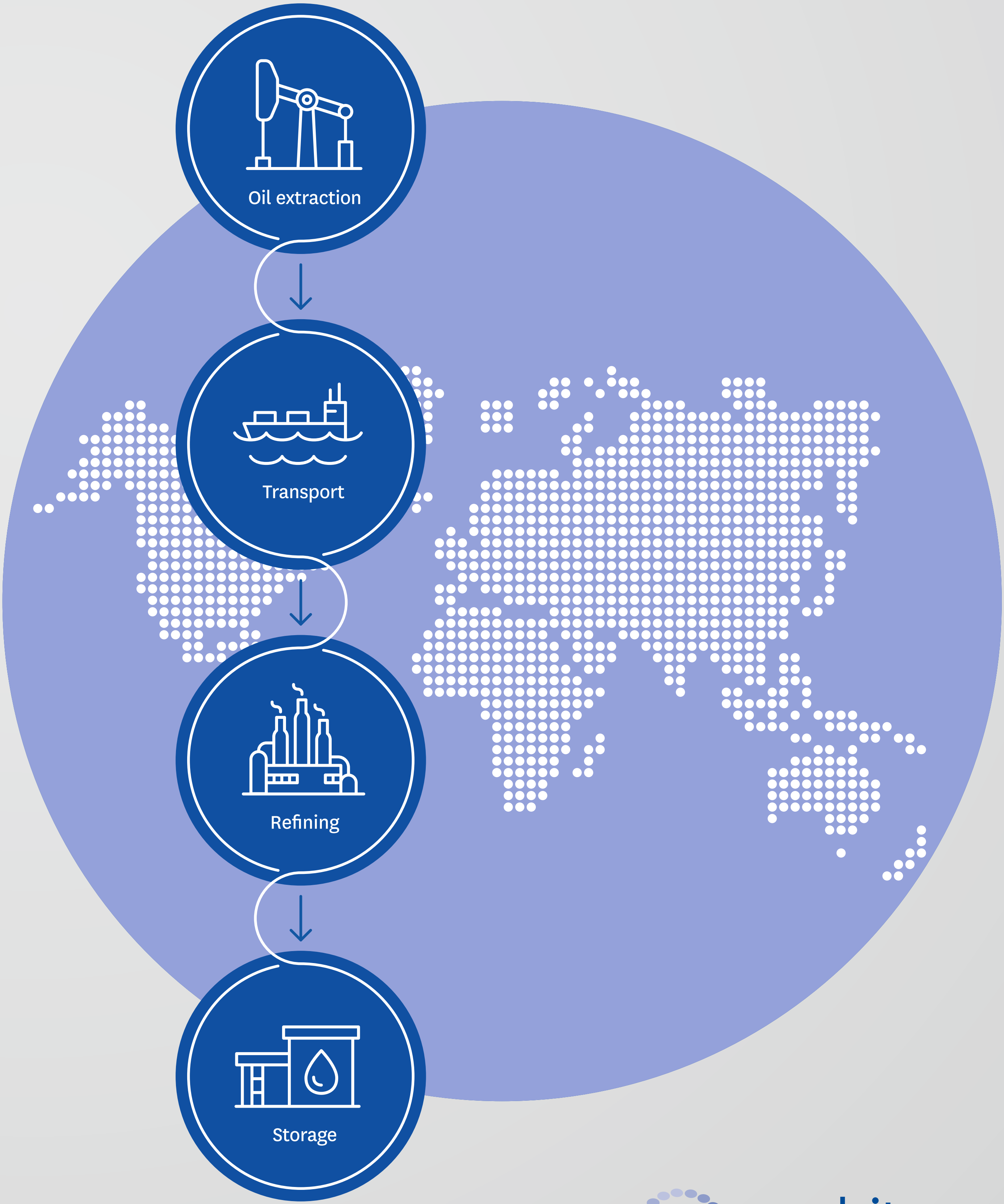
THE EUROBITUME LIFE-CYCLE INVENTORY FOR BITUMEN

VERSION 3.0



eurobitume

D/2019/7512/29

3rd edition December 2019

Published by the European Bitumen Association
Boulevard du Souverain 165
B - 1160 Brussels, Belgium

T: +32 2 566 91 40

info@eurobitume.eu
www.eurobitume.eu

INDEX

1. ACKNOWLEDGEMENTS

Veronique Ducreux – ExxonMobil
Luis Gamez Lopez – Cepsa
Fabio Menton – Deloitte
Laurent Porot – Kraton
Mike Southern – Eurobitume
Richard Taylor – Shell
Wim Teugels – Nynas (chair)
Clara Tromson - Deloitte
Damien Valdenaire – Concawe
Benoit Vandermeeren - ATPC
Celine Verrat – Total
Independent review conducted by **Niels Jungbluth** – ESU Services

2. EXECUTIVE SUMMARY

Following the previous Life-Cycle Inventory published in 2012, Eurobitume has now updated the data and methodology used for this cradle-to-gate study. The LCI covers four of the life-cycle stages;

- Crude oil extraction
- Transportation
- Refining
- Storage within the refinery.

The study covers the production of 1 tonne of straight–run bitumen manufactured by atmospheric and vacuum distillation.

The report is based upon the most recent and representative data available from the crude oil production and refining industry. Principal differences from the previous LCI are;

- The basket of crudes has been revised based on recent European use.
- Crude oil extraction data are now based on a 5-year average, rather than using crude oil data from a single year.
- A consequence of the change to the crude basket is that the transportation distances are revised, with an impact on the overall transportation section of the life-cycle.
- Shipping data have been updated to include the latest generation of Aframax crude carrier and current emission requirements
- Allocation methodology within the refining process has been updated to use a thermodynamic approach.
- An attempt has been made to provide water consumption data, although there is limited certainty about the data.
- A Life-Cycle Impact Assessment has been carried out for the four stages considered in this report.

The primary data sources were chosen on the basis that they were the most robust data available. However, the foreground data were supplemented by background data from EcoInvent (version 3.5) where complete datasets were not available.

A full Inventory is available in an Excel format for use in LCI software. This report provides summary data for the four life-cycle stages with and without infrastructure contributions.

The LCI has been conducted in accordance with ISO 14040 and ISO 14044. As part of the requirements within these standards the report has been reviewed by an Independent LCI expert.

By consulting and/or using this publication, the user acknowledges and agrees to be bound by the following stipulations. Eurobitume has made considerable efforts to compile this publication on the basis of reliable sources. However, Eurobitume cannot and does not guarantee the completeness, accuracy, reliability and effectiveness of the information contained in this publication for whatever purpose. Furthermore, the content of this publication may be changed, suspended, revised and/or removed by Eurobitume, at its sole discretion, at any time for whatever reason and without notice. Finally, except for cases of fraud, neither Eurobitume nor its members are liable for any loss, damages or injury whatsoever relating to the consultation or use of this publication, or the inability to do so.

3. INTRODUCTION

The importance of quantifying the impact of products and services on the environment continues to grow. Consumers and procurement agencies are increasingly demanding information about the environmental impacts of products and interest in comparing potential solutions based upon scientific data is necessary in order to do this.

The bitumen industry recognised the need for such information nearly 20 years ago and produced the first eco-profile, or partial life cycle inventory analysis (LCI). During 2009, it was decided to update the 1999 eco-profile, because more data had become available and LCI methodology had been developed further[1].

Eurobitume has conducted a review of the previous LCI as the document has been published for 6 years. In comparison to the previous version, the main differences of this LCI are described below:

- The basket of crudes has been revised based upon recent European use.
- The data concerning consumption and emissions for crude oil extraction has been updated based on the most recent information.
- A consequence of the change to the crude basket is that the transportation distances are revised, with an impact on the overall transportation section of the life-cycle.
- The allocation methodology for the refining process has been reviewed and an alternative allocation methodology is considered.

This study follows the standards and guidelines ISO 14040 and ISO 14044 and has been peer reviewed.

4. GOAL & SCOPE OF THE STUDY

4.1 Intended application and intended audience

The aim of this study is to provide inventory data on the production of a straight-run paving grade bitumen produced according to EN 12591 in Europe.

The intended application can be seen as a building block in the calculations of the further life cycle inventory studies where paving grade bitumen is used. At the time of the study, no specific Product Category Rules (PCR) from bitumen were recognised. Only a draft PCR (#335) was under preparation for some petroleum products, and Eurobitume was in dialogue with the authors. Hence, this study does not follow a specific PCR for bitumen products.

The Eurobitume LCI is a cradle-to-gate study for the manufacture of bitumen and can be considered to be representative for any European refinery within the European Union, independent of geographical location and/or crude processed in the refinery.

Secondary transportation from the specific refinery gate to the asphalt plant or other processing factory, directly or via intermediate storage at bitumen depots, is not included and must be added.

The target audience consists of customers of bitumen producers and organisations studying environmental issues, such as the European Commission, national official bodies, consultants, universities, asphalt producers, industries, etc.

4.2 Product description

The general assumptions concerning the bitumen studied in this LCI are as follows:

- The bitumen is paving grade bitumen according to EN 12591[2]. This is the most widely used paving grade bitumen in Europe.
- The bitumen is made in a hypothetical modern, complex, heat-integrated refinery, located in EU. The refinery is considered to be a complex refinery manufacturing a broad variety of petroleum products, including bitumen.
- The bitumen is manufactured by straight-run distillation of crude oil, which is the most common production route for paving grade bitumen manufactured in Europe. During this process the residue from the atmospheric distillation of crude oil is further distilled in a vacuum tower to produce paving grade bitumen. The Figure 6 shows a schematic view of the refinery processes and products.
- This LCI does not take into account other refinery processes, such as thermal cracking (visbreaking) or deasphalting. The visbreaking and vacuum flashing processes are primarily used to produce vacuum flashed distillates for use as fuels. The feedstock for the visbreaking unit is vacuum residue. The energy consumption and emissions from the visbreaking and vacuum flashing processes are fully allocated to the vacuum flashed distillate fraction. The vacuum flashed visbroken residue fraction, a by-product from the processes, may be used in bitumen production and is deemed to have the same energy consumption and emissions as the feedstock, i.e. vacuum residue
- The de-asphalting process is used to produce deasphalted oil for the manufacture of lubricating oils. The feedstock for the deasphalting unit is vacuum residue (or bitumen). The energy consumption and emissions from the deasphalting process are fully allocated to the deasphalted oil fraction. The precipitated asphaltene fraction, a by-product from the process, may be used in bitumen production and is deemed to have the same energy consumption and emissions as the feedstock, i.e. vacuum residue.

4.3 Declared unit

The declared unit of this LCI is 1 tonne (1 000 kg) of paving grade bitumen. Refined bitumen is not used on its own and is always blended with other materials, therefore this LCI refers to a quantity of a construction product for use as a reference unit in an Environmental Product Declaration (EPD), Section A1 of EN 15804[3] for asphalt mixtures and other construction products.

4.4 System boundaries

The system boundaries are unchanged in this study compared with the previous LCI from Eurobitume, published in 2012[1]. The LCI covers four stages of the product life-cycle and is a 'cradle to refinery gate' study, covering the product stage of the life cycle (stages A1, A2 and A3 of EN 15804) as follows;

- A1; extraction of crude oil,
- A2; transportation of the crude oil from the country, or region of extraction,
- A3; refining of bitumen from crude oil
- A3; Storage of the refined bitumen within the refinery

A schematic description of the system boundary is provided in Figure 1. A more detailed view of the refinery processes and co-products is shown in Figure 6.

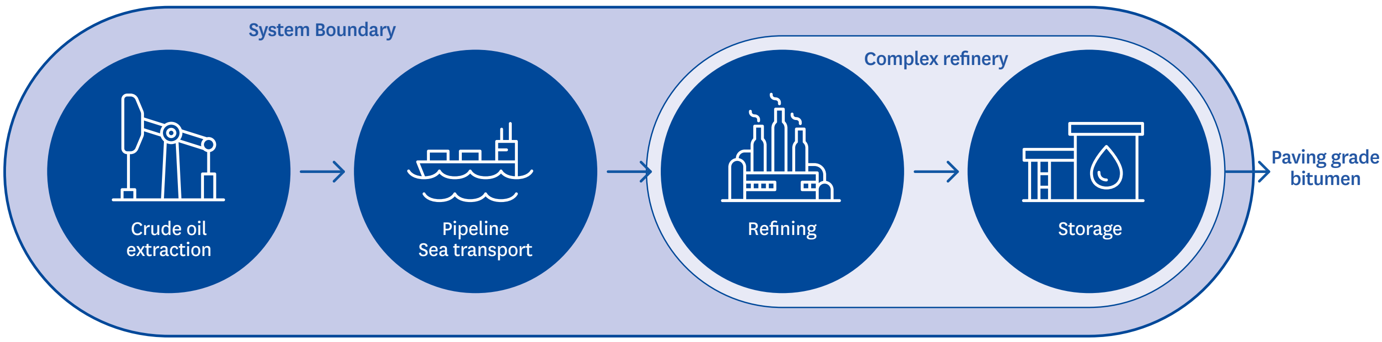


Figure 1. System boundaries for the bitumen LCI (cradle-to-refinery gate approach)

4.5 Allocation procedures

Allocation is the process by which partitioning of the input or output flows of a process or a product system is conducted between the product under study and one or more other products.

Bitumen is a co-product of the crude oil refining process. In order to assess the environmental impact of bitumen, a method must be determined to allocate the impacts of the production chain between bitumen and the other co-products: liquefied petroleum gas, gasoline, kerosene, gas-oil, heavy fuel oil, etc.

The aim of the allocation procedure is to find a suitable parameter so that the inputs and the outputs of the system studied can be assigned to the product under consideration.

According to ISO 14040[4] & ISO 14044[5], there are different ways to address allocation issues: the preference is physical allocation (based on mass, calorific value, etc.) or when this is not possible, economic allocation (based on relative values).

In this LCI, the allocation of the inputs and outputs at the different stages of the production chain are made as follows:

4.5.1 Crude oil extraction step

At crude oil extraction step, the IOGP reports data for "hydrocarbons unit". Burdens at crude oil extraction step are allocated by oil-equivalents (energy allocation).

4.5.2 Refinery step

The allocation at the refinery is changed from the previous LCI and avoided by using an approach following up energy flows within the distillation column, using physical relationships, as proposed in ISO 14040 and ISO 14044. No allocation is made at this stage but the energy uses are modelled bottom-up. The following issues have been taken into account for this decision:

- In a modern, heat-integrated, oil refinery the crude oil is pre-heated using heat recovered from the distillation products before entering a furnace, where it is further heated to the temperature necessary to produce the distillate materials required. The majority of the heat input from the furnace is used to provide the energy required to change the distillate fractions from liquid to vapour phase (the enthalpy of vaporisation). This energy is recovered in heat exchangers from the distillate products as they condense (enthalpy of condensation) and the recovered energy is used to pre-heat the crude oil feed to the main furnace.
- Bitumen does not change state in either the atmospheric or the vacuum distillation column, remaining in the liquid phase throughout the distillation process, therefore the enthalpies of vaporisation and condensation can be disregarded.
- Because bitumen does not change state during the refining process a simplified approach could be adopted. The amount of energy required to change the temperature of the bitumen is calculated from the specific heat capacity of bitumen and the overall temperature change from the crude oil to the run-down temperature of the crude oil. Further detail is provided in section 5.4.

