.10E+0 | - | - | - | - | - | 4.01E+1 | - |
| Boron | kg | na | 4.00E-1 | 4.00E-1 | - | - | - | - | - | - | - |
| Cadmium | kg | na | 1.00E-2 | 1.00E-2 | - | - | - | - | - | - | - |
| Calcium | kg | na | 5.00E+1 | 5.00E+1 | - | - | - | - | - | - | - |
| Chloride | kg | na | 1.87E-5 | 4.00E+2 | - | - | - | - | - | - | - |
| Chromium | kg | 2.24E-1 | 2.24E-1 | 1.00E-2 | - | - | - | - | - | - | - |
| Chromium VI | kg | | | | | | | | | | |
| COD, Chemical Oxygen Demand | kg | 9.54E+1 | 6.12E+1 | 3.30E+1 | 3.56E+1 | 5.63E+1 | - | - | 8.10E+1 | 2.09E+2 | - |
| Cobalt | kg | | | | | | | | | | |
| Copper | kg | na | 1.00E-2 | 1.00E-2 | - | - | - | - | - | - | - |
| Cyanide | kg | 1.38E-2 | 1.73E-1 | 5.00E-2 | - | - | - | - | - | 1.38E-2 | - |
| DOC, Dissolved Organic Carbon | kg | na | 1.58E-8 | | - | - | - | - | - | - | - |
| Fluoride | kg | 4.47E+0 | 4.47E+0 | | - | - | - | - | - | - | - |
| Hydrocarbons, aromatic | kg | 7.19E-1 | 7.19E-1 | | - | - | - | - | - | 7.19E-1 | - |
| Hydrocarbons, unspecified | kg | 9.08E-1 | 2.74E-1 | | 7.52E-1 | 9.93E-1 | - | - | - | 9.80E-1 | - |
| Iron | kg | na | 5.00E-1 | 5.00E-1 | - | - | - | - | - | - | - |
| Lead | kg | 3.16E-1 | 3.16E-1 | 1.00E-2 | - | - | - | - | - | - | - |
| Magnesium | kg | na | 2.50E+1 | 2.50E+1 | - | - | - | - | - | - | - |
| Manganese | kg | na | 2.00E-1 | 2.00E-1 | - | - | - | - | - | - | - |
| Mercury | kg | na | 1.00E-4 | 1.00E-4 | - | - | - | - | - | - | - |
| Molybdenum | kg | na | 1.00E-2 | 1.00E-2 | - | - | - | - | - | - | - |
| Nickel | kg | na | 3.11E-9 | 1.00E-2 | - | - | - | - | - | - | - |
| Nitrate | kg | na | 8.22E+0 | 8.22E+0 | - | - | - | - | - | - | - |
| Nitrite | kg | | | | | | | | | | |
| Nitrogen, organic bound | kg | 1.32E+1 | 1.32E+1 | 4.50E+0 | - | - | - | - | - | - | - |
| Oils, unspecified | kg | 1.97E+0 | 2.66E+0 | 3.24E+0 | - | - | - | 1.35E+0 | 6.15E-1 | - | 3.96E+0 |
| PAH, polycyclic aromatic hydrocarbons | kg | 1.58E-2 | 1.58E-2 | | - | - | - | - | - | - | - |
| Phenol | kg | 4.77E-1 | 1.73E-1 | 1.80E-1 | - | - | - | - | - | 2.74E-1 | 6.81E-1 |
| Phosphate | kg | | | | | | | | | | |
| Phosphorus | kg | 6.36E-1 | 3.87E-1 | 1.00E-1 | - | - | - | 5.25E-1 | 4.61E-1 | 9.21E-1 | - |
| Potassium | kg | na | | 1.00E+1 | - | - | - | - | - | - | - |
| Selenium | kg | na | 1.50E-2 | 1.50E-2 | - | - | - | - | - | - | - |
| Silver | kg | na | 5.00E-2 | 5.00E-2 | - | - | - | - | - | - | - |
| Sodium | kg | na | 3.00E+2 | 3.00E+2 | - | - | - | - | - | - | - |
| Strontium | kg | na | 7.00E-1 | 7.00E-1 | - | - | - | - | - | - | - |
| Sulfate | kg | na | 2.00E+2 | 2.00E+2 | - | - | - | - | - | - | - |
| Sulfide | kg | 5.53E-1 | 1.00E-1 | 4.00E-1 | - | - | - | - | - | - | 5.53E-1 |
| Suspended solids, unspecified | kg | 2.54E+1 | 1.00E+1 | 1.00E+0 | - | - | - | 4.27E+1 | - | 8.07E+0 | - |
| t-Butyl methyl ether | kg | 3.16E-1 | 3.16E-1 | 3.30E+1 | - | - | - | - | - | - | - |
| Tin | kg | | | | | | | | | | |
| TOC, Total Organic Carbon | kg | na | 2.50E+1 | 3.00E+1 | - | - | - | - | - | - | - |
| Toluene | kg | 1.70E-1 | 1.00E+0 | 1.00E+0 | - | - | - | - | - | - | - |
| Vanadium | kg | na | 3.00E-2 | 3.00E-2 | - | - | - | - | - | - | - |
| Xylene | kg | 1.70E-1 | 1.00E-1 | 1.00E-1 | - | - | - | - | - | - | - |
| Zinc | kg | na | 4.06E-8 | | - | - | - | - | - | - | - |

| Name | petrol, unleaded, at refinery | bitumen, at refinery | diesel, at refinery | light fuel oil, at refinery | heavy fuel oil, at refinery | kerosene, at refinery | naphtha, at refinery | propane/ butane, at refinery | refinery gas, at refinery | secondary sulphur, at refinery | petroleum coke, at refinery | electricity, at refinery |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Location | | | | | | | | | | | | |
| InfrastructureProcess | | | | | | | | | | | | |
| Unit | kg | kg | kg | kg | kg | kg | kg | kg | kg | kg | kg | kWh |
| Aluminium | | | | | | | | | | | | |
| Ammonium, ion | | | | | | | | | | | | |
| AOX, Adsorbable Organic Halogen as Cl | | | | | | | | | | | | |
