eurobitume

Life Cycle Assessment 4.0 for bitumen

Summary and comparative analysis on the Global Warming Potential indicator

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Boulevard du Souverain 165
B - 1160 Brussels, Belgium
www.eurobitume.eu

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1 Introduction

Bitumen is manufactured from the distillation of crude oil during petroleum refining. It is produced to meet various specifications based on physical properties for specific end uses. Bitumen main characteristics, which are adhesivity, waterproofing, thermoplasticity, viscoelasticity, durability, ease of modification, reusability and recyclability, make it suitable for construction applications.

For more than 25 years Eurobitume has been committed to perform Life Cycle Assessments (LCA) on the production of bitumen and bituminous binders in Europe, providing relevant environmental information to stakeholders through publicly available bitumen Life Cycle Assessment (LCA).

A review of the LCA for the bitumen industry in Europe was carried out in 2024. It replaces the Eurobitume LCI 3.1 that was published in 2020 and updated in 2022.

The new Eurobitume LCA 4.0 (2025) provides:

- a scientifically robust and peer reviewed report representative of the current situation of bitumen production in Europe according to ISO 14040+Amd1 [1] and ISO 14044 [2];
- Life Cycle Impact Assessment according to the European Standard EN 15804+A2 [3] and therefore suitable for use in future EPDs (Environmental Product Declaration) for construction products;
- appropriate responses to the main shortcomings pointed out in the critical review of the previous study.

The **full report** of this LCA 4.0, including the **critical review**, is available on the Eurobitume website. In addition to that report, the aggregated Life Cycle Inventory dataset is available in the ILCD (International Life Cycle Data System) format that is compatible with commonly used LCA software. These deliverables are primarily intended for LCA practitioners.

This additional document is the **digest version of LCA 4.0**, focusing on the Global Warming Potential indicator for bitumen over a 100-year period (GWP_{100}). It intends to address a wider audience. Its purpose is to present the main assumptions, results and the main differences between the new LCA 4.0 and the previous version LCI 3.1.

The LCA 4.0 covers the bitumen produced by Eurobitume members. The study has been conducted on the basis of a data collection from 17 refineries in Europe and representing more than 75 % of the bitumen production of Eurobitume members.

2 Scope of the study

This LCA study relates to the environmental impacts associated with one **tonne** of bitumen. These enviromental impacts can be used in other life cycle studies for construction materials such as for an Environmental Product Declaration (EPD), under EN 15804+A2 [3].

The geographical coverage of the LCA considers the manufacture of bitumen products within the EU and the UK.

Two product families are considered:

- **refined bitumen**, obtained mainly by vacuum distillation of selected crude oil or blends of crude oils, mostly used in road applications;
- **oxidised bitumen**, produced in an additional bitumen oxidation unit. This process involves passing an air flow through bitumen feedstock at elevated temperatures to significantly change the physical properties of the products. Oxidised bitumen is mainly used in roofing applications.

This study relates to the cradle-to-gate production of bitumen, i.e. it considers the environmental impacts associated with the supply of a feedstock, covering the extraction of a representative crude oil mix, its transportation to a refinery within Europe, the production of bitumen products and storage inside the refinery. The system boundary is identical to the previous study and is consistent with the modules A1, A2 and A3 of EN 15804+A2 [3] covering the life cycle stage production, as defined below:

- A1: Crude oil extraction (and other feedstock production);
- A2: Feedstock transportation from the country or region of extraction to the refinery;
- A3: Production of bitumen through refining processes;
- A3: Bitumen storage within the refinery.

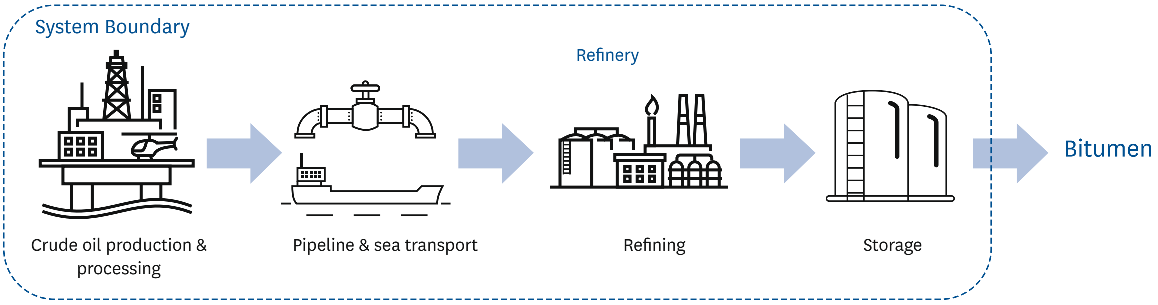

Figure 1. System boundary of the LCA study

The following table provides a list of activities included and excluded from the study system boundary.