In this study energy consumption data are not provided for ancillary processes in the refinery, such as desalting and dewatering of the crude oil as reliable data are not available separately. The energy consumption of ancillary processes is a small fraction, around 3%, of the total energy use within a refinery. This value is based on expert opinion. Overall energy consumption is taken from confidential data from Solomon reports[6] and this percentage is allocated to the ancillary processes, because bitumen production represents typically around 3% of the value of total production of a complex refinery (economic allocation), based on expert opinion.

4.5.3 Storage of bitumen

Allocation for the storage stage of the life-cycle was based upon a mass balance and is unchanged from the previous LCI (2012).

4.6 Data sources

For the main processes (crude oil extraction, straight-run distillation and storage), this LCI is based upon:

The most recent reports of the crude oil and refining industry

- Crude oil extraction data is based on the data from the International Association of Oil and Gas Producers (IOGP), completed with Ecoinvent 3.5 for background processes. Data for crude oil extraction are averaged over the years 2013 – 2017 using data derived from the International Oil & Gas Producers' Association (IOGP) Environmental Performance Indicators reports, the most recent being 2017[7] and previous volumes of the same report.
- Refinery fuel and energy consumption are taken from CONCAWE. Data for emissions and fuel consumption represent 63 refineries and 68% of European refinery throughput so it was considered that this data from CONCAWE was the most source representative of a modern European refinery producing bitumen.

European collated submissions and data collected by industry*

- The average supply distribution of the crudes used specifically for bitumen manufacture is based on internal information from Eurobitume members. The crude oil diet defined in this LCI is representative of the average European supply used for bitumen production.
- For transport by pipeline and ships, actual data from pipeline companies and a ship owner (Wartsila) was used. These data have been completed with further data from the International Maritime Organisation (IMO) concerning emissions to air. It was judged that data from IMO and ship owner was more relevant than ecoinvent. The change in the crude basket has led to changes in the transportation calculations due to the differences in percentage of crude oil from the respective origins and the consequent differences in transportation distance. Further details on the assumptions used are found in section 5.3.2.

Thermodynamic calculation and model

- For energy consumption of refining, the amount of energy was calculated, based on the heat required to raise the temperature of bitumen fraction within the crude oil to 175 °C.

For other processes (electricity production) and infrastructure (oil wells and platforms, ships, pipelines, oil refinery), information from the ecoinvent 3.5 cut-off database has been used. For infrastructure, a review of the data sources used within the ecoinvent 3.5 database[8] concluded that confidence in both the calculations used previously and the source data within ecoinvent was low. This data was corrected, applying the values given in the ESU-services study on life cycle inventories of crude oil extraction[9]. The LCI of bitumen is provided with and without infrastructure.

* Confidential internal data provided by Eurobitume member companies

4.7 Data quality

4.7.1 Temporal, geographical & technological representativeness

The selection of data sources was conducted on the basis of identification of the most appropriate source of data for current production of bitumen in Europe in 2017. The Task Force conducted literature surveys to identify the most recent and relevant reports from which the data were available.

- The data for the principal processes is representative of the European context. The crude oil basket, whilst not necessarily applicable for any individual refinery, is believed to be representative of the average European supply for bitumen manufacture and has been reviewed by Concawe, the European oil refining association. Transportation is representative of the principal routes to Europe from the regions of crude oil extraction.
- Data for crude oil extraction represent 44 of IOGP's 56 members operating companies covering operations in 80 countries worldwide and ~30% of global production sales. In this report data are provided as an average of 5 years (2013 – 2017), the previous LCI report used data from a single year. A review of extraction data over several years indicated that energy consumption and emissions can change significantly from one year to the next, due to differences in reporting and/or due to actual changes in energy/emissions, therefore an average value over 5 years was considered to be the most representative approach.
- Shipping data are taken from technical data sheets of a major ship constructor[10] and transportation distances are derived from a publicly available shipping rate calculator[11].
- Refinery fuel consumption and emissions data are taken from Concawe[12], whose members include 41 companies that operate petroleum refineries in the European Economic Area. Data for emissions and fuel consumption represent 63 refineries and 68% of European refinery throughput.

Other process data from the ecoinvent 3.5 database are representative of the current average technology in Europe.

4.7.2 Precision & accuracy

The LCI is provided in an aggregated format. Since the format of the LCI does not allow to show the standard deviation of each input, a quantitative uncertainty assessment for each flow cannot be provided in a .csv format. However, the Pedigree matrix was assessed for each foreground data. The results are presented in appendix 3. The uncertainty range is also displayed, via a Monte Carlo assessment, on the LCIA results are displayed in Appendix 3.

In addition to using a statistical approach for uncertainty assessment, data quality has been considered. An overall qualitative assessment of accuracy can be given by taking into account the reliability and the completeness of data used (data from literature, measured data or estimated data). This assessment can be given as follows:

- There is reliable accuracy for the most relevant flows in the bitumen production chain: crude oil consumption, natural gas consumption, emission to air of carbon dioxide (CO_2), sulphur dioxide (SO_2), nitrogen oxides (NO_X), methane (CH_4) and non-methane volatile organic compounds (NMVOC). Data from IOGP for the main flows are representative of 84 – 100% of participating company production and are therefore considered to be reliable and representative on a regional basis. Further explanation is provided in section 5 of this report.
- There is good, or satisfactory accuracy for the other flows.

5. INVENTORY ANALYSIS

In several of the data tables the total values may show small inconsistencies due to rounding of values.

5.1 Crude oil basket

The first stage of the LCI review was to evaluate the average crude diet used for the manufacture of bitumen in EU28. A review of the data for typical bitumen crude volumes imported to Europe suggested the changes shown in Table 1 to the crude slate to be used for the LCI.

Within a complex oil refinery numerous different crude oils may be processed. The European Union collects information on all crude oil consumption within the EU[13], these data were reviewed, but were not representative of the typical crude oils used for bitumen manufacture. Certain crudes, generally lighter, low-sulphur crudes, are not used for bitumen production, for which specific, typically heavy, high-sulphur crude oils are used. Refinery crude diets are kept strictly confidential within oil refineries, therefore an internal, Eurobitume member-company review was conducted in order to develop the revised diet, which does not reflect the overall European crude oil consumption data. The crude oil barrel selected is representative of an average EU barrel for bitumen production and has been validated by Eurobitume member companies. The revised figures were reviewed by Concawe and represent a contemporary typical crude diet for a complex refinery. To be noted that no fracking is included as these crude oils tend not to be used for bitumen production and no oil sands crude oil is included since no North American crude oil is considered.

The Inventory analysis uses weighted values for the LCI based upon the relative percentages of crude oils below.

Table 1. Crude diet used for the LCI review in 2012 and 2018 review

Crude source	2012 LCI (%)	2018 LCI (%) – used in this study	Average European crude oil consumption
Former Soviet Union (FSU)	61	30	39
Middle East	18	45	17
South & Central America	11	15	4 *
Europe	10	10	20
Africa	0	0	20
Total	**100**	**100**	**100**

5.2 Crude oil extraction

Crude oil extraction data is based on the IOGP data, completed with Ecoinvent 3.5 datasets for background processes. Data for crude oil extraction are averaged over the years 2013 – 2017 using data derived from the International Oil & Gas Producers' Association (IOGP) Environmental Performance Indicators reports, the most recent being 2017[14] and previous volumes of the same report. These data represent oil and gas wellhead production of 2,072 million tonnes (15,4 billion BOE**), about 27% of 2017 global production sales[15], with the absolute and relative production values at similar levels in previous years to 2010. Regional coverage is uneven, ranging from 82% of known production in Europe to 10% in the Former Soviet Union (FSU). The data are considered to be representative of IOGP membership production. In discussion with IOGP, the data for Russian Federation are the less robust data. This is due to a lack of reporting from Russian oil and gas producers. However, despite this, data are provided by IOGP member companies that have Joint Venture relationships in the Russian Federation. Much of the IOGP data are independently verified so confidence in the data is considered to be adequate for the aggregated data used in this study, but the uncertainties suggest that such data should not be used for individual refineries, or specific crude oils.

IOGP data include the following operations

- Drilling (exploration, appraisal and production drilling)
- Oil and gas extraction and separation (primary production)
- Primary oil processing (water separation, stabilisation)
- Crude oil transportation by pipeline to storage facilities
- Offshore crude oil ship loading from primary production
- Onshore crude oil storage connected by pipeline to primary production facilities
- Gas transportation to processing plant (offshore/onshore)
- Primary gas processing (dehydration, liquids separation, sweetening, CO_2 removal) performed with the intent of making the produced gas meet sales specifications
- Floating Storage Units (FSUs)
- Offshore support and standby vessels
- Exploration (including seismic) activities
- Activities related to geologic storage of CO_2 from natural gas processing
- Mining activities related to the extraction of hydrocarbons

The following items are specifically excluded by IOGP

- Gas processing activities with the primary intent of producing gas liquids for sale (unless data cannot be separated out);
  - Secondary liquid separation (i.e. Natural Gas Liquids [NGL] extraction using refrigeration processing)
  - Ethane, Propane, Butane, Condensate (EPBC) fractionation
  - Liquefied Natural Gas (LNG) and Gas to Liquids (GTL) operations (LNG data are being compiled separately from the E&P data using this same process)
- Transportation of personnel
- Transportation of oil and gas, after sales metering devices (LACT units) or after ship loading at the primary production site
- Storage of refined products
- Partners' operations
- Non-operated joint ventures, except when the operator is not an IOGP member and the joint venture has agreed that one company should take the lead on data reporting
- Upgrading activities related to the extraction of hydrocarbons. All other non-E&P activities

* Percentage of crude oil from south, central and north America
** Barrels of Oil Equivalent

5.2.1 Raw material

Raw material energy use and emission data were derived from the IOGP environmental reports, providing data between 2003 and 2017. In the previous LCI data from a single year, 2009, were used. However, it became clear that differences in reporting meant that data from single years may not provide a representative picture, therefore mean values of the reported data for the years 2013 – 2017 were selected for this report. Figure 2 illustrates the variability in annual emission data for CO_2e on a regional basis.

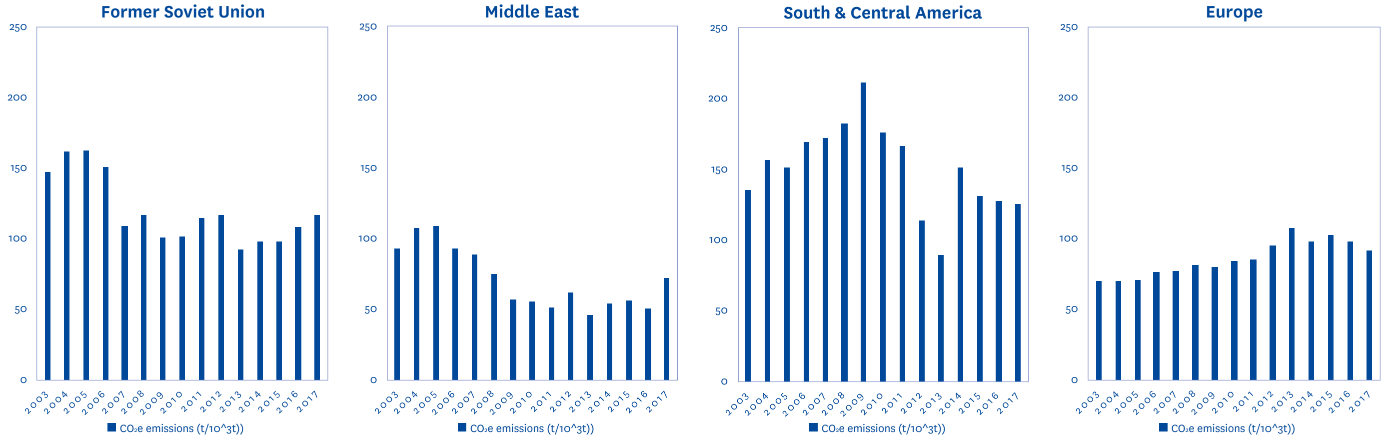


Figure 2. CO_2e emissions for crude oil extraction, by region over time

The aggregated CO_2e emission data for crude oil extraction compared to the data used in the previous report and for 2013 – 2017 are shown in Figure 3.

Data available from IOGP are believed to be the most reliable source for crude oil extraction. Therefore, the main flows provided by IOGP were included into ecoinvent inventories. These flows were also completed by considering indirect emissions, from energy and material purchase. To be noted that IOGP data are not available in commercial LCI databases, but were also considered in the study from Meili et al. on life cycle inventories of crude oil extraction[9].

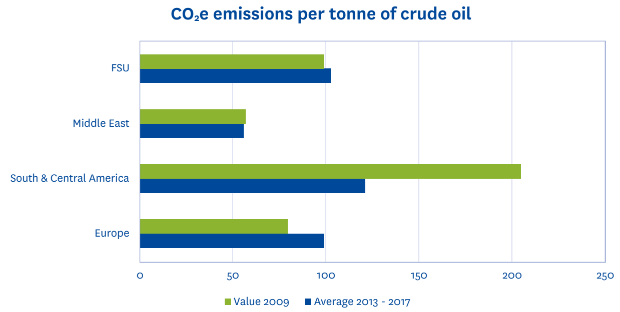


Figure 3. Comparison of 2009 crude oil extraction data with values for 2013–2017 (source IOGP)

IOGP reports a range of environmental endpoints and for this study the following inputs and outputs were selected:

- Total energy consumption per unit of production
- Carbon dioxide (CO_2) emissions
- Methane (CH_4) emissions
- Greenhouse Gas (GHG) emissions (CO_2e)
- Non-Methane Volatile Organic Compound (NMVOC) emissions
- Sulphur dioxide (SO_2) emissions
- Nitrogen oxide (NO_X) emissions
- Emissions to water
- Emissions to soil

The following definitions are used for the emissions and energy consumption per unit of production:

5.2.2 Consumption of energy resources

For the oil extraction process, the energy consumption given in the IOGP report ranges from 344 MJ/t to 1 432 MJ/t depending on the type of crude oil and the location, most of the energy is locally produced (table 2). The split between gas and crude oil depends on the crude oil type and is generally assumed to be natural gas. The split between onsite combustion and purchased energy is taken from the IOGP environmental report, purchased energy is assumed to be electricity. In this report data are presented as % onsite combustion, purchased energy and unspecified. For this report it was considered that oil producers would know when energy was purchased, therefore unspecified was considered to be onsite production.

The reported energy is converted into masses using calorific values of 43 MJ/kg for crude oil and 49,4 MJ/kg for natural gas, the same values were used for the previous Eurobitume LCI (2012).

Table 2. Resource consumption for energy consumed during crude oil extraction

Consumption of natural resources used for energy production		Former Soviet Union	Middle East	South America	Europe
Energy consumption	MJ/t	1226	344	1170	1432
Crude oil	kg/t	0	0	13	0
Natural gas	kg/t	23,1	5,1	11,3	26
Electricity	kWh/t	19,2	21,4	12,1	33,4

The purchased electricity was considered into the scope of this LCI, as it was not included into the OGP data.

5.2.3 Greenhouse gas emissions

For crude oil extraction, Carbon Dioxide (CO_2) and methane (CH_4) are the principal contributors to greenhouse gas emissions, arsing mainly from flaring and processing. When the source of emissions was specified, 68% of the reported carbon dioxide emissions are from energy use, 25% are from flaring, 6% are from venting and 1% are from fugitive losses.
This amount of fugitive losses are in line with the report made by the ICCT (International Council on Clean Transportation) for the European Commission[16]. The table 4.13 of this report shows that in some cases fugitive emissions may represent a higher percentage of oil production emissions, up to 19%, for example, for Duri in Indonesia, but in many cases the fugitive emissions are less than 1% (for wells in the USA, Canada, Saudi Arabia, Libya, Russia, UK and Norway). It should be highlighted, however, that these are highly dependent on the well characteristics and a strong variability is observed even within a same country.