| Arsenic | | | | | | | | | | | | |
| Barium | | | | | | | | | | | | |
| Benzene | | | | | | | | | | | | |
| Benzene, ethyl- | | | | | | | | | | | | |
| BOD5, Biological Oxygen Demand | | | | | | | | | | | | |
| Boron | | | | | | | | | | | | |
| Cadmium | | | | | | | | | | | | |
| Calcium | | | | | | | | | | | | |
| Chloride | | | | | | | | | | | | |
| Chromium | | | | | | | | | | | | |
| Chromium VI | | | | | | | | | | | | |
| COD, Chemical Oxygen Demand | | | | | | | | | | | | |
| Cobalt | | | | | | | | | | | | |
| Copper | | | | | | | | | | | | |
| Cyanide | | | | | | | | | | | | |
| DOC, Dissolved Organic Carbon | | | | | | | | | | | | |
| Fluoride | | | | | | | | | | | | |
| Hydrocarbons, aromatic | | | | | | | | | | | | |
| Hydrocarbons, unspecified | | | | | | | | | | | | |
| Iron | | | | | | | | | | | | |
| Lead | | | | | | | | | | | | |
| Magnesium | | | | | | | | | | | | |
| Manganese | | | | | | | | | | | | |
| Mercury | | | | | | | | | | | | |
| Molybdenum | | | | | | | | | | | | |
| Nickel | | | | | | | | | | | | |
| Nitrate | | | | | | | | | | | | |
| Nitrite | | | | | | | | | | | | |
| Nitrogen, organic bound | | | | | | | | | | | | |
| Oils, unspecified | | | | | | | | | | | | |
| PAH, polycyclic aromatic hydrocarbons | | | | | | | | | | | | |
| Phenol | | | | | | | | | | | | |
| Phosphate | | | | | | | | | | | | |
| Phosphorus | | | | | | | | | | | | |
| Potassium | | | | | | | | | | | | |
| Selenium | | | | | | | | | | | | |
| Silver | | | | | | | | | | | | |
| Sodium | | | | | | | | | | | | |
| Strontium | | | | | | | | | | | | |
| Sulfate | | | | | | | | | | | | |
| Sulfide | | | | | | | | | | | | |
| Suspended solids, unspecified | | | | | | | | | | | | |
| t-Butyl methyl ether | | | | | | | | | | | | |
| Tin | | | | | | | | | | | | |
| TOC, Total Organic Carbon | | | | | | | | | | | | |
| Toluene | | | | | | | | | | | | |
| Vanadium | | | | | | | | | | | | |
| Xylene | | | | | | | | | | | | |
| Zinc | | | | | | | | | | | | |
| | Share of production | | | | | | | | | | | |
| | 18.3% | 0.1% | 38.4% | 10.9% | 11.8% | 7.2% | 6.2% | 2.5% | 3.0% | 0.4% | 1.3% | 2.15E-2 |

| Name | Tab. 9.61 | mean values | estimation water emmissions | crude oil, in refinery | crude oil, in refinery Godorf | crude oil, in refinery Harburg | crude oil, in refinery | crude oil, in refinery, Naantali | crude oil, in refinery, Porvoo | crude oil, in refinery | crude oil, in refinery, Concawe, IEA |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | 0 | RER | RER | RER | DE | DE | FR | FI | FI | SE | RER |
| | 0 | 0 | 2007 | 1996 | 2000 | 2000 | 2001 | 2002 | 2002 | 1999 | 1998 |
| | 0 | kg, mg/l | mg/l | kg | kg | kg | kg | kg | kg | kg | kg |
| Aluminium | kg | | | | | | | | | | |
| Ammonium, ion | kg | | | Frischknecht et al. 1996 | Shell 2000 | Shell 2000 | CPDP 2001 | Fortum 2002 | Fortum 2002 | Janson 1999 | Cecil et al. 1998, IEA 2001 |
| AOX, Adsorbable Organic Halogen as Cl | kg | | | | | | | | | | |
| Arsenic | kg | | | | | | | | | | |
| Barium | kg | | | | | | | | | | |
| Benzene | kg | | | | | | | | | | |
| Benzene, ethyl- | kg | | | | | | | | | | |
| BOD5, Biological Oxygen Demand | kg | | | | | | | | | | |
| Boron | kg | | | | | | | | | | |
| Cadmium | kg | | | | | | | | | | |
| Calcium | kg | | | | | | | | | | |
| Chloride | kg | | | | | | | | | | |
| Chromium | kg | | | | | | | | | | |
| Chromium VI | kg | | | | | | | | | | |
| COD, Chemical Oxygen Demand | kg | | | | | | | | | | |
| Cobalt | kg | | | | | | | | | | |
| Copper | kg | | | | | | | | | | |
| Cyanide | kg | | | | | | | | | | |
| DOC, Dissolved Organic Carbon | kg | | | | | | | | | | |
| Fluoride | kg | | | | | | | | | | |
| Hydrocarbons, aromatic | kg | | | | | | | | | | |
| Hydrocarbons, unspecified | kg | | | | | | | | | | |
| Iron | kg | | | | | | | | | | |
| Lead | kg | | | | | | | | | | |
| Magnesium | kg | | | | | | | | | | |
| Manganese | kg | | | | | | | | | | |
| Mercury | kg | | | | | | | | | | |
| Molybdenum | kg | | | | | | | | | | |
| Nickel | kg | | | | | | | | | | |
| Nitrate | kg | | | | | | | | | | |
| Nitrite | kg | | | | | | | | | | |
| Nitrogen, organic bound | kg | | | | | | | | | | |
| Oils, unspecified | kg | | | | | | | | | | |
| PAH, polycyclic aromatic hydrocarbons | kg | | | | | | | | | | |
| Phenol | kg | | | | | | | | | | |
| Phosphate | kg | | | | | | | | | | |
| Phosphorus | kg | | | | | | | | | | |
| Potassium | kg | | | | | | | | | | |
| Selenium | kg | | | | | | | | | | |
| Silver | kg | | | | | | | | | | |
| Sodium | kg | | | | | | | | | | |
| Strontium | kg | | | | | | | | | | |
| Sulfate | kg | | | | | | | | | | |
| Sulfide | kg | | | | | | | | | | |
| Suspended solids, unspecified | kg | | | | | | | | | | |
| t-Butyl methyl ether | kg | | | | | | | | | | |
| Tin | kg | | | | | | | | | | |
| TOC, Total Organic Carbon | kg | | | | | | | | | | |
| Toluene | kg | | | | | | | | | | |
| Vanadium | kg | | | | | | | | | | |
| Xylene | kg | | | | | | | | | | |
| Zinc | kg | | | | | | | | | | |
| | | | | Frischknecht et al. 2046 | Shell 2050 | Shell 2050 | CPDP 2051 | Fortum 2052 | Fortum 2052 | Janson 2049 | Cecil et al. 1998, IEA 2051 |
| | | 2.00E+0 | | 9.43E-1 | 4.28E+0 | 3.84E+0 | 1.00E+0 | 8.70E-1 | 1.00E+0 | 9.60E-1 | 1.04E+0 |
| | | #BEZUG! | | 1.06E+0 | 1.00E+0 | 1.00E+0 | 1.00E+0 | 1.00E+0 | 1.00E+0 | 1.00E+0 | 1.00E+0 |
| | | #WERT! | 0 | 8.00E-2 | 7.02E-3 | 7.27E-3 | 0 | 0 | 0 | 0 | 0 |

| Name | crude oil in refinery, 1993 | crude oil, in refinery, Schwechat | crude oil, in refinery, BREF | min | max | crude oil, in refinery Godorf | crude oil, in refinery Harburg | crude oil, in refinery | crude oil, in refinery, Naantali | crude oil, in refinery, Porvoo | crude oil, in refinery | crude oil, in refinery, Concawe, IEA | crude oil, in refinery | crude oil, in refinery | crude oil, in refinery | crude oil, in refinery | crude oil, in refinery | crude oil, in refinery | crude oil, in refinery | crude oil, in refinery | crude oil, in refinery | | crude oil, in refinery |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Location | RER | AT | RER | RER | RER | DE | DE | FR | FI | FI | SE | RER | RER | DE | DE | DE | DE | RER | RER | RER | RER | | RER |
| InfrastructureProcess | 1993 | 2000 | 2001 | | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2007 | 2014 | 2014 | 2014 | 2016 | 2015 | 2016 | 2010-16 | 2016 | | 2016 |
| Unit | kg | kg | kg | kg | kg | a | a | a | a | a | a | a | kg | kg | kg | kg | kg | kg | kg | kg | % | | kg |
| petrol, at refinery | | | | | | 1.89E+9 | 1.48E+9 | 1.70E+10 | 5.80E+8 | 3.50E+9 | 5.40E+9 | 1.50E+11 | 2.15E-1 | 2.24E-1 | | | 2.15E-1 | | 19.10% | | | 1.91E-01 | 1.83E-01 |
| bitumen, at refinery | | | | | | - | - | 3.73E+9 | 2.23E+5 | 1.67E+4 | - | 7.66E+8 | 1.09E-3 | 3.46E-2 | | | 3.67E-2 | | | | | 7.68E-04 | 7.34E-04 |
| diesel, at refinery | | | | | | 1.89E+9 | 1.32E+9 | 2.20E+10 | - | - | - | 7.03E+10 | 1.00E-1 | 4.06E-1 | | 2.14E-1 | 4.10E-1 | | 40.10% | | | 4.01E-01 | 3.84E-01 |
| light fuel oil, at refinery | | | | | | 1.66E+9 | 1.04E+9 | 1.25E+10 | 8.70E+8 | 5.12E+9 | 7.53E+9 | 1.88E+11 | 2.68E-1 | 1.22E-1 | | 2.13E-4 | 1.16E-1 | | 11.40% | | | 1.14E-01 | 1.09E-01 |
| heavy fuel oil, at refinery | | | | | | 7.13E+9 | 4.83E+9 | 1.06E+10 | 2.90E+8 | 1.12E+6 | 5.40E+9 | 1.23E+11 | 1.76E-1 | 3.37E-2 | | | 3.87E-2 | | | 9.39E-3 | | 1.23E-01 | 1.18E-01 |
| kerosene, at refinery | | | | | | 9.73E+8 | 5.90E+7 | 6.95E+7 | - | - | - | 4.67E+10 | 6.68E-2 | 7.79E-2 | | 1.91E-1 | 8.61E-2 | | 7.50% | | | 7.50E-02 | 7.18E-02 |
| naphtha, at refinery | | | | | | 2.52E+9 | 2.87E+8 | 2.31E+10 | 1.16E+5 | - | - | 4.75E+10 | 6.79E-2 | 7.12E-2 | | | 7.23E-2 | | 6.50% | | | 6.50E-02 | 6.22E-02 |
| propane/ butane, at refinery | | | | | | 1.44E+8 | 6.20E+7 | 2.30E+9 | 2.48E+4 | 2.33E+5 | 1.93E+8 | 1.98E+10 | 2.83E-2 | 6.02E-2 | | | 5.78E-2 | | 2.60% | | | 2.60E-02 | 2.49E-02 |
| refinery gas, at refinery | | | | | | 2.16E+10 | 1.03E+10 | 2.55E+9 | - | - | 7.72E+8 | 8.20E+10 | 1.17E-1 | | | | | | | 3.04E-2 | | 3.04E-02 | 3.04E-02 |