Differences between the values in Table 4 and the calculated values from the averaged CO_2 and CH_4 values are the result of rounding and averaging of reported values and year-to-year reporting differences.

5.2.4 Non-Methane Volatile Organic Compounds (NMVOCs)

NMVOC emissions mainly occur from flaring, venting and fugitive releases and, to a lesser extent, combustion equipment.

5.2.5 Sulphur dioxide (SO_2)

Sulphur oxide emissions arise through oxidation during combustion of sulphur naturally contained within flared gas (Hydrogen Sulphide (H_2S) content) and diesel (sulphur content). The figures provided are the sum of sulphur dioxide (SO_2) and sulphur trioxide (SO_3) expressed as SO_2 equivalent.
Where the source was specified, 51% of sulphur dioxide emissions reported were from flaring, 48% were from energy use and 1% were from venting.

5.2.6 Nitrogen oxides (NO_X)

Emissions of nitrogen oxides, (principally nitric oxide (NO) and nitrogen dioxide (NO_2) expressed as NO_X), occur almost exclusively from the combustion of natural gas or other fuels. These emissions are a function of the combustion equipment, loading and technology.
Where the source was specified, 95% of nitrogen oxide emissions reported were from energy use and 5% were from flaring.

5.2.7 Halon emissions

The emissions of halon and firefighting equipment occurs for offshore crude oil production in Europe. An amount of 0,7 mg halon/t crude oil extracted offshore was considered[9], with 20% as Halon 1301 and 80% as Trifluoromethane. No halogenic emissions were considered for onshore operations.

5.2.8 Losses

Fugitive losses occur from venting and other uncontrolled releases. Methane emissions arise mainly from the process and tank vents and are recorded as 'Natural gas - vented' under the losses section. Direct emissions from venting and fugitive losses are covered by the IOGP study.

Regarding the natural gas venting, the range of values for methane emissions from vented natural gas found in the literature is very high, from $3{,}11 \cdot 10^{-4}$ Nm^3 to 42,2 Nm^3 per tonne of oil extracted[9]. In this study, the total amount of methane emissions from venting represents 0,28 Nm^3 per tonne of oil extracted*, which is much lower than the IEA value (14,2 Nm^3/tonne OE) used in the ESU-services study[9].

5.2.9 Emissions to water

5.2.9.1 Water emissions

Produced water is the highest volume liquid discharge generated during the production of oil and gas. It consists of formation water (water present naturally in the oil reservoir), and/or floodwater (water previously injected into the reservoir).

After extraction, produced water is separated and treated (de-oiled) before discharge to surface water (including seas, rivers, lakes, etc.) or to land (including to evaporation ponds). Produced water can also be injected either into the producing reservoir where it can enhance hydrocarbon recovery or into another appropriate formation for disposal. The volume of produced water typically increases as recovery of oil and gas from a field progresses, that is, as the field becomes 'mature'.

The quality of produced water is most widely expressed in terms of its oil content. There are a number of analytical methodologies in use around the world for measuring oil in water.

In 2017, IOGP participating companies reported the oil content of 976 million tonnes of discharged produced water. Where the location was specified, approximately 82% of water discharged was from offshore operations and 18% was from onshore operations.

Onshore, where disposal to surface is often constrained by regulatory and environmental concerns, injection of produced water is the principal disposal route. In 2017, 86% of water produced from onshore assets was returned below ground in data sets where the volumes of re-injected water were provided by reporting companies .

5.2.9.2 Oil spills to water

Accidental oil spills due to accidents on offshore platforms have caused large oil spills. Based on a literature review, Meili et al.[9] defined that a ratio of 36g crude oil spilled/tonne crude oil produced offshore is representative of the oil emissions to water occurring during accidental oil spills. This value was applied in this study. Since only oil from Europe is extracted offshore (10% of the crude oil basket), this study considers that 3,6 g/tonne of crude oil is emitted into the water during the oil extraction stage.

* This estimation was made, considering the value of 0,34 kg/t OE of vented natural gas, with 0,58 kg CH_4/kg natural gas and a density of 0,71kg CH_4/Nm^3

5.2.10 Emissions to soil (Oil spills)

Spills are an important environmental performance indicator for the oil and gas industry since they can have a significant and visible impact on the environment.

The environmental impact is highly dependent on the nature of the release, where it occurred and how it was subsequently managed. Most oil exploration and production companies have spill contingency plans and measures in place to respond to and mitigate spills.

For the purpose of this report a spill is defined as any loss of containment from which the released material reaches the environment (i.e. is not retained within secondary or other containment). The volume reported represents the total volume that reached the environment, irrespective of quantity of released material that may be recovered.

Spills may have a number of causes such as equipment failure (including corrosion), operating errors, and unlawful third-party damage such as sabotage and theft.

5.2.11 Fresh water drawn from the environment

The definition of fresh water varies in accordance with local statutes and regulations. Where it is not defined by local regulations, fresh water is defined for reporting purposes as non-brackish water and may include drinking water, potable water, water used in agriculture, etc.

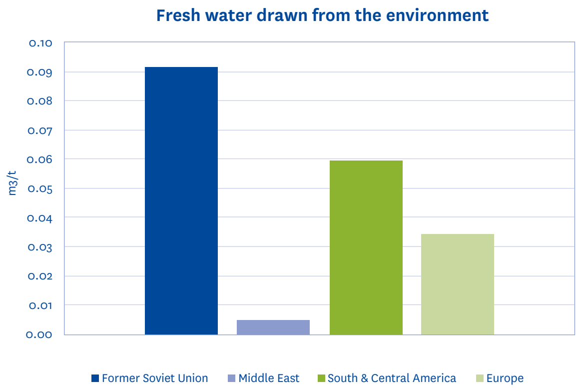


Figure 4. Fresh water drawn from the environment (m^3/t), by region

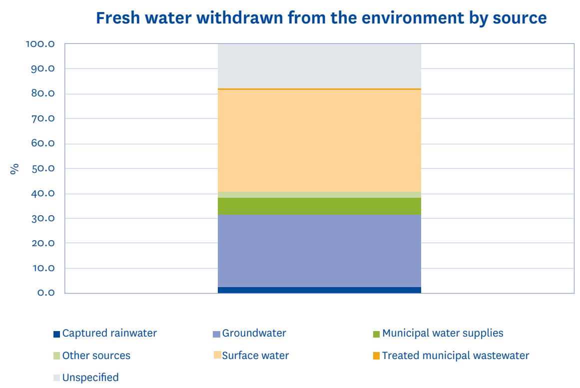


Figure 5. Fresh water drawn from the environment, by source

In 2017 regional averages for quantity of fresh water withdrawn for the purpose of use expressed per unit of production varied from 4,6 to 371,45 cubic litres per tonne of hydrocarbon production. Figures 4 and 5 show fresh water consumption and source for crude oil production. The water consumption was characterised by their water region in the final LCI, as show in Figure 4, using the following flows:

Table 3. Water flow modelling for crude oil extraction

Region	Elementary flow
Former Soviet Union	Water, unspecified natural origin, RU
Middle East	Water, unspecified natural origin, RME
South & Central America	Water, unspecified natural origin, VE (used as a proxy)
Europe	Water, unspecified natural origin, Europe without Switzerland

5.2.12 Crude oil extraction data

Table 4. Summary data for crude oil extraction

	Unit	Former Soviet Union	Middle East	South America	Europe	Total
Crude oil source	%	30	45	15	10	100
Raw material						
Crude oil	kg/t	1 000	1 000	1 000	1 000	1 000
Fresh water	L/t	92	4,9	59	34	42
Consumption of energy resources						
Process						
Crude oil - onsite combustion	kg/t	0	0	13,0	0	1,9
Natural gas - onsite combustion	kg/t	23	5,1	11	26	14
Purchased electricity	kWh/t	19	21	12	33	21
Losses						
Natural gas, flared	kg/t	10	5,5	7,8	3,5	7,0
Natural gas, vented	kg/t	0,48	0,10	0,70	0,48	0,34
Emissions to air						
CO_2	g/t	104 962	71 259	108 419	103 212	90 139
CO [1)]	g/t	14	11	8,7	11	12
SO_2	g/t	267	633	144	79	395
NO_x	g/t	227	158	499	359	250
CH_4	g/t	509	137	757	482	376
NMVOC	g/t	160	310	755	264	327
Particulates [1)]	g/t	31	7,6	4,9	24	16
Emissions to water						
Oil	g/t	0,7	10	9,9	44,7	10,7
Emissions to soil						
Oil spills	g/t	4,8	12	6,4	6,1	8,4

1) From Ecoinvent v3.5 background data

5.3 Transport of crude oil to Europe

The crude oils for European bitumen production are mainly transported to the refinery by ship. The exception is Former Soviet Union crude oil, that is partly transported by pipeline. In this study it is assumed that the FSU crude oil is transported from the Samara area to the Baltic Sea by the Baltic Pipeline System (BPS) and then, from the Baltic Sea to the Amsterdam-Rotterdam-Antwerp (ARA) region by ship.

5.3.1 Transport by pipeline

For transport by pipeline, data from pipeline companies was used. The energy requirement of the BPS was not available. As a consequence, an estimate was calculated using data from another pipeline and a topographical analysis, as the main energy requirement depends on the topography and length of the route. The topography of various pipelines was modelled[17].

The SPSE pipeline between Lavera, France and Karlsruhe, Germany is regarded as having the closest topographic profile to the BPS. The same amount of energy per tonne of crude oil and per 100 km needed by the SPSE was used to calculate the energy needed by the BPS.

See Table 5 for the summary information for transport by pipeline.

It was assumed that electricity was produced by a diesel generator consuming around 0,1 litres of diesel per kWh, this value is a significant change from the 2012 report. This is a conservative assumption, as it is known that some of the power consumed is also produced by gas-driven generators and some comes directly from the grid.

The consumptions and emissions attributable to the diesel burned are given in the life cycle inventory “Diesel, burned in diesel-electric generating set {GLO}| market for | Cut-off, U” of the ecoinvent 3.5 database.
The data concerning pipeline infrastructure are presented in Appendix 1.

Table 5. Summary data for pipeline transport.

	Unit	Former Soviet Union	Middle East	South America	Europe	Total
Crude oil source	%	30	45	15	10	100
Distance	km	1800				
Energy	MJ/t	129,6	0,0	0,0	0,0	38,9
Electricity	kWh/t/100 km	2,0				0,6
	kWh/t	36,0	0,0	0,0	0,0	10,8

5.3.2 Transport by ship

In the calculations, crude oil is transported to Europe in 106 000 Dead Weight Tonne (DWT) Aframax* vessels. This is a typical vessel size for Former Soviet Union and South America. For Middle East crude oil using the route via Suez, the size varies between 130 000 DWT and 250 000 DWT, and for Europe the size is 70 000 DWT. The use of a 106 000 DWT ship for all regions is considered to be a conservative compromise. Data are summarised in Table 7. The inventory "Transport, freight, sea, transoceanic tanker {GLO}| processing" from ecoinvent v3.5 was adapted with more up-to-date and specific data.

5.3.2.1 Consumption of energy resources

Data for fuel consumption were taken from Wärtsilä Aframax data sheet10, fuel consumption assumptions used are provided in Table 6.

Table 6. Ship fuel consumption data

Average Speed	13,5 knots (25 km/h)
Fuel consumption	
Fully loaded	36 t/day
Ballasted	26 t/day
Loading**	2t (10 hours)
Discharging**	11,5t (12 hours)
Fuel consumption	9,87E-04 kg fuel/ t.km

The transportation distance is calculated with a port-to-port distance calculation tool[11]. The duration of the voyage is calculated using an average speed of 13,5 knots.

The fuel consumption is calculated with one way fully loaded and a return trip ballasted and includes loading and discharging.

The consumptions and emissions due to the production of marine fuel are given in the life cycle inventory "Heavy fuel oil {RER}| market group for | Cut-off, U" of the Ecoinvent 3.5 database.

5.3.2.2 Emissions to air

Emission factors for ship fuel combustion were taken from the IMO GHG3 report[18], using data for slow-speed diesel, 2-stroke diesel engines compliant with IMO Tier II criteria. These data are considered to provide a conservative estimate of emissions, as the ship for which the data are provided is fitted with emission reduction technology, compliant with IMO Tier III criteria, which would reduce SOx and NO_x emissions. Compliance with Tier III would reduce NO_x emissions by a factor of approximately 4.

SO_2 emissions are calculated on the basis of High Sulphur Fuel Oil being used outside the Sulphur Oxide Emission Control (SECA) area and 0,1% sulphur fuel oil within the SECA area. Data from Marintek[19] reported that there are no methane emissions from diesel engines running Medium or Heavy Fuel Oil, therefore no methane emissions are attributed to shipping fuel combustion.

The IMO has established a maximum sulphur content of 3,5% for fuel oil, the typical highest value in use today is 2,7% sulphur, this figure has been used for ship emissions outside any Emission Control Area (ECA). This value will be reduced to 0,5% in 2020 and will have a concomitant impact on emissions of sulphur oxides from that time. Within the Sulphur Emission Control Area (SECA) of Europe the maximum content of sulphur in fuel oil is 0,1%, this figure is used for shipping fuel combustion in SECA waters. A comparison with ecoinvent dataset can be found in appendix 2.

* Average Freight Rate Assessment (AFRA) denomination for oil tankers
** Data taken from MT Mastera

5.2.3.3 Emissions to water

Emissions to water from shipping are assumed to be zero. The ship travels from the crude oil loading terminal full of crude oil and returns to the loading terminal with ballast water. Ballast water is treated at the loading terminal. The emissions of pollutants and chemicals substances from bilge water and tank washing are not covered in this study.

5.2.3.3.1 Oil spills

Nowadays, the volume of oil spilt represents a very small fraction of the volume that is transported in tankers. The total amount of oil spilt from 2000 to 2009 (19 600 tonnes[20]) represents less than 0,001% of the total amount of crude oil transported between 2000 and 2009***. Based on this value, it was considered that the spills from shipping represent 10 g crude oil spilled/t crude oil transported.

*** Considering an amount of 15 414 millions tonnes of oil transported, based on unctad data (https://unctad.org/en/PublicationsLibrary/rmt2018_en.pdf)

Table 7. Ship transportation data

Crude oil source	Unit	Former Soviet Union	Middle East	South America	Europe	Total
	%	30	45	15	10	100
Sea transport to ARA from		St, Petersburg	Ras Tanura	Maracaibo	Bergen	
		Russia 1)	Saudi Arabia 2)	Venezuela	North Sea	
Data on sea transport						
Vessel	DWT (t)	106 000	106 000	106 000	106 000	106 000
Distance	km	2 332	12 040	8 253	1 007	7 456
Speed	km/h	25	25	25	25	
Duration	h	93	482	330	40	298
Fuel consumption, total	t/trip	253	1 252	862	117	780
- Fuel 2,7% S	t/trip		1 164	781		641
- Fuel 1,0% S	t/trip				59	5,9
- Fuel 0,1% S	t/trip	253	88	81	59	133
Consumption of energy resources						
Heavy fuel oil	kg/t	2,39	11,81	8,13	1,10	7,36

1) Around Denmark, not via the Kiel Canal

2) Via Suez

The data for infrastructure is described in Appendix 1.