| secondary sulphur, at refinery | | | | | | 2.60E+7 | 1.40E+7 | 2.34E+8 | 8.50E+6 | 3.72E+7 | 6.39E+7 | 3.87E+9 | 5.53E-3 | | | | | | | | | 3.88E-03 | 3.71E-03 |
| petroleum coke, at refinery | | | | | | - | - | 9.51E+8 | - | - | - | 1.94E+8 | 2.78E-4 | | | 5.87E-5 | | | | 1.32E-2 | | 1.32E-02 | 1.32E-02 |
| electricity, at refinery | | | | | | 1.27E+8 | 1.35E+7 | | - | 5.70E+8 | | | 2.07E-2 | | | | | 2.15E-02 | 12.80% | | | 2.15E-02 | 2.15E-02 |
| Water, unspecified natural origin, RER | | 1.00E-4 | 5.30E-4 | 9.00E-5 | 1.60E-3 | 4.39E+6 | 1.81E+6 | | 6.67E+5 | 6.51E+6 | 5.08E+6 | 3.29E+8 | 7.00E-4 | 4.36E-4 | 1.42E-03 | 1.47E-3 | 4.01E-4 | 6.60E-03 | | | | | 6.60E-03 |
| Water, cooling, unspecified natural origin, RER | | 9.00E-4 | - | - | - | 6.90E+5 | 1.59E+7 | | 1.70E+6 | 5.02E+8 | 1.34E+7 | 2.96E+9 | 4.00E-3 | | | | | 7.69E-03 | | | | | 7.69E-03 |
| Water, RER | | 1.00E-4 | 5.30E-4 | 9.00E-5 | 1.60E-3 | 4.39E+6 | 1.81E+6 | | 6.67E+5 | 6.51E+6 | 1.34E+7 | 3.29E+8 | 7.00E-4 | 4.36E-4 | 1.42E-03 | #WERT! | 4.01E-4 | 6.60E-03 | | | | | 1.43E-02 |
| crude oil, import mix, at long distance transport | | | | | | 8.84E+9 | 5.04E+9 | - | 2.01E+9 | 8.66E+9 | 2.01E+10 | 7.00E+11 | 1.00E+0 | | | | | | | | | | 1.00E+00 |
| electricity, medium voltage, production ENTSO, at grid | | | | | | 9.38E+5 | 2.20E+7 | | 1.43E+8 | 6.30E+8 | | | 3.71E-2 | 4.69E-2 | 9.48E-2 | 9.53E-2 | 4.62E-2 | | | 6.13E-2 | | | 6.13E-02 |
| natural gas, burned in industrial furnace low-NOx >100kW | | | | | | | | | | | | | 0 | | | | | | | 5.20E-1 | | | 5.20E-01 |
| refinery gas, burned in furnace | | 2.80E+0 | 2.12E+0 | 1.19E+0 | ###### | 2.15E+10 | 1.03E+10 | 1.17E+11 | | 9.35E+9 | 3.60E+10 | 1.30E+12 | 2.42E+0 | | 4.82E+0 | 4.84E+0 | | | | 1.48E+0 | | | 1.48E+00 |
| heavy fuel oil, burned in refinery furnace | | 1.20E+0 | 9.09E-1 | 5.10E-1 | ###### | 6.50E+9 | 3.72E+9 | 8.56E+10 | | 4.01E+9 | | 4.73E+11 | 8.58E-1 | | 3.30E-1 | 3.32E-1 | | | | 3.87E-1 | | | 3.87E-01 |
| petroleum coke, burned in refinery furnace | | 1.20E+0 | 9.09E-1 | 5.10E-1 | ###### | 6.50E+9 | 3.72E+9 | 8.56E+10 | | 4.01E+9 | | - | 0 | | 2.95E-1 | 2.97E-1 | | | | 4.20E-1 | | | 4.20E-01 |
| refinery gas, burned in flare | | | | | | | | | | | | | 1.01E-1 | | | | | | | | | | 0.00E+00 |
| tap water, unspecified natural origin RER, at user | | - | 0 | - | - | 8.54E+8 | 1.26E+8 | - | - | - | - | - | 1.52E-2 | | 1.85E-4 | | | | | | | | 1.52E-02 |
| ammonia, liquid, at regional storehouse | | | | | | | | | | | | | 2.00E-6 | | | | | | | | | | 2.00E-06 |
| calcium chloride, CaCl2, at plant | | | | | | 2.57E+5 | 1.70E+4 | | | | | | 1.62E-5 | | | | | | | | | | 1.62E-05 |
| chlorine, liquid, production mix, at plant | | | | | | 6.65E+5 | 4.44E+4 | | | | | | 4.20E-5 | | | | | | | | | | 4.20E-05 |
| chemicals organic, at plant | | | 3.00E-04 | | | 6.10E+7 | 3.50E+7 | | | | | | 3.00E-4 | | | | | | | | | | 3.00E-04 |
| hydrochloric acid, 30% in H2O, at plant | | | | | | 8.16E+5 | 4.32E+5 | | | | | | 8.90E-5 | | | | | | | | | | 8.90E-05 |
| iron sulphate, at plant | | | | | | | | | | | | | 5.00E-5 | | | | | | | | | | 5.00E-05 |
| lime, hydrated, packed, at plant | | | | | | 2.51E+5 | | | | | | | 3.50E-5 | | | | | | | | | | 3.50E-05 |
| lubricating oil, at plant | | | | | | 2.64E+5 | 9.90E+4 | | | | | | 2.48E-5 | 5.71E-6 | | | 6.57E-6 | | | | | | 1.23E-05 |
| naphtha, at refinery | | | | | | 1.37E+9 | 4.82E+8 | | 2.10E+8 | 9.00E+8 | | | -1.24E-5 | | | | | | | | | | 0.00E+00 |
| nitrogen, liquid, at plant | | | | | | 1.09E+7 | 2.06E+6 | | | | | | 8.24E-4 | 1.39E-3 | | | 1.16E-3 | | | | | | 1.13E-03 |
| propylene glycol, liquid, at plant | | | | | | | | | | | | | 6.00E-6 | | | | | | | | | | 6.00E-06 |
| soap, at plant | | | | | | 2.80E+4 | 1.10E+4 | | | | | | 2.68E-6 | | | | | | | | | | 2.68E-06 |
| sodium hypochlorite, 15% in H2O, at plant | | | | | | | | | | | | | 5.00E-5 | | | | | | | | | | 5.00E-05 |
| sodium hydroxide, 50% in H2O, production mix, at plant | | | | | | 9.60E+5 | 1.92E+6 | | | | | | 2.45E-4 | | | | | | | | | | 2.45E-04 |
| sulphuric acid, liquid, at plant | | | | | | 1.37E+5 | 4.20E+4 | | | | | | 1.19E-5 | 8.95E-6 | | | 8.20E-6 | | | | | | 9.69E-06 |
| Rhenium | | | 2.24E-8 | 2.00E-8 | 2.50E-8 | | | | | | | | 8.01E-10 | | | | | | | | | | 8.01E-10 |
| molybdenum, at regional storage | | | 1.13E-6 | 4.00E-7 | 3.20E-6 | | | | | | | | 4.05E-8 | | | | | | | | | | 4.05E-08 |
| cobalt, at plant | | | 3.00E-7 | 1.50E-7 | 6.00E-7 | | | | | | | | 1.07E-8 | | | | | | | | | | 1.07E-08 |
| nickel, 99.5%, at plant | | | 1.68E-7 | 4.02E-8 | 7.00E-7 | | | | | | | | 6.00E-9 | | | | | | | | | | 6.00E-09 |
| palladium, at regional storage | | | 7.07E-7 | 5.00E-7 | 1.00E-6 | | | | | | | | 2.53E-8 | | | | | | | | | | 2.53E-08 |
| platinum, at regional storage | | | 2.24E-8 | 2.00E-8 | 2.50E-8 | | | | | | | | 8.01E-10 | | | | | | | | | | 8.01E-10 |
| rhodium, at regional storage | | | 2.24E-8 | 2.00E-8 | 2.50E-8 | | | | | | | | 8.01E-10 | | | | | | | | | | 8.01E-10 |
| zeolite, powder, at plant | | | 2.77E-4 | 2.07E-4 | 3.69E-4 | | | | | | | | 9.92E-6 | | | | | | | | | | 9.92E-06 |
| zinc, primary, at regional storage | | | 3.00E-6 | 3.00E-6 | 3.00E-6 | | | | | | | | 1.07E-7 | | | | | | | | | | 1.07E-07 |
| transport, lorry >16t, fleet average | | | | | | | | | | | | | 1.71E-4 | | | 1.90E-4 | | | | | | | 1.99E-4 |
| transport, freight, rail | | | | | | | | | | | | | 1.02E-3 | | | 2.69E-4 | | | | | | | 1.20E-3 |
| refinery | | | | | | | | | | | | | 3.33E-11 | | | | | | | | | | 3.33E-11 |
| disposal, municipal solid waste, 22.9% water, to municipal incineration | | | 7.47E-4 | 1.33E-4 | 4.20E-3 | 3.59E+5 | 2.00E+3 | | 6.32E+5 | 3.44E+6 | | | 1.88E-4 | 6.71E-4 | 8.29E-7 | 2.40E-3 | 8.85E-4 | | | 1.45E-3 | | | 1.45E-03 |
| disposal, refinery sludge, 89.5% water, to hazardous waste incineration | | | 1.41E-4 | 1.00E-5 | 2.00E-3 | 2.18E+6 | 1.06E+6 | | 1.27E+7 | 1.87E+6 | | | 2.00E-4 | 4.32E-4 | 1.94E-6 | 1.09E-3 | 3.33E-4 | | | 1.07E-3 | | | 1.07E-03 |
| disposal, catalytic converter NOx reduction, 0% water, to underground deposit | | | 2.79E-4 | 2.08E-4 | 3.75E-4 | 1.78E+5 | 2.23E+5 | | - | - | | | 1.00E-6 | | | | | | | | | | 1.00E-06 |
| Heat, waste | | - | - | - | - | 3.38E+6 | 7.92E+7 | - | 5.15E+8 | 2.27E+9 | - | - | 6.68E-2 | | | | | Tab. 3.12 | | | | | 2.21E-01 |
| Ammonia | | 7.35E-8 | | | | | | | | | | | 7.35E-8 | | | | | 1.10E-06 | | | | | 1.10E-06 |
| Benzene | | | | | | | | | | | | | 5.36E-6 | | | | | 2.50E-06 | | | | | 2.50E-06 |
| Benzene, ethyl- | | | | | | | | | | | | | 1.34E-6 | | | | | | | | | | 1.02E-06 |
| Butane | | | | | | | | | | | | | 5.36E-5 | | | | | | | | | | 4.08E-05 |
| Butene | | | | | | | | | | | | | 1.34E-6 | | | | | | | | | | 1.02E-06 |
| Dinitrogen monoxide | | 2.03E-6 | | | | | | | | | | | 2.03E-6 | | 4.70E-6 | 4.44E-6 | | | | | | | - |
| Ethane | | | | | | | | | | | | | 1.34E-5 | | | | | | | | | | 1.02E-05 |
| Ethene | | | | | | | | | | | | | 2.68E-6 | | | | | | | | | | 2.04E-06 |
| Heptane | | | | | | | | | | | | | 1.34E-5 | | | | | | | | | | 1.02E-05 |
| Hexane | | | | | | | | | | | | | 2.68E-5 | | | | | | | | | | 2.04E-05 |
| Hydrocarbons, aliphatic, alkanes, unspecified | | | | | | | | | | | 9.00E-1 | | 4.48E-11 | | | | | | | | | | 3.41E-11 |
| Hydrocarbons, aliphatic, unsaturated | | | | | | | | | | | 4.95E-2 | | 2.46E-12 | | | | | | | | | | 1.88E-12 |
| Hydrocarbons, aromatic | | | | | | | | | | | 1.35E-2 | | 6.72E-13 | | | | | | | | | | 5.12E-13 |
| Methane, fossil | | | | | | | | | | | | | 4.00E-5 | | 2.76E-6 | 3.49E-6 | | 8.50E-06 | | | | | 8.50E-06 |
| Nickel | | | | | | | | | | | | | | | | | | | | | | | - |
| Nitrogen oxides | | 3.50E-4 | 1.73E-4 | 6.00E-5 | 5.00E-4 | 2.35E+6 | 1.15E+6 | | 3.50E+5 | 3.43E+6 | 2.11E+6 | | 2.79E-5 | 1.21E-4 | | 2.73E-4 | 1.21E-4 | 2.63E-04 | | | | | - |
| Particulates, > 10 um | | 1.00E-5 | 1.73E-4 | 1.00E-5 | 3.00E-3 | 1.42E+5 | 2.88E+4 | | 3.52E+5 | 3.66E+5 | | | 1.00E-5 | 1.16E-6 | 7.46E-6 | 8.24E-6 | 9.00E-7 | 1.50E-05 | | | | | 1.50E-05 |