5.4 Bitumen production

The straight-run distillation process is shown in Figure 6. In this process, the residue from the atmospheric distillation of crude oil is further distilled in a vacuum tower to produce paving grade bitumen. In a complex refinery a broad range of petroleum products is produced, bitumen being a minor product compared with other products.

The bitumen yield from the average European bitumen crude blend is 28,5% by mass.

The process unit emission values include a share of common resources such as crude oil handling, desalting, flaring, loading area, general heating and lighting. No chemicals are added to paving grade bitumen or to the straight-run distillation process.

5.4.1 Consumption of energy resources

The allocation of energy and emissions at the refining level is complex due to the numerous coproducts produced during the distillation process. An economic allocation was used in the previous LCI, as this is the method used within the refinery to determine a relative value for different oil products. However, the process of distillation is governed by the thermodynamic principals governing change-of-state (from liquid to vapour), therefore for this review the Task Force considered a different approach should be used. In the previous LCI (2012) the relative value of bitumen to crude oil was taken as 0,61. However, there is not a formal relationship between hydrocarbon value used in the refinery and crude oil. The 2012 value was derived using a 'Complexity Weighted Tonne' (CWT) approach developed by Solomon Associates[21].

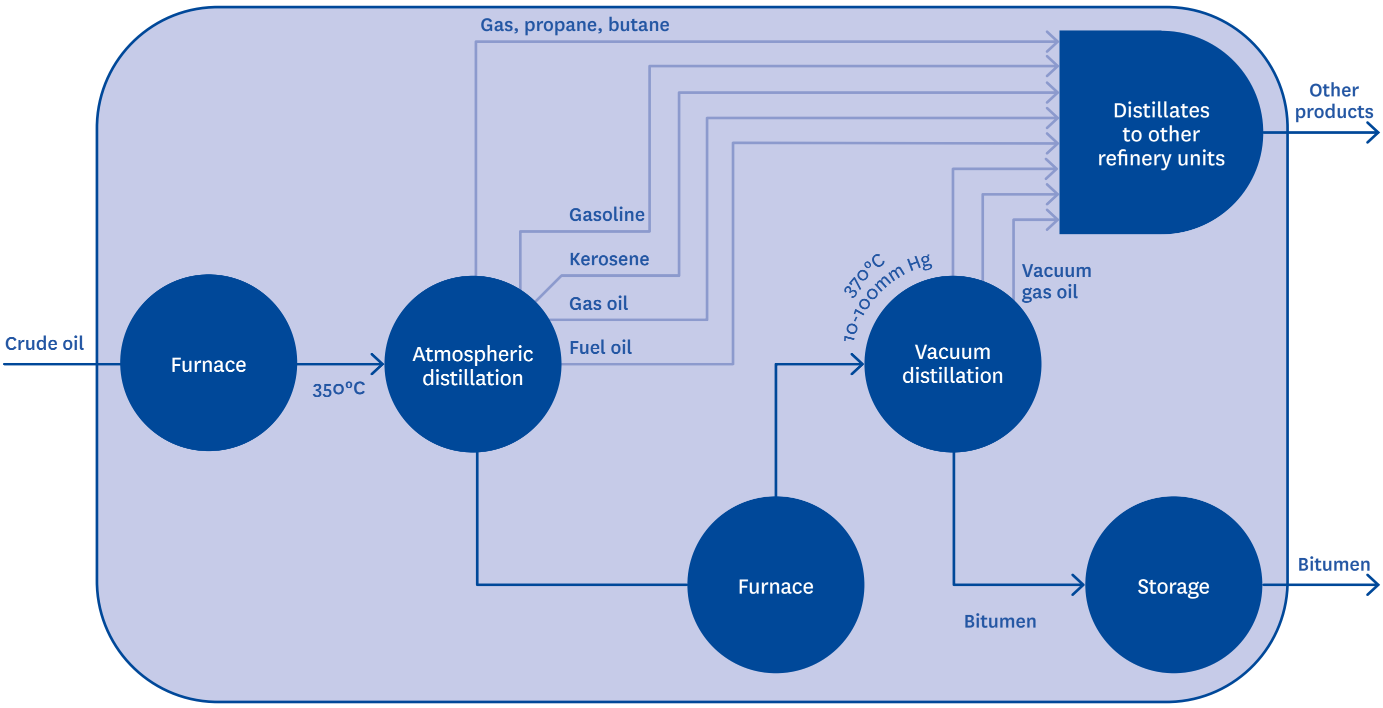


Figure 6. Schematic diagram of the refinery process

As mentioned in section 4.5 of the report, physical allocation is preferred in the ISO standards.

The majority of the energy that is input to the distillation process is used to provide the enthalpy of vaporisation, to change the distillate fractions from liquid to vapour phase (enthalpy of vaporisation). This energy is recovered as the enthalpy of condensation when the distillates condense further up the distillation column and is collected through heat exchangers and, in a heat-integrated refinery, used to pre-heat the crude oil prior to the furnace.

Bitumen is a residual stream and does not change state during the distillation process. The approach used in this LCI has been to consider only the heat required to change the temperature of the bitumen molecules within the crude oil using the specific heat capacity of bitumen[22] to determine the amount of energy required to raise the temperature of the bitumen fraction of the crude oil to 175 °C. A conservative estimate of heat-exchanger efficiency of 90% was assumed and energy consumption was adjusted accordingly.

At this time a further study to develop a model of a heat-integrated refinery is under consideration, such a model would take into account the energy flow for each of the major streams from the atmospheric and vacuum distillation columns and heat transferred between products and heat exchangers.

Based on this allocation method, the energy required for the production of straight-run bitumen is 315 MJ/t.
Other options for allocation are possible and would change the results for the refining part of the life-cycle.
The sensible heat method uses the mass of material and its specific heat capacity and includes an efficiency term for the heat exchangers used in the refinery as follows;

$$\frac{C \cdot \Delta T}{\eta} = \text{Thermal energy required}$$

Where;
C = specific heat capacity (J/K)
ΔT = net change in temperature of bitumen (K)
η = efficiency of heat exchangers

Table 8. Bitumen manufacture calculations

	Unit	Value	ΔT
Crude oil temperature	°C	40	
Atmospheric distillation			
Furnace inlet temperature	°C	260	220
Furnace outlet temperature	°C	350	90
Atmospheric column outlet temperature	°C	350	
Vacuum distillation			
Furnace inlet temperature	°C	350	0
Furnace outlet temperature	°C	370	20
Vacuum residue temperature	°C	370	0
Run-down temperature to storage	°C	175	-195
Overall temperature change			**135**
Specific heat capacity of bitumen	J/kg·K	2 100	
Temperature adjustment	J/K	0	
Energy required to heat bitumen	J/kg	283 500	
	MJ/t	315*	

* Heat exchanger efficiency assumed to be 90%

The energy mix used for the calculations was based upon data from Concawe from a survey conducted in 2010[23]. 93,5% of the total energy (steam, heat and internal electricity) needed for the production is produced in the refinery from refinery gas (86,7%) and heavy fuel oil (13,3%), the remaining 6,5% is assumed (by Concawe) to be gaseous fuels, such as natural gas. All gaseous fuels were considered equivalent to refinery gas (same calorific value and life cycle inventory).

Table 9. Distribution of energy sources for bitumen production in refinery

Distribution of energy sources for bitumen production in refinery		MJ/t bitumen
Heavy fuel oil	13,3%	41,9
Refinery gas	86,7%	273,1
Total	**100%**	**315**

The calorific values of the heavy fuel oil (40,0 MJ/kg) and refinery gas (49,4 MJ/kg) allow the calculation of the consumption of energy for the production of bitumen by straight-run distillation. The following amount of heavy fuel oil and refinery gas were considered:

Table 10. Energy consumption for bitumen production in refinery

Heavy fuel oil	1,05 kg/t bitumen
Refinery gas	5,53 kg/t bitumen

The consumptions and emissions due to the production and consumption of refinery gas and heavy fuel oil are given in the following life cycle inventories of the Ecoinvent 3.5 database: “Heat, district or industrial, other than natural gas {Europe without Switzerland}| refinery gas, burned in furnace | Cut-off, U” and “Heavy fuel oil, burned in refinery furnace {Europe without Switzerland}| processing | Cut-off, U”.

5.4.2 Water consumption.

Data for water consumption were taken from Concawe[24]. The data represent water consumption from 70 European refineries and cover intake, discharge and consumption. Water consumption varies depending upon refinery complexity, with more complex refineries consuming more water than less complex refineries. The report considers water consumption for refineries with 4 categories of Nelson Complexity Index (NCI)[25] in which bitumen production is assigned an NCI of 1.5. Therefore, water consumption was taken as a mean of class 1 and 2 data. In total, 342,50 L water/ t crude oil are consumed. However, it is not possible to regionalise this flow since this LCI described an average refinery based in Europe.

However, the source of fresh water for the refining stage was considered, as shown in figure 7. Water consumption associated with storage is assumed to be included in the refining data.

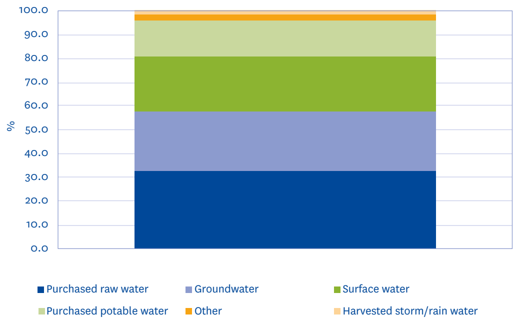


Figure 7. Refining fresh water consumption by source

The following flows were used to characterise the fresh water source:

Table 11. Water flow modelling in refinery

Source	Elementary flow
Rain water	Water, rain
Other	Water, unspecified natural origin/m^3
Purchased potable water	Water, process, drinking
Surface water	Water, river
Ground water	Water, groundwater consumption
Purchased raw water	Water, unspecified natural origin/m^3

5.4.3 Refinery infrastructure

The infrastructure for refinery was based on the ecoinvent inventory "Petroleum refinery {RER}| construction | Cut-off, U".

5.5 Bitumen storage

Directly after production, bitumen is transferred into heated storage tanks at the refinery where it is held at the required temperature. The bitumen remains within these tanks until loaded for subsequent transfer.

An average size storage tank of about 6 200 m^3 in volume is used for the study. A typical storage temperature is 175°C; bitumen is also transferred from the production process at this temperature. Bitumen in the storage tank is circulated constantly using a pump powered by an electric motor. The same pump is also used for loading. The annual throughput of the tank is fixed at 40 000 tonnes. The infrastructure for bitumen storage is not covered due to the lack of specific data.

5.5.1 Consumption of energy resources

The mean energy losses from the storage tanks and pipework were calculated by three independent sources using standard engineering methodology and calculations. The average energy use was as follows:

- Maintain the bitumen temperature within the storage tank 70,1 MJ/t
- Maintain the temperature within the pipework 20,2 MJ/t
- Circulate and load bitumen 9,7 MJ/t
- Total storage energy 100 MJ/t

Table 12. Energy calculations for bitumen storage.

Bitumen tank			**Heat losses**		
Volume	m^3	6 200	**Bitumen storage**	MJ/t	**70,1**
Temperature	°C	175	**Pipelines**		
Annual throughput	t	40 000	- bitumen	MJ/t	**20,2**
Outside conditions			- heating oil	MJ/t	
Temperature	°C	10	**Total storage**	MJ/t	**90,3**
Wind	m/s	5	**Energy need**	MJ/t	**90,3**
Annual use	h	8 000	Fuel for Hot oil		
Heating oil effiency	%	85	**Energy need**	MJ/t	**9,7**
Pumps	kW	11	Electricity		
Annual usage time	h	8 760	**Total energy**	**MJ/t**	**100,0**

Refinery fuels are used in heating the tank and pipe work. The split between refinery gas and heavy fuel oil is the same as in the refinery. The circulation and loading pump utilises electricity from the grid.

Table 13. Energy source at refinery for bitumen storage

Energy source	Split %	Energy MJ/t	Fuel kg/t bitumen	Energy kWh/t bitumen
Refinery gas	79,3	71,6	1,45	
Heavy fuel oil	20,7	18,7	0,47	
Electricity	-	9,7		2,69

The consumptions and emissions due to the production of electricity and to the production and combustion of heavy fuel oil and refinery gas are calculated in the same way as in the refining step.

6. SUMMARY DATA (CUMULATIVE LCI RESULTS)

- As summary of the life-cycle inventory for the production of 1 tonne of bitumen is presented in Table 14. The table presents the most relevant flows and an aggregation of other flows. A complete inventory in a SimaPro csv format is available on the Eurobitume website: www.eurobitume.eu
- In this LCI it is important to note that that crude oil is used in different ways;
  - As an energy source that is consumed when extracting, transporting and refining of crude oil;
  - As a raw material to produce bitumen, which is the heaviest fraction of crude oil. This part of the crude oil is not an energy use. However, in the context of EN 158043 this use would comprise a "non-renewable energy source used as material".

The table below presents the life cycle inventory for the process.

Table 14. Summary Life-Cycle Inventory for the production of 1 tonne of bitumen – without infrastructure

Production of 1 tonne of bitumen (process without infrastructure)	Unit	Crude oil extraction	Transport	Refinery	Storage	Total
Raw material						
Crude oil	kg	1 000				1 000
Consumption of energy resources						
Natural gas	kg	24	0,3	0,037	0,079	25
Crude oil	kg	3,6	8,7	1,2	0,54	14
Consumption of non-energy resources						
Water1)	L	103	29	203	6,7	342
Emissions to air						
CO_2	g	90 139	21 248	18 814	6 595	136 797
SO_2	g	395	351	45	22	813
NO_X	g	250	604	19	8,0	881
CO	g	12	39	5,1	2,0	58
CH_4	g	376	11	2,9	2,6	392
NMVOC	g	327	30	2,4	0,91	361
Particulates	g	16	57	3,8	3,0	80
Emissions to water						
Chemical Oxygen Demand	g	18 987	2 220	39	5,5	21 251
Biological Oxygen Demand	g	18 969	2 219	16	5,3	21 209
Suspended solids	g	47	0,7	6,38	0,23	54
Hydrocarbon (crude oil)	g	10,7	75 265	4,2	1,7	75 281
Emissions to soil						
Hydrocarbon (crude oil)	g	8,4	35	3,9	1,8	49

1) Excluding water cooling and turbine use

2) Excluding raw material

HFO & diesel consumption assumed to be equivalent to crude oil

The Table below presents the Life-Cycle Inventory for process and infrastructure. It includes the flows associated with the building of the infrastructure required to produce, transport and refine crude oil.

Table 15. Summary Life-Cycle Inventory for the production of 1 tonne of bitumen – with infrastructure

Production of 1 tonne of bitumen (process with infrastructure)	Unit	Crude oil extraction	Transport	Refinery	Storage	Total
Raw material						
Crude oil	kg	1 000				1 000
Consumption of energy resources						
Natural gas	kg	26	1,0	0,054	0,082	27
Crude oil	kg	11,2	9,5	1,2	0,54	22
Consumption of non-energy resources						
Water1)	L	811	90	206	7,2	1 115
Emissions to air						
CO_2	g	130 157	33 258	19 278	6 650	189 343
SO_2	g	486	384	48	22	940
NO_X	g	549	646	20	8,3	1 224
CO	g	385	96	11,0	2,3	494
CH_4	g	486	42	4,3	2,7	535
NMVOC	g	411	39	3,0	0,98	455
Particulates	g	159	102	6,3	3,2	271
Emissions to water						
Chemical Oxygen Demand	g	19 257	2 241	40	5,7	21 544
Biological Oxygen Demand	g	19 098	2 232	16	5,4	21 352
Suspended solids	g	260	34,2	7,22	0,55	302
Hydrocarbon (crude oil)	g	33,5	75 268	4,3	1,7	75 307
Emissions to soil						
Hydrocarbon (crude oil)	g	31,7	38	4,0	1,8	75

1) Excluding water cooling and turbine use

7. LIFE CYCLE IMPACT ASSESSMENT

A general functional unit cannot be given to application-unspecific materials such as bitumen, hence the following "declared unit" was assessed: **1 tonne (1 000 kg) of paving grade bitumen.**

The same system boundary as presented in section 4.4 was considered. The set of environmental impact categories considered are the impact categories considered relevant for the LCI, the following table summarizes the environmental indicators considered for this LCIA:

Table 16 - Environmental impact categories and indicators assessed and analysed

Impact category	Impact indicator	Characterisation method - model	Unit
Climate change	Global warming potential	IPCC 2013 (AR5), Baseline model of 100 yrs (IPCC, 2013) IPCC 2007 (AR5), Baseline model of 100 yrs (IPCC, 2007)	kg CO_2 eq.
Ozone Depletion	Ozone Depletion Potential (ODP)	Steady-state ODPs as in (WMO 1999)	kg CFC-11 eq
Acidification	Accumulated Exceedance (AE)	Seppala 2006	mol H+ eq.
Resource use, energy carriers	Abiotic resource depletion – fossil fuels (ADP-fossil)	CML v4.8 (2016) based on van Oers et al. (2002)	MJ
Photochemical Ozone Formation	Photochemical ozone creation potential (POCP)	LOTOS-EUROS (Van Zelm et al, 2008) as applied in the EF Method adapted by Pré	kg NMVOC eq.

The following table and figure provide the results for the declared unit (DU) per life cycle steps:

Table 17 - Potential environmental impact for the production of 1 tonne of paving grade bitumen – without infrastructure

Impact category	Unit	Crude oil production	Transportation	Refining step	Storage	Total
Climate change - IPCC 2013	kg CO_2 eq	102,1	21,8	18,9	6,7	149,6
Climate change - IPCC 2007	kg CO_2 eq	100,4	21,8	18,9	6,7	147,8
Ozone depletion	kg CFC-11 eq	2,94E-06	6,43E-06	8,54E-07	4,67E-07	1,07E-05
Acidification	mol H^+ eq	0,72	0,92	0,07	0,04	1,75
Resource use, energy carriers	MJ	44521	396	52	46	45015
Photochemical ozone formation	kg NMVOC eq	0,62	0,67	0,03	0,01	1,32

Table 18 - Potential environmental impact for the production of 1 tonne of paving grade bitumen – with infrastructure

Impact category	Unit	Crude oil production	Transportation	Refining step	Storage	Total
Climate change - IPCC 2013	kg CO_2 eq	146,3	35,0	19,4	6,8	207,5
Climate change - IPCC 2007	kg CO_2 eq	143,9	34,8	19,4	6,8	204,9
Ozone depletion	kg CFC-11 eq	8,78E-06	7,36E-06	8,87E-07	4,72E-07	1,75E-05
Acidification	mol H^+ eq	1,1	1,0	0,1	0,04	2,18
Resource use, energy carriers	MJ	45 094,1	572,5	58,5	47,2	45 772
Photochemical ozone formation	kg NMVOC eq	1,0	0,7	0,03	0,01	1,79

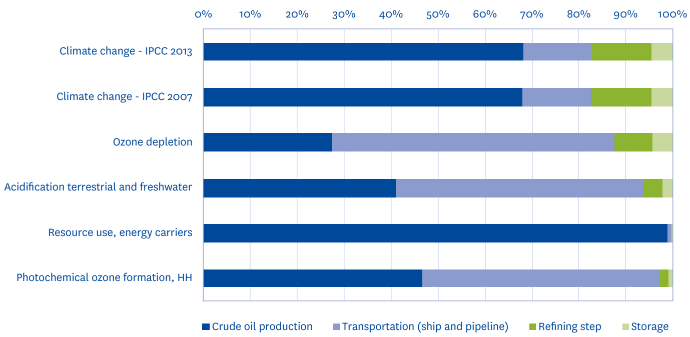


Figure 8 Breakdown of potential environmental impacts on the main life cycle steps - Results for 1 declared unit, without infrastructure

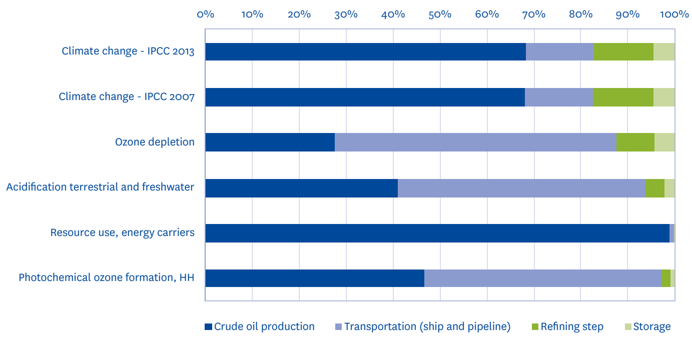


Figure 9 Breakdown of potential environmental impacts on the main life cycle steps - Results for 1 declared unit, with infrastructure

The following observations can be made for the results without infrastructure:

- The crude oil production is the main contributor to the potential impacts, for the impact categories considered. It represents 27% of the impact for the ozone depletion indicator, and more than 41% of the other impact categories with up to 99% of the potential impacts for the category resource use, energy carriers.
- The transportation step also has a significant contribution, especially for the terrestrial and freshwater acidification category. This is mainly related to the consumption of heavy fuel oil for the sea transportation by ship.
- The refining and storage steps have a lower contribution: around 13% for climate change and less than 8% for the other categories for the refining step, and less the 5% of all impact categories for the storage step.

Infrastructure has a big impact on the results, leading to an increase of 39% of the category climate change and 64% on the category photochemical ozone formation. This is driven by the production of onshore well and diesel consumption at wells.

In the study done by Jungbluth et al[26] on the inventories of oil refinery processes, a value of 720 kg CO_2e/t bitumen was calculated, compared to 208 kg CO_2e/t bitumen in this study. This is mostly due to the difference in the amount of GHG emissions considered at the crude oil extraction stage. Indeed, this study uses lower GHG emissions data compared to the data used in the ESU-services study.

Regarding the contributions, a strong contribution from the crude oil extraction stage was also found in the ESU-services study. This is mainly due to venting emissions not related to technical issues, which is not considered for the study at hand.

However, in the Jungbluth study[26], the second most important factor is the fuel combustion at the refinery step. This is not the case in this LCIA, with the refinery step being the third contributor to the impacts. This is partly because the amount of energy consumed per t of bitumen at the refinery is much lower (315 MJ/t bitumen) compared to the Jungbluth study (1 950 MJ/t bitumen). This difference stems from the methodological choice used to allocate the refinery inputs and outputs to the various refinery products. The 2010 Eurobitume LCI applied an economic allocation that also led to a higher value of 510 MJ/t bitumen for the refinery step.

8. UNCERTAINTIES

The uncertainties of the LCI were calculated via Monte Carlo simulations, based on the uncertainty assessment done via the Pedigree Matrix. The scores for the Pedigree Matrix are shown in Appendix 3. Lognormal distribution has been used for all values.

However, this approach is only applied to the foreground data, and it does not consider the uncertainty linked to missing or wrong information and improper background dataset. The following table gives the uncertainty parameters for the five impact categories studied in this report for the results with and without infrastructure with a confidence interval of 95%:

Table 19 - Uncertainty results for a confidence interval of 95%- without infrastructure

Impact category	Unit	Mean	Median	Standard deviation	Coefficient of variation	2,50%	97,50%	Standard Error of the Mean
Climate change - IPCC 2013	kg CO_2 eq	149,43	149,11	5,98	4,00	138,73	162,09	0,19
Climate change - IPCC 2007	kg CO_2 eq	147,65	147,26	5,88	3,98	137,11	159,89	0,19
Ozone depletion	kg CFC-11 eq	1,08E-05	9,85E-06	4,54E-06	4,21E+01	5,45E-06	2,14E-05	1,43E-07
Acidification terrestrial and freshwater	mol H^+ eq	1,75	1,74	0,30	17,04	1,22	2,35	0,01
Resource use, energy carriers	MJ	44 968	44 628	4 013	9	38 259	53 071	127
Photochemical ozone formation	kg NMVOC eq	1,32	1,31	0,13	9,47	1,10	1,59	3,96E-03

Table 20 -Uncertainty results for a confidence interval of 95% - with infrastructure

Impact category	Unit	Mean	Median	Standard deviation	Coefficient of variation	2,50%	97,50%	Standard Error of the Mean
Climate change - IPCC 2013	kg CO_2 eq	206,41	202,66	23,52	11,40	179,00	255,38	0,74
Climate change - IPCC 2007	kg CO_2 eq	203,83	200,01	23,44	11,50	176,86	252,01	0,74
Ozone depletion	kg CFC-11 eq	1,71E-05	1,56E-05	7,52E-06	4,40E+01	8,49E-06	3,79E-05	2,38E-07
Acidification terrestrial and freshwater	mol H^+ eq	2,16	2,11	0,47	21,85	1,57	3,03	0,01
Resource use, energy carriers	MJ	45 694	45 284	4 230	9	38 499	54 831	134
Photochemical ozone formation	kg NMVOC eq	1,77	1,69	0,49	27,80	1,37	2,64	0,02

9. USE OF THE LIFE-CYCLE INVENTORY DATA

The life cycle inventory is a phase of the life cycle assessment involving the compilation of inputs and outputs for a product throughout its life cycle. An environmental impact assessment is conducted on the basis of the inventory flows. Different methods can be used to deal with impact assessment (e.g. CML, Impact 2002+, ReCiPe). These methodologies mainly deal with impacts on “Human health”, “Ecosystem quality”, “Climate change” and “Resource depletion” and they differ in the definition, calculation and aggregation of impacts.

Bitumen is almost never used on its own, but is generally a raw material used in the manufacture of construction products. In the context of EN 15804 this LCI is intended to provide data for Type III environmental product declarations (EPD) for stage A1 (raw material supply) of the product life-cycle.

The data provided in this LCI are based around average data from sources that Eurobitume believes are the most reliable information available and are representative for bitumen production at the gate of any refinery in Europe.

Considering the reliability and completeness of the data sources used to establish the LCI Eurobitume estimates that there is high accuracy for the most relevant flows in the bitumen production chain: crude oil consumption, natural gas consumption, emission to air of carbon dioxide (CO_2), sulphur dioxide (SO_2), nitrogen oxides (NO_X), methane (CH_4) and Non Methane Volatile Organic Compounds (NMVOC). For that reason, Eurobitume believes that this LCI is suitable for analysing environmental impact indicators such as;

- Abiotic depletion, non-renewable, fossil energy
- Global Warming Potential
- Ozone depletion
- Acidification
- Photochemical oxidation

The LCI is less suitable for the analysis of toxicity and ecotoxicity indicators.

9.1 Additional processing of bitumen

Bituminous binder can also be processed to adjust some properties before its use in final construction products. This includes, as example, blends of different bitumen grade at a depot, polymer modification, manufacture of bitumen emulsion, bitumen blending with additives or extenders. In this context the LCI of the new blend will be determined considering;

- Raw materials, A1, with bitumen and the present LCI can be used, the additional raw materials either polymer, additive, water, etc.
- Transport, A2, of the raw materials from the gate of the refinery to the plant or the depot where the final binder will be processed
- Process, A3, including storage of the bitumen and other materials, the specific process if any to make the end binder

In this context the environmental impacts of each stage A1 to A3 should be taken into account. This includes any positive or negative (credit) impacts such as the biogenic carbon.

- The final results can be further used as inputs for raw materials in the final product.

9.2 Example of calculation

This LCI can be used as input for further LCA or EPD calculations[27]. Eurobitume considers this LCI to be suitable for use as the most reliable and representative data to reflect bitumen production in Europe. As a reference example, the Green House Gas contribution (GHG) as reported in section 7 will be 150 kg CO_2e per tonne of bitumen at the refinery gate not including the infrastructure. Compared to the previous 2012 LCI, the value was 189 kg CO_2e without infrastructure. The main differences are the result of the new basket of crude oil, revised data for crude oil extraction, revised transportation data and a new allocation methodology used at the refinery. Compared to other, commercially available databases, the main differences arise from the extraction of crude oil, transportation and allocation methodology in the oil refinery and exclusion of infrastructure.

For a typical asphalt mixture, assuming a binder content of 5%, bitumen will contribute, as raw material (excluding secondary transportation);

- 150·5% = 7,50 kg CO_2e per tonne of asphalt mixture.

9.3 Reliability of data

For certain applications, such as green public procurement, environmental data have, from time to time, been requested on a project basis. Eurobitume considers that average data for bitumen production are the most suitable for such applications for the following reasons;

- Crude oil extraction and transportation comprise the majority of the energy use. As demonstrated in section 5.2, the energy and emissions for extraction of crude oil vary significantly on a year-to-year basis. Furthermore, within a complex refinery it is unlikely that detailed information on crude origin would be available. Data are not available at the level of individual oil fields, but only on a regional basis.
- The fuel consumption of a crude oil carrier (ship) is highly dependent on the speed of the vessel, e.g. a 10% increase in speed can lead to a 50% increase in fuel consumption. For individual cargoes it is not possible to know the actual speed of the vessel and therefore the actual fuel consumption. For this reason, average values are the only practical means for allocation of emissions associated with crude oil transport.

For the above reasons Eurobitume believes that it is not possible to obtain reliable data on either a specific crude oil cargo, or refinery basis. Therefore, it is recommended that the data provided in this report should be used as a general figure for bitumen in Europe in an environmental declaration.

9.4 Feedstock energy

Bitumen is derived from crude oil, therefore it has feedstock energy. However, since it is unlikely the feedstock energy will be released, as asphalt mixtures are not used as a source of fuel, feedstock energy should be reported separately according to EN 15804, Table 4 “*Use of non-renewable primary energy resources used as raw materials*”.

Most refinery products, apart from bitumen, are combusted as fuels, or otherwise disposed of after use. However, bitumen used in asphalt mixtures has a service life that is typically measured in decades and is widely re-used in new asphalt mixtures at the end of life, therefore the product is not consumed and this should be reflected at the end of life of the construction product when the bitumen is re-used in new asphalt. When bitumen is used in construction products it does not emit greenhouse gas and its energy content is not lost. The benefits from re-use should be highlighted in section D of an Environmental Product Declaration.

10. SUMMARY REMARKS

Considering the reliability and the completeness of data used to establish the LCI, Eurobitume estimates that there is high accuracy for the most relevant flows in the bitumen production chain: crude oil consumption, natural gas consumption, emission to air of carbon dioxide (CO_2), sulphur dioxide (SO_2), nitrogen oxides (NO_X), methane (CH_4) and non-methane volatile organic compounds (NMVOC). For that reason, this LCI is suitable for analysing environmental impact indicators such as: abiotic depletion non-renewable fossil energy, global warming potential, ozone depletion, acidification, photochemical oxidation. This LCI is not suitable for analysing toxicity and eco-toxicity indicators.