| Pentane | | | | | | | | | | | | | 6.70E-5 | | | | | | | | | | 5.11E-05 |
| Propane | | | | | | | | | | | | | 5.36E-5 | | | | | | | | | | 4.08E-05 |
| Propene | | | | | | | | | | | | | 2.68E-6 | | | | | | | | | | 2.04E-06 |
| Sulfur dioxide | | 3.90E-4 | 4.24E-4 | 3.00E-5 | 6.00E-3 | 5.20E+6 | 9.95E+5 | | 1.20E+6 | 3.93E+6 | 1.77E+6 | | 3.69E-4 | 3.25E-4 | | 5.34E-4 | 4.15E-4 | 7.98E-04 | | | | | - |
| Toluene | | | | | | | | | | | | | 8.04E-6 | | | | | | | | | | 6.13E-06 |
| Xylene | | | | | | | | | | | | | 5.36E-6 | | | | | | | | | | 4.08E-06 |

| Name | crude oil in refinery, 1993 | crude oil, in refinery, Schwechat | crude oil, in refinery, BREF | min | max | crude oil, in refinery Godorf | crude oil, in refinery Harburg | crude oil, in refinery | crude oil, in refinery, Naantali | crude oil, in refinery, Porvoo | crude oil, in refinery | crude oil, in refinery, Concawe, IEA | crude oil, in refinery | crude oil, in refinery | crude oil, in refinery | crude oil, in refinery | crude oil, in refinery | crude oil, in refinery | crude oil, in refinery | crude oil, in refinery | crude oil, in refinery | crude oil, in refinery |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Location | RER | AT | RER | RER | RER | DE | DE | FR | FI | FI | SE | RER | RER | DE | DE | DE | DE | RER | RER | RER | RER | RER |
| InfrastructureProcess | 1993 | 2000 | 2001 | | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2007 | 2014 | 2014 | 2014 | 2016 | 2015 | 2016 | 2010-16 | 2016 | 2016 |
| Unit | kg | kg | kg | kg | kg | a | a | a | a | a | a | a | kg | kg | kg | kg | kg | kg | kg | kg | % | kg |
| Aluminium | | | | | | | | | | | | | 1.28E-8 | | | | | | | | | 1.28E-08 |
| Ammonium, ion | | | 6.00E+0 | 2.50E-1 | ###### | | | | | | | 5.60E+6 | 1.53E-6 | | | | | 1.20E-06 | | | | 1.20E-06 |
| AOX, Adsorbable Organic Halogen as Cl | | | 1.58E-2 | 5.00E-3 | 5.00E-2 | | | | | | 2.34E+2 | | 4.04E-9 | 8.00E-9 | | | 6.50E-9 | 6.00E-08 | | | | 6.00E-08 |
| Arsenic | | | | | | | | | | | | | 2.56E-9 | | | | | 7.00E-10 | | | | 7.00E-10 |
| Barium | | | | | | | | | | | | | 2.56E-8 | | | | | | | | | 2.56E-08 |
| Benzene | 2.00E-1 | | 2.24E-2 | 5.00E-4 | ###### | | | | | | | | 5.71E-9 | | | | | 2.00E-09 | | | | 2.00E-09 |
| Benzene, ethyl- | 1.50E-2 | | | | | | | | | | | | 5.11E-11 | | | | | 4.00E-09 | | | | 4.00E-09 |
| BOD5, Biological Oxygen Demand | | | 6.32E+0 | 2.00E+0 | ###### | | | | | | 2.04E+5 | | 1.62E-6 | 1.34E-6 | | 1.08E-6 | 1.78E-6 | 4.40E-06 | | | | 4.40E-06 |
| Boron | | | | | | | | | | | | | 1.02E-7 | | | | | 2.64E-12 | | | | 2.64E-12 |
| Cadmium | | | | | | | | | | | | | 2.56E-9 | | | | | 1.00E-09 | | | | 1.00E-09 |
| Calcium | | | | | | | | | | | | | 1.28E-5 | | | | | | | | | 1.28E-05 |
| Chloride | | | | | | | | | | | | | 2.03E-5 | 2.11E-4 | | | 2.10E-4 | | | | | 1.47E-04 |
| Chromium | | | 2.24E-1 | 1.00E-1 | 5.00E-1 | | | | | | | | 5.71E-8 | | | | | 1.00E-09 | | | | 1.00E-09 |
| Chromium VI | | | | | | | | | | | | | | | | | | 1.00E-09 | | | | 1.00E-09 |
| COD, Chemical Oxygen Demand | | | 6.12E+1 | 3.00E+1 | ###### | 1.56E+5 | 1.02E+5 | | | 5.27E+5 | 1.06E+6 | | 1.56E-5 | | | 2.63E-5 | | 2.72E-05 | | | | 2.72E-05 |
| Cobalt | | | | | | | | | | | | | | | | | | 6.60E-15 | | | | 6.60E-15 |
| Copper | | | | | | | | | | | | | 2.56E-9 | | | | | 2.00E-09 | | | | 2.00E-09 |
| Cyanide | | | 1.73E-1 | 3.00E-2 | ###### | | | | | | 7.00E+1 | | 4.43E-8 | | | | | 4.00E-09 | | | | 4.00E-09 |
| DOC, Dissolved Organic Carbon | | | | | | | | | | | | | 1.58E-8 | | | | | | | | | 1.58E-08 |
| Fluoride | | | 4.47E+0 | 1.00E+0 | ###### | | | | | | | | 1.14E-6 | | | | | 6.00E-07 | | | | 6.00E-07 |
| Hydrocarbons, aromatic | | | | | | | | | | | 3.66E+3 | | 1.84E-7 | | | | | 1.00E-08 | | | | 1.00E-08 |
| Hydrocarbons, unspecified | | | 2.74E-1 | 5.00E-2 | ###### | 3.30E+3 | 1.80E+3 | | | | 4.98E+3 | | 7.00E-8 | 1.11E-7 | | 4.66E-9 | 6.09E-8 | 5.00E-07 | | | | 5.00E-07 |
| Iron | | | | | | | | | | | | | 1.28E-7 | | | | | 1.50E-07 | | | | 1.50E-07 |