APPENDICES

APPENDIX 1 – INFRASTRUCTURE DATA

The Ecoinvent database gives some information on infrastructures needed for crude oil extraction, transport and refining. Some of these values have been revised, based on the report: Life cycle inventories of crude oil extraction, Christoph Meili; Niels Jungbluth; Jasmin Annaheim (2018) ESU-services Ltd.

11.1.1.1 Geographical distribution

It is considered here that the extraction of crude oil for the production of bitumen takes place in 4 different locations:

- Norway: 10%
- Russia: 30%
- The Middle-East: 45%
- South-America: 15%

Since there was no available inventory for South-America, the production of oil in the Middle-East was used as a proxy for this location.

11.1.1.2 Crude oil extraction infrastructure

In Ecoinvent, the inventory of well for crude oil extraction is given for 1 m of well. The inventory of plant or platform is given for 1 plant or platform.

a. Norway

Offshore crude oil extraction:

- Amount of well per kg of crude oil:
  $2{,}60 \cdot 10^{-6}$ *m per kg*
- Amount of "offshore platform" used per kg of crude oil:
  $5{,}11 \cdot 10^{-11}$ *plant per kg*

b. Russia

Onshore crude oil extraction:

- Amount of well per kg of crude oil:
  $2{,}55 \cdot 10^{-5}$ *m per kg* – revised value
- Amount of "onshore platform" used per kg of crude oil:
  $5{,}13 \cdot 10^{-9}$ *plant per kg*
- Amount of pipeline used per kg of crude oil:
  $4{,}55 \cdot 10^{-8}$ *km per kg*

c. Middle-East

Onshore crude oil extraction:

- Amount of well per kg of crude oil:
  $7{,}60 \cdot 10^{-7}$ *m per kg* – revised value
- Amount of "onshore platform" used per kg of crude oil:
  $1{,}38 \cdot 10^{-10}$ *plant per kg*
- Amount of pipeline used per kg of crude oil:
  $7{,}70 \cdot 10^{-9}$ *km per kg*

d. South America

Onshore crude oil extraction:

- Amount of well per kg of crude oil:
  $3{,}71 \cdot 10^{-5}$ m per kg – revised value
- Amount of "onshore platform" used per kg of crude oil:
  $1{,}38 \cdot 10^{-10}$ plant per kg
- Amount of pipeline used per kg of crude oil:
  $7{,}70 \cdot 10^{-9}$ km per kg

11.1.1.3 Transport infrastructure

In Ecoinvent, pipeline inventory is given for 1 m of pipeline. This inventory does not take the production location into account. In the process "Transport, pipeline, onshore, petroleum {RoW}", the distance of pipeline that is used to transport one tkm of crude oil is:

$9{,}46 \cdot 10^{-9}$ *km pipeline per tkm*

The distance to transport the oil through pipelines is 1800 km. Then, the length of pipeline needed per kg of crude oil is:

$9{,}46 \cdot 10^{-9} \cdot 1\,000 \cdot 1800/1\,000 = \mathbf{1{,}70 \cdot 10^{-5}}$ *m pipeline per kg*

The same calculation must be performed for the tanker. The Ecoinvent process "Transport, freight, sea, transoceanic ship {GLO}" mentions the use of a tanker, with the following figure:

$1{,}54 \cdot 10^{-11}$ *tanker per tkm*

The oil is transported over a distance of 7456 km. The amount of tanker used per kg of crude oil is:

$1{,}54 \cdot 10^{-11} \cdot 1\,000 \cdot 7456/1\,000 = \mathbf{1{,}15 \cdot 10^{-7}}$ *tanker per kg*

11.1.1.4 Refinery infrastructure

In Ecoinvent, the inventory of refinery is used, and the amount of refinery is based on the inventory "Pitch {CH}| petroleum refinery operation | Cut-off, U".

- Amount of refinery per kg of bitumen:
  $3{,}3299 \cdot 10^{-11}$ *refinery per kg*

APPENDIX 2 – COMPARISON FOR SHIP TRANSPORTATION WITH ECOINVENT DATA

The table below summarizes the amount of fuel oil and direct emissions caused by the combustion of heavy fuel oil in the ecoinvent dataset and in Eurobitume LCI.

		Ecoinvent v3.5 dataset	Eurobitume values
Amount of fuel oil - kg/tkm		0,0013	0,0010
Emissions index (g/kg fuel)	CO_2	3 080	2 370
	SO_2	70	52,8 to 2,64
	NO_X	80,4	78,5
	NMVOC	2,7	3,1
	CO	7,4	2,8
	PM	7,3	5,4

In Ecoinvent, the amount of fuel consumed is based on data from 1993, whereas Eurobitume's data for fuel consumption is based on Wärtsilä Aframax data sheet and emissions profile is from the Third IMO Greenhouse Gas Study 2014. This data is more recent and more representative of the type of fuel and type of ship used to transport crude oil.

APPENDIX 3 –
UNCERTAINTY ASSESSMENT OF FOREGROUND DATA

The uncertainty of foreground data was assessed using the Pedigree matrix that is composed of five data quality indicators (reliability, completeness, temporal correlation, geographical correlation, further technological correlation). Each indicator is scored from 1 to 5, with 1 describing a data of high quality and 5 of low quality. The five indicators are assessed, with the following criteria:

Indicator score	1	2	3	4	5
Reliability	Verified data based on measurements	Verified data partly based on assumptions or non-verified data based on measurements	Non-verified data partly based on qualified estimates	Qualified estimate (e.g. by industrial expert)	Non-qualified estimate
Completeness	Representative data from all sites relevant for the market considered, over an adequate period to even out normal fluctuations	Representative data from >50% of the sites relevant for the market considered, over an adequate period to even out normal fluctuations	Representative data from only some sites (<<50%) relevant for the market considered or >50% of sites but from shorter periods	Representative data from only one site relevant for the market considered or some sites but from shorter periods	Representativeness unknown or data from a small number of sites and from shorter periods
Temporal correlation	Less than 3 years of difference to the time period of the dataset	Less than 6 years of difference to the time period of the dataset	Less than 10 years of difference to the time period of the dataset	Less than 15 years of difference to the time period of the dataset	Age of data unknown or more than 15 years of difference to the time period of the dataset
Geographical correlation	Data from area under study	Average data from larger area in which the area under study is included	Data from area with similar production conditions	Data from area with slightly similar production conditions	Data from unknown or distinctly different area (North America instead of Middle East, OECD-Europe instead of Russia)
Further technological correlation	Data from enterprises, processes and materials under study	Data from processes and materials under study (i.e. identical technology) but from different enterprises	Data from processes and materials under study but from different technology	Data on related processes or materials	Data on related processes on laboratory scale or from different technology

The following table gives the results of the uncertainty assessment:

Crude oil extraction	Reliability	Completeness	Temporal correlation	Geographical correlation	Further technological correlation	Comment
Emissions to air						
Carbon dioxide, fossil	2	2	1	1	2	IOGP average 2013-2017 data, Measured and calculated data verified from a third party. Data for South America are representative for 86%, and other regions for over 90%
Sulfur dioxide	2	2	1	1	2	
Nitrogen oxides	2	2	1	1	2	
Methane, fossil, low.pop	1	2	1	1	2	
NMVOC	2	2	1	1	2	
Emissions to water						
Oils to water	1	2	1	1	2	OGP average 2013-2017 data
Emissions to soil						
Oils, to soil	1	2	1	1	2	OGP average 2013-2017 data, FSU is representative of 78% of the sites, other regions for over 90%
Consumption of energy resources						
Electricity	2	2	1	1	2	OGP average 2013-2017 data
Consumption of natural resources						
Oil, crude, in ground	1	2	1	1	2	OGP average 2013-2017 data for RME
Gas, natural/kg, in ground	1	2	1	1	2	OGP average 2013-2017 data
Water	1	2	1	1	2	OGP average 2013-2017 data
Losses						
Natural Gas, flared	1	2	1	1	2	OGP average 2013-2017 data
Natural gas, vented	2	2	1	1	2	OGP average 2013-2017 data

Pipeline transport	Reliability	Completeness	Temporal correlation	Geographical correlation	Further technological correlation	Comment
Other						
Carbon dioxide, fossil	2	2	1	1	2	For Crude oil from FSU only, calculation for the Drusba pipeline, from Almetyevsk to Primorsk

Sea transport	Reliability	Completeness	Temporal correlation	Geographical correlation	Further technological correlation	Comment
Emissions to air						
Carbon dioxide, fossil	1	2	3	2	2	Third IMO Greenhouse Gas Study 2014, measured emissions
Sulfur dioxide	1	2	3	2	2	
Nitrogen oxides	1	2	3	2	2	
Methane, fossil	1	2	3	2	2	
NMVOC	1	2	3	2	2	
Particulate matter	1	2	3	2	2	
Consumption of energy resources						
Heavy fuel oil	3	4	1	1	2	Based on engine consumption data from Wartsila, calculated
Other						
Transportation distance	4	1	1	1	1	Estimate, based on a distance calculation tool

Refinery	Reliability	Completeness	Temporal correlation	Geographical correlation	Further technological correlation	Comment
Consumption of energy resources						
Heavy fuel oil	3	1	1	1	1	Heat capacity calculation based on assumptions
Refinery gas	3	1	1	1	1	Heat capacity calculation based on assumptions
Consumption of non energy resources						
Water	2	2	2	3	2	Concawe data, report 12/18 (2013)fig 25, for a refinery complexity class 1.5

Storage	Reliability	Completeness	Temporal correlation	Geographical correlation	Further technological correlation	Comment
Consumption of energy resources						
Heavy fuel oil	3	1	3	1	2	Calculation, based on the 2012 bitumen LCI from Eurobitume
Refinery gas	3	1	3	1	2	
Electricity	3	1	3	1	2	

ESU-services
fair consulting in sustainability

2019

Critical Review Statement

Eurobitume Life-Cycle Inventory for bitumen manufacture

Dr. Niels Jungbluth (ESU-services Ltd.)

Niels Jungbluth Dr. sc. Techn. Dipl. Ing. TU
ESU-services GmbH
T +41 44 940 61 32

CEO
Vorstadt 14
F +41 44 940 67 94

www.esu-services.ch
CH-8200 Schaffhausen
jungbluth@esu-services.ch

Eurobitume

Imprint

Title	Eurobitume Life-Cycle Inventory for bitumen manufacture
Authors	Niels Jungbluth ESU-services Ltd., fair consulting in sustainability Vorstadt 14, CH-8200 Schaffhausen Tel. 044 940 61 32 jungbluth@esu-services.ch www.esu-services.ch
Commissioner	Eurobitume Mike Southern Bituconsult Limited Senior Technical Advisor for Eurobitume Boulevard du Souverain 165 B - 1160 Brussels Tel.: +32/(0)2 566 91 40 mike.southern@eurobitume.eu www.eurobitume.eu
Publications	Each reference to this review statement is only allowed if the same publication shows also the full review statement without alterations.
Version	22.11.19 09:29 https://esuservices-my.sharepoint.com/personal/mitarbeiter1_esuservices_onmicrosoft_com/Documents/379 Review LCI Bitumen/2018 Update Critical Review/jungbluth-2019-CR-LCI-bitumen-ReviewStatement-v3.0.docx

Contents

1 Background and Objectives

Eurobitume has elaborated a life cycle inventory (LCI) study for bitumen produced in Europe. In 2011 up-to-date inventory data were collected for crude oil production (4 main producing countries), transportation to Europe, and actual crude oil throughput for bitumen production and refining in Europe. Only bitumen is considered as a final product of the refinery. Further processing to bitumen products was included in the analysis. This LCI was peer-reviewed by Niels Jungbluth and published in 2011 (Eurobitume 2011).

In 2019 the organization has elaborated a revised report (Tromson & Menten 2019). The revised report is now subject to independent review. The aim is to update and publish life cycle inventory data that can be used by the public and in LCI databases such as ecoinvent. All calculations are made in SimaPro.

The LCA was carried out according to the standards ISO 14040-44. In this context, the customer asked for an external critical review according to the standard ISO 14040 of this study. This critical review must address the points defined in the ISO standard (objectives and scope, inventory analysis, impact assessment and interpretation). For this LCA, one LCA expert should conduct the review (for compliance to ISO14044).

2 Description of the work to be reviewed

The commissioner asked Dr. Niels Jungbluth for a critical peer review. Key characteristics for this review are summarized in the following Tab. 2.1.

The International Organization for Standardization (ISO) (2006a:6.3) states the following concerning the procedure for the review of a comparative study planned to be published:

"A critical review may be carried out as a review by interested parties. In such a case, an external independent expert should be selected by the original study commissioner to act as chairperson of a review panel of at least three members. Based on the goal and scope of the study, the chairperson should select other independent qualified reviewers. This panel may include other interested parties affected by the conclusions drawn from the LCA, such as government agencies, non-governmental groups, competitors and affected industries."

Tab. 2.1 Key characteristics of the work to be reviewed

Title	Eurobitume Life-Cycle Inventory for bitumen manufacture
Commissioner	Eurobitume
Main author	Mike Southern, Eurobitume (1st draft) Clara Tromson, Fabio Menten, Deloitte Conseil (2nd draft and after)
Products and variants investigated	Life cycle inventory analysis for bitumen produced in Europe
Scope	Cradle to gate
Reference flow	Data per mass (tonne) of bitumen at refinery gata as reference flow
Standard to be applied	International Organization for Standardization (ISO) 2006a, b
Product category rules	A draft PCR[1] was available, but not followed for this project.
Comparative study	No
Publication foreseen	Yes
Size of documentation provided for re-view	43 pages report, including a summary
Software for background calculations	SimaPro 9.0
Background database	ecoinvent Centre 2018, Cut-Off
Foreground data	Crude oil extraction, crude transportation, oil refinery, bitumen storage mainly based on literature data and assumptions by the authors. No primary data.
Provision of LCI data for review	Documented in report and SimaPro
Life cycle impact assessment	5 category indicators (EPD 2017) often used for EPD
Stages of the review	One stage for review of the full LCA
Meetings in person	One Meeting in Brussels
Reviewer	Dr. Niels Jungbluth, ESU-services Ltd.

3 Standards and review criteria

The critical review was carried out according to the International Standards ISO 14040 and 14044 (International Organization for Standardization (ISO) 2006a, b).

The LCA was reviewed according to the following five aspects outlined in ISO 14040. It is assessed whether

- *"the methods used to carry out the LCA are consistent with this International Standard,*
- *the methods used to carry out the LCA are scientifically and technically valid,*
- *the data used are appropriate and reasonable in relation to the goal of the study,*
- *the interpretations reflect the limitations identified and the goal of the study, and*
- *the study report is transparent and consistent."*

4 Tasks of the reviewer

The tasks of the reviewer is to review the provided documentation according to Tab. 2.1 including the four LCA phases, namely

1 https://www.environdec.com/PCR/Detail/?Pcr=7065

- Goal and scope definition,
- Inventory analysis
- Impact assessment, and
- Interpretation

The goal of the study as such is not reviewed as this lies in the responsibility of the commissioner. However, it is reviewed whether the goal is stated explicitly and transparently. The definition of the scope, the definition of the functional unit, the system definition and its boundaries, the allocation approaches and the impact category indicators recommended is part of the critical review.