| Lead | | | 3.16E-1 | 2.00E-1 | 5.00E-1 | | | | | | | | 8.08E-8 | | | | | 5.00E-09 | | | | 5.00E-09 |
| Magnesium | | | | | | | | | | | | | 6.39E-6 | | | | | | | | | 6.39E-06 |
| Manganese | | | | | | | | | | | | | 5.11E-8 | | | | | 4.00E-08 | | | | 4.00E-08 |
| Mercury | | | | | | | | | | | | | 2.56E-11 | | | | | 1.00E-10 | | | | 1.00E-10 |
| Molybdenum | | | | | | | | | | | | | 2.56E-9 | | | | | 6.60E-14 | | | | 6.60E-14 |
| Nickel | | | | | | | | | | | | | 3.37E-9 | | | | | 6.00E-09 | | | | 6.00E-09 |
| Nitrate | | | | | | | | | | | | | 2.10E-6 | | | | | 6.20E-06 | | | | 6.20E-06 |
| Nitrite | | | | | | | | | | | | | | | | | | 1.00E-07 | | | | 1.00E-07 |
| Nitrogen, organic bound | | | 1.32E+1 | 5.00E+0 | ###### | | | | | | | | 3.38E-6 | | | | | 4.00E-06 | | | | 4.00E-06 |
| Oils, unspecified | | | 7.00E-1 | 5.00E-2 | ###### | | | | 9.00E+2 | 4.00E+3 | | 1.30E+6 | 6.79E-7 | | | | | | | | | 6.79E-07 |
| PAH, polycyclic aromatic hydrocarbons | | | 1.58E-2 | 5.00E-3 | 5.00E-2 | | | | | | | | 4.04E-9 | | | | | 3.00E-10 | | | | 3.00E-10 |
| Phenol | | | 1.73E-1 | 3.00E-2 | ###### | | | | | | 1.39E+3 | 2.24E+5 | 4.43E-8 | | | 2.85E-10 | | 2.00E-08 | | | | 2.00E-08 |
| Phosphate | | | | | | | | | | | | | | | | | | 1.30E-07 | | | | 1.30E-07 |
| Phosphorus | | | 3.87E-1 | 1.00E-1 | ###### | | | | 3.50E+2 | 3.00E+3 | 4.68E+3 | | 9.90E-8 | 1.23E-7 | | 3.80E-7 | 1.07E-7 | 3.00E-07 | | | | 3.00E-07 |
| Potassium | | | | | | | | | | | | | 2.56E-6 | | | | | | | | | 2.56E-06 |
| Selenium | | | | | | | | | | | | | 3.83E-9 | | | | | 2.64E-13 | | | | 2.64E-13 |
| Silver | | | | | | | | | | | | | 1.28E-8 | | | | | | | | | 1.28E-08 |
| Sodium | | | | | | | | | | | | | 7.67E-5 | | | | | | | | | 7.67E-05 |
| Strontium | | | | | | | | | | | | | 1.79E-7 | | | | | | | | | 1.79E-07 |
| Sulfate | | | | | | | | | | | | | 5.11E-5 | | | | | | | | | 5.11E-05 |
| Sulfide | | | 1.00E-1 | 1.00E-2 | ###### | | | | | | | 1.82E+5 | 2.56E-8 | | | | | 2.50E-08 | | | | 2.50E-08 |
| Suspended solids, unspecified | | | 1.00E+1 | 2.00E+0 | ###### | | | | 2.85E+4 | | 4.10E+4 | | 2.56E-6 | | | | | 6.30E-06 | | | | 6.30E-06 |
| t-Butyl methyl ether | | | 3.16E-1 | 1.00E-1 | ###### | | | | | | | | 8.08E-8 | | | | | 5.00E-09 | | | | 5.00E-09 |
| Tin | | | | | | | | | | | | | | | | | | 4.00E-09 | | | | 4.00E-09 |
| TOC, Total Organic Carbon | | | | | | | | | | | | | 6.39E-6 | 5.06E-6 | | | 5.29E-6 | 5.50E-06 | | | | 5.50E-06 |
| Toluene | 1.70E-1 | | | | | | | | | | | | 2.56E-7 | | | | | 4.00E-09 | | | | 4.00E-09 |
| Vanadium | | | | | | | | | | | | | 7.67E-9 | | | | | 3.00E-09 | | | | 3.00E-09 |
| Xylene | 1.70E-1 | | | | | | | | | | | | 2.56E-8 | | | | | 4.00E-09 | | | | 4.00E-09 |
| Zinc | | | | | | | | | | | | | 4.41E-8 | | | | | 1.50E-08 | | | | 1.50E-08 |

| Name | crude oil in refinery, 1993 | crude oil, in refinery, Schwechat | crude oil, in refinery, BREF | min | max | crude oil, in refinery Godorf | crude oil, in refinery Harburg | crude oil, in refinery | crude oil, in refinery, Naantali | crude oil, in refinery, Porvoo | crude oil, in refinery | crude oil, in refinery, Concawe, IEA | crude oil, in refinery | crude oil, in refinery | crude oil, in refinery | crude oil, in refinery | crude oil, in refinery | crude oil, in refinery | crude oil, in refinery | crude oil, in refinery | crude oil, in refinery | | crude oil, in refinery |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Location | RER | AT | RER | RER | RER | DE | DE | FR | FI | FI | SE | RER | RER | DE | DE | DE | DE | RER | RER | RER | RER | | RER |
| InfrastructureProcess | 1993 | 2000 | 2001 | | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2007 | 2014 | 2014 | 2014 | 2016 | 2015 | 2016 | 2010-16 | 2016 | | 2016 |
| Unit | kg | kg | kg | kg | kg | a | a | a | a | a | a | a | kg | kg | kg | kg | kg | kg | kg | kg | % | | kg |
| Aluminium | | | | | | | | | | | | | 2.22E-8 | | | | | | | | | | |
| Ammonium, ion | | Ecker & Winter 2000 | IPPC 2001 | | | | | | | | | | 2.67E-6 | | | | | | | | | | |