The authors of the study were asked to provide access to all data necessary for an informed critical review. This holds also true for data provided by third parties and for confidential data. The review of the inventory analysis includes the inventory raw data (input data), the modelling approaches and selected inventory results. The modelling of the LCI is also reviewed. Therefore, the LCA project exported from SimaPro including the data and calculation setups is made available to the reviewer.

Within the interpretation phase, the consistency of the modelling, the data used, and the conclusions is reviewed and checked whether it is in line with the goal and scope definition. Data quality aspects, significance and sensitivity analyses as well as completeness checks are subject to the critical review too.

The following interactions between the commissioner, the practitioner and the reviewer took place:

- Provision of draft LCA report dated 14.12.2018, 27 pages in Word-format, including a full description of the study and an Excel table with details of the calculation.
- Submission of first round of review comments (19.12.2018)
- Exchange of emails and telephone calls
- Personal meeting in Brussels for discussing comments with the main author (5.9.2019)
- Provision of revised draft LCA report dated 2.10.2019, 40 pages in Word-format
- Submission of second round of review comments (14.10.2019)
- Personal communication between reviewer and authors.
- Provision of the third draft LCA report dated 4.11.2019, 41 pages in Word-format
- Submission of third round of review comments (12.11.2019)
- Some further explanations by the authors via Email (13.11.2019)
- Provision of the final report dated 21.11.2019 including a summary, 43 pages
- Final draft review statement dated 22.11.2019

- Most questions of the reviewer were answered sufficiently. Upon reviewer's request revisions were made concerning documentation in the report and description of results. The critical review process took place in an open and constructive atmosphere.
- The present final version of the review statement considers the revisions made by the practitioner after submitting the feedback on the pre-final report.
- The goal of the study as such was not reviewed as this lies in the responsibility of the commissioner. However, it was reviewed whether the goal is stated explicitly and transparently.

The definition of the scope was part of the critical review, the definition of the functional unit, the system definition and its boundaries and the allocation approaches.

- The review of the inventory analysis includes the inventory raw data in electronic format (input data), the modelling approaches and selected inventory results.
- The review of the impact assessment includes the impact indicator results and, eventually, the normalized results.
- Within the interpretation phase, the consistency of the modelling, the data used, and the conclusions are reviewed and checked whether they are in line with the goal and scope definition. Data quality aspects, significance, and sensitivity analyses as well as completeness checks are subject to the critical review too.
- It was not in the responsibility of the reviewer to check the report for formatting, layout, grammar, and spelling issues.
- This review report is only valid for the full LCA report as it was provided for final review.
- No additional abstracts or summaries of this report have been reviewed in its last version.

5 Critical review report

In a first feedback on the presented work a detailed list of findings and recommendations was provided. This first feedback was provided to the authors only. It was used to improve the work and is not intended for publication.

The critical review report is based on the revised documentation and the answers provided by the authors given to the detailed review comments. It contains a summary of the findings of the critical review and shall be published together with the documentation on the LCA.

5.1 Consistency of the methods with the ISO standards

The declared unit and reference flow are considered appropriate for the goal and scope of this study.

5.2 Scientific and technical validity of the methods applied

In general, the inventory models established are scientifically and technically valid.

Some emissions reported in the LCI (hydrocarbons, unspecified) are not characterised in the used LCIA method. Thus, impacts are underestimated.

5.3 Appropriateness of data

All foreground data, including the whole modelling and calculations, were presented for the first draft version to the reviewer in Excel format. For the second draft the modelling has been made in SimaPro. This facilitated the review considerably and is highly acknowledged.

The emissions due to unintended gas releases on oil fields (venting) are rather uncertain. The estimation taken by the authors is at the lowest range of values found in literature.

The data and changes to underlying ecoinvent datasets are not always documented in the electronic format nor in the report. Thus, data should only be checked based on ultimate results, but not based on the underlying assumptions. Sometimes negative emissions are reported in the data to balance for reported emissions, which is difficult to follow up.

Some known inputs e.g. infrastructure or emissions of methane from oil and gas fields were cut-off. This is not appropriate for an LCA.

Besides the issues mentioned above, most of the data used in the foreground and in the background are appropriate and reasonable in view of the goal and scope of the study. Nevertheless, it is not possible to fully ensure the correctness and validity of all calculations within such a review process.

5.4 Assessment of the interpretation in view of limitations and goal and scope

There are some limitations regarding interpretation which are summarized under conclusions.

5.5 Transparency and consistency of study report

All relevant information could be found in the report. The report is clearly structured and well-readable. The report is acknowledged as transparent and consistent.

5.6 Self-declaration of reviewer independence & competencies

(According to ISO/PDTS 14071, Annex B)

I (Niels Jungbluth), hereby declare that:

- I am not a full- or part-time employee of the study's commissioner or practitioner.
- I have not been involved in scoping or carrying out any of the work to conduct the LCA study at hand, i.e. I have not been part of the commissioner's or practitioner's project team(s).
- I do not have vested financial, political, or other interests in the outcome of the study.

My competencies relevant to the Critical Review at hand include knowledge of and proficiency in:

- ISO 14040 and ISO 14044.
- LCA methodology and practice, particularly in the context of LCI, (including data set generation and data set review, if applicable).
- Critical Review practice.
- The scientific disciplines relevant to the important impact categories of the study.
- Environmental, technical, and other relevant performance aspects of the product system(s) assessed.
- Language used for the study.

A short CV and a list of relevant references are part of the review report.

I assure that the above statements are truthful and complete.

5.7 Conclusions

The reviewed LCI study as outlined in Tab. 2.1 complies with the requirements of the ISO standards 14040 and 14044. The goal and scope are appropriately defined.

Huge differences can be observed if comparing the results of this study with available commercial databases. The results of this study are presented in Fig. 5.1 in green and are compared with results from other databases.

The ESU database 2019 (ESU 2019; Jungbluth et al. 2020; Meili & Jungbluth 2019a, b) includes all available updates for the oil and gas chain. Furthermore, the allocation factors in the refinery for bitumen have been reconsidered based on the study under review. UVEK (2018 plus oil updates (Jungbluth et al. 2018a; Meili et al. 2018; Meili & Jungbluth 2018; UVEK 2018) includes the updates reviewed and published in 2018 (ecoinvent Centre 2018; Jungbluth et al. 2018a; Meili et al. 2018; Meili & Jungbluth 2018). The other three databases to not yet include any updates specific for the oil chain (ecoinvent Centre 2018; KBOB v2.2: 2016; UVEK 2018), but are the ones publicly available on www.ecoinvent.org.

Some reasons for the huge differences have been identified in the review process and are summarized below:

- Ozone layer depletion: ecoinvent v3.5 is fully outdated. The present study shows lower emissions than the other updates because of a lower share (10%) of offshore crude oil production in the supply chain modelled for bitumen.
- Abiotic depletion, fossil fuels: Differences are not to relevant. They are mainly influenced by slightly different allocation of crude oil input and energy uses in the refinery.
- Photochemical oxidation, global warming, and acidification: The present study shows much lower results. This seems to be mainly due to estimations for venting during crude oil extraction.

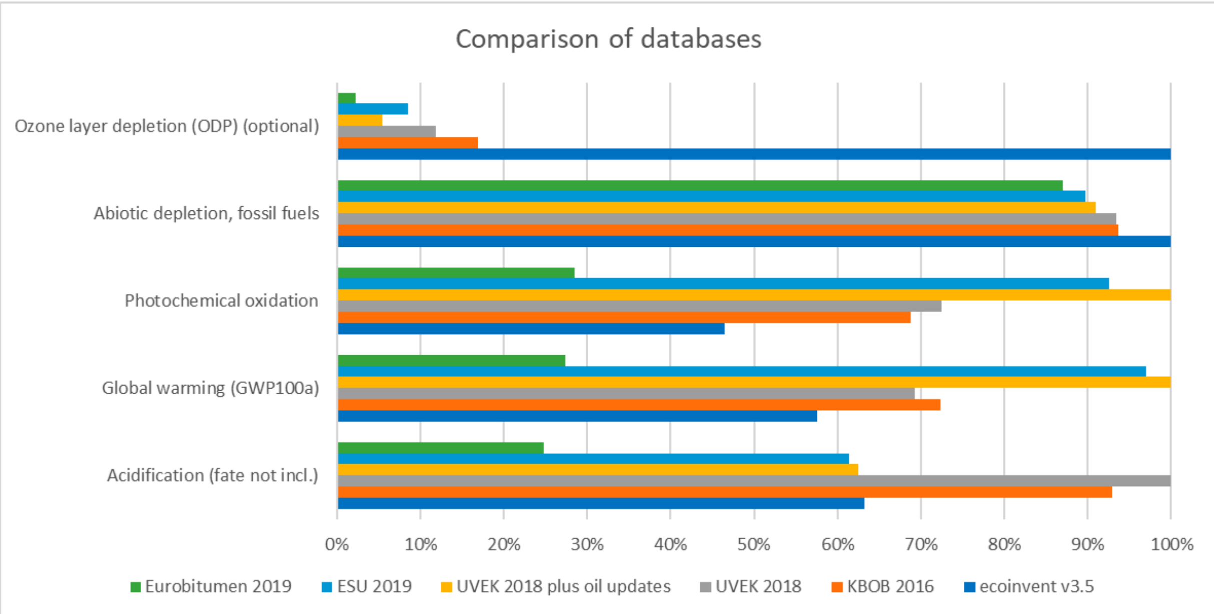


Fig. 5.1 Comparison of LCIA results from different database version with the reviewed study

The main benefits of this report (also compared to commercial databases) are:

- It makes sense to investigate the impacts of refining in more detail. The bottom-up approach applied in this study is a good starting point. It seems reasonable that allocation factors used in literature (Jungbluth et al. 2018a) overestimate the importance of the refinery stage for the bitumen production and thus these findings will be applied in a foreseen update (Jungbluth et al. 2020). The final energy use found in this study is 10 times lower than the average energy use in refineries and thus some issues like overhead operations might have been underestimated.

- The update of some data for crude oil transports seems to be reasonable.
- Considering the specific crude oil mix for refineries producing bitumen makes sense in this specific case, but it might be hard to be applied in generic databases.

The main shortcomings of this study (also compared to commercial databases and updates for ecoinvent data publicly available) are:

- In a study elaborated by an industry association it would be expected to use first-hand foreground data for the refining process e.g. based on averaged information from member companies. Only literature data have been used for this stage. In the present form it might thus not be acceptable as a basis for an EPD (environmental product declaration).
- Updates made for the crude oil extraction, transportation and refining are only considered in the foreground for bitumen, but not in background processes used as inputs (e.g. diesel for transportation or fuel oil for refinery operation). Thus, assumptions in background and foreground data are not fully harmonized.
- The issue of unintended releases of methane due to crude oil extraction (venting) is not discussed in enough detail. The most recent independent inventory assumes a much higher release and a huge importance of these emissions (Meili & Jungbluth 2018). The reviewer considers this as an underestimation of global warming impacts by a factor of about 2. This issue influences also results for photochemical oxidation and acidification.
- The latest studies of ESU-services for updating the data are considered only partly. Many estimates in the foreground data are based on ecoinvent v3.5 which dates to (Jungbluth 2007). It was recommended in the review process to use the much more recent data available (Jungbluth et al. 2018b) as a backbone and modify these were assumed to be necessary.
- Other actual inventories of refineries prefer an energy allocation of crude oil input to the refinery instead of mass allocation from an overall perspective. Even if in the case of bitumen mass might make more sense, in an overall view it might be difficult to reach full consistency on this issue when trying to consider all refinery products. But the difference is small and thus not a major issue.
- There is a tendency to cut-off certain other impacts e.g. by presenting results without infrastructure as key results.
- Some smaller issues have been identified e.g. regarding matching between LCI and LCIA methods applied, cut-off criteria (e.g. omission of infrastructure in certain stages), etc. which further limit the reliability of the results.
- Not much effort has been taken to cross-compare different data sources and to explain relevant differences. Clear focus has been given to industry data instead of using independent or peer-reviewed data sources.
- Finally, the authors make an example calculation stating a carbon footprint of 150 kg CO2eq per tonne of bitumen. As this figure is calculated without infrastructure[2] and due to the other reasons mentioned above this might underestimate the real emissions by a factor of 3 to 5 if compared with the other databases. Taking the figure reported with infrastructure (207 kg CO2eq per tonne), the possible underestimation still lies between factors of 2 and 3.5. Thus,

[2] According to the authors, the reason for presenting results with and without infrastructure is because most of the carbon calculators in use across EU for construction products do not require the inclusion of infrastructure.

there is still a need to better harmonize the assumption in generic databases and the product specific LCI presented in the study under review.

To use this study as a background report for an EPD further improvements and harmonization of data sources seem to be necessary.

The report is complete. Conclusions and recommendations are based on the results of the analyses, respecting the limitations described in the report.

I recommend submitting the entire LCI report including this review report to the commissioner.

Dr. sc. tech. ETH, Niels Jungbluth

Chief Executive Officer ESU-services Ltd.

Schaffhausen, Friday, 22 November 2019

6 References

ecoinvent Centre 2018 ecoinvent Centre (2018) ecoinvent data v3.5, Cut-Off model. Swiss Centre for Life Cycle Inventories, Zurich, Switzerland, retrieved from: www.ecoinvent.org.

EPD 2017 EPD (2017) General Programme Instructions for the International EPD®System. Version 3.0, dated 2017-12-11. EPD International, retrieved from: https://www.environdec.com/contentassets/95ee9211a9614f1faa7461ff32cecc91/general-programme-instructions-v3.0.pdf.

ESU 2019 ESU (2019) The ESU database. ESU-services Ltd., Schaffhausen, retrieved from: www.esu-services.ch/data/database/.

Eurobitume 2011 Eurobitume (2011) Life Cycle Inventory: Bitumen. European Bitumen Association, Task Force Life Cycle Inventory: Timo Blomberg – Nynas – Chairman, Jeff Barnes – Total, Bernard Frédérick – Total, Philippe Dewez - Eurobitume, Stéphane Le Clerc – Shell, Marco Pfitzmann – BP, Laurent Porot - Shell,Mike Southern – Eurobitume, Ron Taylor - Petroplus, With the collaboration of: Charlotte Petiot – Bio Intelligence Service, Yannick Leguern – Bio Intelligence Service, Brussels, BE, retrieved from: www.eurobitume.eu/system/files/LifeCycleInventoryBitumen09Mar2011_0.pdf.

International Organization for Standardization (ISO) 2006a International Organization for Standardization (ISO) (2006a) Environmental management - Life cycle assessment - Principles and framework. ISO 14040:2006; Second Edition 2006-06, Geneva.

International Organization for Standardization (ISO) 2006b International Organization for Standardization (ISO) (2006b) Environmental management - Life cycle assessment - Requirements and guidelines. ISO 14044:2006; First edition 2006-07-01, Geneva.

Jungbluth 2007 Jungbluth N. (2007) Erdöl. In: *Sachbilanzen von Energiesystemen: Grundlagen für den ökologischen Vergleich von Energiesystemen und den Einbezug von Energiesystemen in Ökobilanzen für die Schweiz,* Vol. ecoinvent report No. 6-IV, v2.0 (Ed. Dones R.). Paul Scherrer Institut Villigen, Swiss Centre for Life Cycle Inventories, Dübendorf, CH retrieved from: www.ecoinvent.org.

Jungbluth et al. 2018a Jungbluth N., Meili C. and Wenzel P. (2018a) Life cycle inventories of oil refinery processing and products. ESU-services Ltd. commissioned by BFE, BAFU, Erdöl-Vereinigung, Schaffhausen, Switzerland, retrieved from: www.esu-services.ch/data/public-lci-reports/.

Jungbluth et al. 2018b Jungbluth N., Meili C. and Wenzel P. (2018b) Update of LCI data for crude oil and mineral oil products. ESU-services Ltd. commissioned by BFE, BAFU, Erdöl-Vereinigung, Schaffhausen, Switzerland, retrieved from: www.esu-services.ch/data/public-lci-reports/.

Jungbluth et al. 2020 Jungbluth N., Meili C. and Wenzel P. (2020) Life cycle inventories of oil refinery processing and products (forthcoming. ESU-services Ltd. commissioned by BFE, BAFU, Schaffhausen, Switzerland, retrieved from: www.esu-services.ch/data/public-lci-reports/.

KBOB v2.2: 2016 KBOB v2.2: (2016) Datenbestand KBOB v2.2:2016. Bundesamt für Umwelt BAFU, Switzerland, retrieved from: www.ecoinvent.org.

Meili et al. 2018 Meili C., Jungbluth N. and Wenzel P. (2018) Life cycle inventories of long distance transport of crude oil. ESU-services Ltd. commissioned by BFE, BAFU, Erdöl-Vereinigung, Schaffhausen, Switzerland, retrieved from: www.esu-services.ch/data/public-lci-reports/.

Meili & Jungbluth 2018 Meili C. and Jungbluth N. (2018) Life cycle inventories of crude oil extraction. ESU-services Ltd. commissioned by BFE, BAFU, Erdöl-Vereinigung, Schaffhausen, Switzerland, retrieved from: www.esu-services.ch/data/public-lci-reports/.

Meili & Jungbluth 2019a Meili C. and Jungbluth N. (2019a) Life cycle inventories of long-distance transport of crude oil. ESU-services Ltd. commissioned by Plastics Europe, Schaffhausen, Switzerland, retrieved from: www.esu-services.ch/data/public-lci-reports/.

Meili & Jungbluth 2019b Meili C. and Jungbluth N. (2019b) Life cycle inventories of crude oil and natural gas extraction. ESU-services Ltd. commissioned by Plastics Europe, Schaffhausen, Switzerland, retrieved from: www.esu-services.ch/data/public-lci-reports/.

SimaPro 9.0 SimaPro (9.0) SimaPro 9.0 (2019) LCA software package. PRé Consultants, Amersfoort, NL, retrieved from: www.simapro.ch.

Tromson & Menten 2019 Tromson C. and Menten F. (2019) Life-Cycle Inventory for bitumen manufacture. Deloitte commissioned by Eurobitume - European Bitumen Association, Brussels, BE.

UVEK 2018 UVEK (2018) UVEK LCI Data 2018. Bundesamt für Umwelt BAFU, Switzerland, retrieved from: www.ecoinvent.org.

7 The reviewers experience and company

7.1 Dr. Niels Jungbluth, Chief Executive Officer (CEO)

7.1.1 Philosophy of ESU-services Ltd.

ESU-services Ltd. was founded in 1998. Its core business is research, consulting, review and training in the field of Life Cycle Assessment (LCA). This methodology aims to investigate environmental aspects of products and services from cradle to grave, from resource extraction to manufacture, use and end of life treatment. We also work with related methods such as carbon footprinting and Substance Flow Analysis (SFA).

Fairness, independence and transparency are the main characteristics of our consulting philosophy. We work issue-related and accomplish our analyses without prejudice. We document our studies and our work in a transparent and comprehensible manner. We offer a fair and competent consultation, which enables our clients to control and continuously improve their environmental performance.

ESU-services covers several economic sectors such as energy, basic minerals, metals and chemicals, biomass, transportation, waste management, information technology, food and lifestyles. ESU-services also contributes to the development of impact assessment methods such as ecological scarcity 2006. Since 2007, ESU-services runs the Regional SimaPro Competence Centre of Switzerland, Germany, Liechtenstein and Austria.

7.1.2 CV

Dr. Niels Jungbluth studied Environmental Engineering at the Technical University of Berlin. He made his diploma thesis during a six month stay at the TATA Energy Research Institute in New Delhi, where he prepared a life cycle inventory for cooking fuels in India. Between 1996 and 2000 he worked on a Ph.D. Project at the Swiss Federal Institute of Technology (ETH) in Zurich at the chair of Natural and Social Science Interface. His Ph. D. thesis on the environmental consequences of food consumption has been awarded with the Greenhirn Price 2000 by the German Öko-Institut. In this thesis he investigated food consumption patterns by means of life cycle assessment.

He started working with ESU-service in 2000. Between 2006-2012 he was managing partner together with Rolf Frischknecht. Since 2012 he acts as a managing director. His main working areas are food, biomass, energy systems, input-output-analysis and sustainable consumption. He is responsible for the SimaPro centre and the data-on-demand service of ESU.

Dr. Niels Jungbluth is in the editorial board of the "Int. Journal of LCA" and works as reviewer for several other scientific journals. He works as a special expert for several organisations as e.g. Deutsche Bundesstiftung Umwelt, United Nations Framework Convention on Climate Change UNFCCC, CEN TC 383 standard (GHG accounting on biofuels), UNEP-SETAC life cycle initiative, Swiss law on tax exemption for biofuels.

7.1.3 References (selection)

ESU-services has conducted more than 300 projects related to LCA in the past 20 years. See below for a brief list of the most recent and relevant projects involving a review. A full description of the company including a list of several hundred project references can be found on the Internet (www.esu-services.ch/projects/fulllist/). The full list of papers peer-reviewed by Niels Jungbluth can be found on publons.com/author/488732/niels-jungbluth#profile.

Year	Project title	Commissioned by
Since 1999	Peer Reviews of papers	www.publons.com/researcher/488732/niels-jungbluth
Since 2001	Subject Editor "LCA for Energy Systems and Food Products"	The International Journal of LCA
Since 2011	Editorial Board ecoinvent for the themes: 06 Extraction of crude petroleum and natural gas, 19 Coke and refined petroleum products, 27 Electrical equipment and several other themes	ecoinvent Centre
Since 2014	Individual verifier for the international EPD® System	On request
2019	Verification: EPD of the Stadler doubledecker train KISS	Stadler Bussnang AG
2019	Critical Review: Comparative carbon footprint of transport services	Denkstatt, AT
2019	Verification: EPD of a thin film solar cell	Miljögiraff & MälarEnergi
2019	Verification: EPD of a glass-glass PV module	Fachhochschule Nordwestschweiz
2019	Critical Review: LCA of meat trays made from different materials	Fraunhofer-Institut für Umwelt-, Sicherheits- und Energietechnik, DE
2019	Verification: EPD model for lightweight concrete drainage channels	BG-Graspointer GmbH & Co KG, AT
2019	Evaluation of the Bioeconomic Research Programme Baden-Württemberg	Ministerium für Wissenschaft, Forschung und Kunst Baden-Württemberg
2018-19	Critical Review life cycle inventory of bitumen products	Eurobitume, BE
2018-19	Expert panel for the revision of "Product Category Rules (PCR) for preparing an Environmental Product Declaration (EPD) for Electricity, Town Gas, Steam, and Hot and Cold Water Generation and Distribution"	ESU-services
2018	Critical Review: Life cycle assessment of concrete drainage channels of BG-Graspointer GmbH & Co KG	BG-Graspointer GmbH & Co KG, AT
2018	Update Critical review of an LCA study on transport packages for vegetables and fruits	Fraunhofer-Institut für Umwelt-, Sicherheits- und Energietechnik, DE
2017-18	Critical Review: Comparative LCA between bio-isobutene (produced from sugar beet) and fossil propane/butane for gas cooker application	Butagaz, FR
2017-18	Critical Review: LCA of mono propylene glycol	Oleon, FR
2017	Validation of company specific LCA guidelines	Nestec Ltd. │ Nestlé Research Center
2016-17	Critical Review of developments for the Product Biodiversity Footprint	i care & consult
2016	Critical review of an LCA study on transport packages for vegetables and fruits	Fraunhofer-Institut für Umwelt-, Sicherheits- und Energietechnik, DE
2015	Critical review of an LCA study on cotton recycling	H & M
2014	Critical review of an LCA study on coffee	Luigi Lavazza S.p.A.
2014	Critical review of the GreenCALC web tool	NEFAB
2014	Critical review of an LCA for bread baking	FP7 Low Energy Ovens (LEO) project
2014	Critical review of an LCA and ILCD dataset for global organic cotton production	TEXTILEEXCHANGE
2013	Critical Review of an LCA of a water consumption device	Itron
2013	Review of research proposals	The European Commission, 7th Framework Programme
2012, 2013	Review of project proposals FNR	Fonds National de la Recherche, Luxembourg
2012	Critical Review "Life Cycle Assessment of Toray Film Europe's PET and OPP films"	Toray Film Europe
2012	Critical Review of a study on the carbon footprint and energy use for unconventional natural gas from fractionating	International Institute for Sustainability Analysis and Strategy (IINAS)
2011	Critical Review life cycle inventory of bitumen products	Eurobitume, BE
2010	Critical review of an EPD for agricultural biogas	AXPO AG
2010	Critical Review of an LCA study of bio-ethylene vs. ethylene	The Procter and Gamble Co., US
2010	Review of the ecological footprint calculator	WWF Switzerland
2009	Review of project proposals for the French Food Research Programme ALIA	INRA support Unit of ANR, FR
2008	Background review of consumer information	Coop
2008	Critical review of an LCA of green waste disposal and utilization in Basel	ERZ Entsorgung und Recycling Zürich
2007	Review of CO2-intensities used by EnvImpact	Centre Info
2007	Critical Review of an LCA for hand drying systems	HTS Suisse SA
2004	Critical Review according to ISO 14040ff of different LCA studies for biofuel production and use	Various
2004 - 2007	Project leader "Life cycle assessment of bioenergy products". Coordination of project partners, validation of data for ecoinvent v2.0. Review of project reports.	Bundesamt für Energie, Bundesamt für Landwirtschaft and Bundesamt für Umwelt, Wald und Landschaft
2004 - 2008	RENEW: Renewable fuels for advanced powertrains. LCA of BtL-fuel (Biomass-to-Liquid) production including critical review according to ISO 14040, 44	FP7, The European Commission, Bundesamt für Energie and Bundesamt für Bildung und Wissenschaft
2003	ecoinvent 2000: validation of ecoinvent reports for waste management and transport systems	Federal Office for the Environment (FOEN)

REFERENCES

1 Life Cycle Inventory: Bitumen, Eurobitume 2012, ISBN 2-930160-26-8
2 EN 12591: 2009, Bitumen and bituminous binders - Specifications for paving grade bitumens
3 EN 15804+A1 Sustainability of Construction Works — Environmental Product Declarations — Core Rules for the Product Category of Construction Products
4 EN ISO 14040:2006, Environmental management - Life cycle assessment – Principles and framework
5 EN ISO 14044:2006, Environmental management - Life cycle assessment – Requirements and guidelines
6 Energy consumption at refinery, Solomon Associates, Confidential report
7 Environmental performance indicators – 2017 data, International Association of Oil & Gas Producers, Report 2017e, October 2018
8 www.ecoinvent.org
9 Life cycle inventories of crude oil extraction. C Meili, N Jungbluth, J Annaheim. ESU-services Ltd. commissioned by BAFU, BFE & Erdöl-Vereinigung, Schaff-hausen, Switzerland, http://esu-services.ch/data/public-lci-reports/, 2018
10 Efficient Aframax Design Providing Solutions for Emissions Legislation (SOX and NOX), https://www.wartsila.com
11 https://www.searates.com
12 Sulphur dioxide emissions from oil refineries in Europe (2010), Concawe report 1/16
13 https://ec.europa.eu/energy/en/data-analysis/eu-crude-oil-imports
14 Environmental performance indicators – 2017 data, International Association of Oil & Gas Producers, Report 2017e, October 2018
15 BP Statistical Review of World Energy 2017
16 ICCT. Upstream Emissions of Fossil Fuel Feedstocks for Transport Fuels Consumed in the European Union.: C Malins, S Galarza, A Baral, A Brandt, H El-Houjeiri, G Howorth, T Grabiel, D Kodjak. Washington D.C.: The International Council on Clean Transportation (ICCT), 2014.
17 Mineralölversorgung mit Pipelines, www.MWV.de
18 Third IMO Greenhouse Gas Study 2014; Published in 2015 by the International Maritime Organization,
19 Emission factors for CH_4, NOx, particulates and black carbon for domestic shipping in Norway, revision 1; Nielsen J, Stenersen D, Norwegian Marine Technology Technology Research Institute (Marintek), Report MT22 A10—199, 2010.
20 ITOPF, 2019, Oil Tanker Spill Statistics 2018
21 Refinery CO2 benchmarking : What happens next. https://www.concawe.eu/wp-content/uploads/2017/01/cs_09_t3-3_bourgeois-refinery_co2_benchmarking_what_happens_next-2011-00702-01-e.pdf
22 Shell Bitumen Handbook, 6th Edition, 2015 (pp742), ISBN 978-0-7277-5837-8
23 Sulphur dioxide emissions from oil refineries in Europe (2010), Concawe report 1/16
24 2013 survey of effluent quality and water use at European refineries, Concawe report 12/18
25 Nelson complexity index, http://pakpas.org/0.REFINERY%20LIBRARY/2.EDC-business_petroleum_refiningmktg_lc_ncf.pdf
26 Life cycle inventories of oil refinery processing and products. N Jungbluth, C Meili, P Wenzel (2018) ESU-services Ltd. commissioned by BAFU, BFE & Erdöl-Vereinigung, Schaffhausen, Switzerland, http://esu-services.ch/data/public-lci-reports/
27 Guidance for preparing Product Category Rules (PCR) and Environmental Product declarations (EPD) for asphalt mixtures, EAPA 2017, https://eapa.org/wp-content/uploads/2018/07/GCA-17-N215-EAPA-Guidance.pdf

Eurobitume
Boulevard du Souverain 165
B-1160 Brussels
Belgium
T: +32 2 566 91 40
E: info@eurobitume.eu

Eurobitume Benelux
Max von Devivere
Utrechtseweg 167
NL-3818 ED Amersfoort
The Netherlands
T: +31 6 31 688 948
E: max.vondevivere@eurobitume.eu

Eurobitume Deutschland
Anja Sörensen
Im Gewerbepark C 25
D-93059 Regensburg
Germany
T: +49 941 46 36 222
E: anja.soerensen@eurobitume.eu

Eurobitume France
Jean-Michel Michou
5 place de la Pyramide
Tour Ariane La Défense 9
F-92088 Paris-La Défense Cedex
France
T: +33 1 55 68 11 26
E: jean-michel.michou@eurobitume.eu

Eurobitume Switzerland
Hans-Peter Beyeler
Sonnhaldenstrasse 64
CH-3210 Kerzers
Switzerland
T: +41 79 345 05 86
E: hans-peter.beyeler@eurobitume.eu

Eurobitume UK
David Ernest Giles
Suite 8
White Horse Business Centre
Lewin Street
Middlewich
Cheshire
CW10 9AS
United Kingdom
T: +44 1606 832 489
E: david.giles@eurobitume.eu

eurobitume

www.eurobitume.eu
www.linkedin.com/company/eurobitume
www.twitter.com/eurobitume