| AOX, Adsorbable Organic Halogen as Cl | | | | | | | | | | | | | 7.03E-9 | | | | | | | | | | |
| Arsenic | | | | | | | | | | | | | 4.45E-9 | | | | | | | | | | |
| Barium | | | | | | | | | | | | | 4.45E-8 | | | | | | | | | | |
| Benzene | | | | | | | | | | | | | 9.94E-9 | | | | | | | | | | |
| Benzene, ethyl- | | | | | | | | | | | | | 8.89E-11 | | | | | | | | | | |
| BOD5, Biological Oxygen Demand | | | | | | | | | | | | | 2.81E-6 | | | | | | | | | | |
| Boron | | | | | | | | | | | | | 1.78E-7 | | | | | | | | | | |
| Cadmium | | | | | | | | | | | | | 4.45E-9 | | | | | | | | | | |
| Calcium | | | | | | | | | | | | | 2.22E-5 | | | | | | | | | | |
| Chloride | | | | | | | | | | | | | 3.54E-5 | | | | | | | | | | |
| Chromium | | | | | | | | | | | | | 9.94E-8 | | | | | | | | | | |
| Chromium VI | | | | | | | | | | | | | 0 | | | | | | | | | | |
| COD, Chemical Oxygen Demand | | | | | | | | | | | | | 2.72E-5 | | | | | | | | | | |
| Cobalt | | | | | | | | | | | | | 0 | | | | | | | | | | |
| Copper | | | | | | | | | | | | | 4.45E-9 | | | | | | | | | | |
| Cyanide | | | | | | | | | | | | | 7.70E-8 | | | | | | | | | | |
| DOC, Dissolved Organic Carbon | | | | | | | | | | | | | 2.74E-8 | | | | | | | | | | |
| Fluoride | | | | | | | | | | | | | 1.99E-6 | | | | | | | | | | |
| Hydrocarbons, aromatic | | | | | | | | | | | | | 3.20E-7 | | | | | | | | | | |
| Hydrocarbons, unspecified | | | | | | | | | | | | | 1.22E-7 | | | | | | | | | | |
| Iron | | | | | | | | | | | | | 2.22E-7 | | | | | | | | | | |
| Lead | | | | | | | | | | | | | 1.41E-7 | | | | | | | | | | |
| Magnesium | | | | | | | | | | | | | 1.11E-5 | | | | | | | | | | |
| Manganese | | | | | | | | | | | | | 8.89E-8 | | | | | | | | | | |
| Mercury | | | | | | | | | | | | | 4.45E-11 | | | | | | | | | | |
| Molybdenum | | | | | | | | | | | | | 4.45E-9 | | | | | | | | | | |
| Nickel | | | | | | | | | | | | | 5.87E-9 | | | | | | | | | | |
| Nitrate | | | | | | | | | | | | | 3.65E-6 | | | | | | | | | | |
| Nitrite | | | | | | | | | | | | | 0 | | | | | | | | | | |
| Nitrogen, organic bound | | | | | | | | | | | | | 5.88E-6 | | | | | | | | | | |
| Oils, unspecified | | | | | | | | | | | | | 1.18E-6 | | | | | | | | | | |
| PAH, polycyclic aromatic hydrocarbons | | | | | | | | | | | | | 7.03E-9 | | | | | | | | | | |
| Phenol | | | | | | | | | | | | | 7.70E-8 | | | | | | | | | | |
| Phosphate | | | | | | | | | | | | | 0 | | | | | | | | | | |
| Phosphorus | | | | | | | | | | | | | 1.72E-7 | | | | | | | | | | |
| Potassium | | | | | | | | | | | | | 4.45E-6 | | | | | | | | | | |
| Selenium | | | | | | | | | | | | | 6.67E-9 | | | | | | | | | | |
| Silver | | | | | | | | | | | | | 2.22E-8 | | | | | | | | | | |
| Sodium | | | | | | | | | | | | | 1.33E-4 | | | | | | | | | | |
| Strontium | | | | | | | | | | | | | 3.11E-7 | | | | | | | | | | |
| Sulfate | | | | | | | | | | | | | 8.89E-5 | | | | | | | | | | |
| Sulfide | | | | | | | | | | | | | 4.45E-8 | | | | | | | | | | |
| Suspended solids, unspecified | | | | | | | | | | | | | 4.45E-6 | | | | | | | | | | |
| t-Butyl methyl ether | | | | | | | | | | | | | 1.41E-7 | | | | | | | | | | |
| Tin | | | | | | | | | | | | | 0 | | | | | | | | | | |
| TOC, Total Organic Carbon | | | | | | | | | | | | | 1.11E-5 | | | | | | | | | | |
| Toluene | | | | | | | | | | | | | 4.45E-7 | | | | | | | | | | |
| Vanadium | | | | | | | | | | | | | 1.33E-8 | | | | | | | | | | |
| Xylene | | | | | | | | | | | | | 4.45E-8 | | | | | | | | | | |
| Zinc | | | | | | | | | | | | | 7.66E-8 | | | | | | | | | | |
| | | Ecker & Winter 2050 | IPPC 2051 | | | | | | | | | | | | | | | | | | | | |
| | | | | | | 3.78E+10 | 1.93E+10 | 8.82E+10 | 1.75E+9 | 8.66E+9 | 1.93E+10 | 7.29E+11 | 7.29E+11 | 1.030 | - | 0.405 | 1.032 | - | 0.872 | 0.053 | - | 1.044 | 1.000 |
| | | | | | | 8.84E+9 | 5.04E+9 | 8.82E+10 | 2.01E+9 | 8.66E+9 | 2.01E+10 | 7.00E+11 | 7.00E+11 | - | - | - | - | - | - | - | - | - | 1.000 |
| | 0 | 0 | 3.00E-4 | 0 | 0 | 6.21E+7 | 3.66E+7 | 0 | 0 | 0 | 0 | 0 | 4.20E-4 | 5.71E-6 | 0 | 0 | 6.57E-6 | 0 | 0 | 0 | 0 | 0 | 4.07E-4 |