Table 1. Elements in the system boundary and excluded

Included	Excluded
Crude oil extraction	Employee commute
Production of other feedstocks (e.g. HFO)	Infrastructure manufacturing, use, and end of life
Feedstock transportation by pipeline and sea vessel	Other refinery processes associated with the production of refined fuels and petrochemicals
Atmospheric and vacuum distillation	
Air-blowing (air-rectification and oxidation) of vacuum-residue to meet requirements of bitumen and oxidised products	
Bitumen storage within refinery	

3 Life Cycle Inventory Analysis

3.1 Crude oil supply

Not all crude oils are suitable for bitumen production, with the most suitable ones being described as 'heavy' i.e. they have a high bitumen content. Crude oil production is modelled in Sphera's MLC (Managed LCA Content) datasets 2024.1 [4].

These data sets represent the estimated impacts of crude oils extraction in each country taking into consideration the mix of extraction technologies used (conventional vs. unconventional as well as onshore vs. offshore). The reference year for all datasets is 2020.

The relative share of countries from which crude oil is imported can vary over time. Consequently, it was decided that the average feedstock supply mix weighted by bitumen output of the included refineries would be a 3-year average (2021-2023) to flatten possible fluctuations over time. As the information about the country of origin for the crude slates is sensitive information for the refineries, the weighted averaged feedstock supply has been aggregated to a continental/regional breakdown in Table 2.

Table 2. Weighted feedstock supply mixes by continent/ region, 3-year average (2021-2023)

Origin of crude oil	3-year average [%]
Africa	5
Europe	28
Former Soviet Union (FSU)	18
Middle East	27
North America	6
South America	2
Other feedstock (HFO)	14
Total	**100**

The range of carbon intensity from country-specific crude oil production, taken from Sphera's MLC 2024.1 database [4], is wide. The major factors influencing this large range are the venting, flaring and fugitive (VFF) emissions associated with crude oil extraction. Particularly, the amounts of flared and vented associated gas, and fugitive methane emissions from the equipment used to produce and transport well fluids and crude oil, can be quite different across countries. The data basis for the VFF emissions in the MLC database is the International Energy Agency (IEA) Global Methane Tracker [5].

3.2 Crude oil transport

The transport of the extracted crude oil from the country of origin to the refinery is modelled using a combination of pipelines and maritime vessel transportation. For each of the crude oil blends from the various crude oil exporting countries from which the individual refineries are supplied, a specific combination of modes of transportation (e.g., pipeline-sea vessel-pipeline, pipeline-sea vessel) and distances have been established.

Table 3. Aggregated transport distances per feedstock supply, 3-year average scenario (2021-2023)

Feedstock supply	Pipeline (oil field to terminal refinery) [km]	Oil tanker (export terminal to import terminal refinery) [km]	Pipeline (import terminal to refinery) [km]
3-year average (2021-2023)	780	4 550	50

3.3 Refinery operations

The most common refining process for producing bitumen is a straight reduction to grade from petroleum crude oil or a crude blend, using successive atmospheric and vacuum distillation.

The energy consumption of the distillation process is calculated by using the collected primary data from the considered refineries and applying an **allocation by energy** (net calorific value) to partition the impacts of the distillation units between the multiple coproducts of the refinery.

The air-blowing process can be applied to obtain oxidised bitumen for specific applications. This process involves passing air flow through bitumen feedstock at elevated temperatures to significantly change the physical properties of the products.

The bitumen products are stored in heated and insulated storage tanks at the refineries. Storage conditions, e.g., temperature, safety, maintenance, and cleaning are carefully monitored.

Other processes at the refinery are considered:

- Electricity supply: the representative refinery modelled in the foreground system sources electricity from an onsite power plant and the grid. A fraction of the electricity consumption (34,4 %) is generated by an onsite combined heat and power (CHP) plant. The rest (65,6 %) is assumed to be sourced from the respective national grid.
- Steam and heat supply: for the direct combustion of fuels in the refinery units to provide heat or steam the CO_2 emissions have been calculated based on CO_2 emission factors provided by the IPCC [6] and the amount of combusted fuel.
- Entire refinery's overhead: a few utilities (i.e., water consumption, wastewater, waste disposal) and the overhead operations could not be related to specific refining processes as this kind of data is mostly not separately collected by the refineries. Therefore, primary data on entire refinery have been allocated to the different products of the averaged refinery alongside overhead's energy use assumptions.

4 Global Warming Potential (GWP_{100}) indicator results

Results are shown in Figure 2 for the Global Warming Potential over a 100-year period (GWP_{100}) calculated according to IPCC's Sixth Assessment Report (AR6) [6] methodologies. GWP_{100} for the bitumen is **530 kg CO_2 eq./t of bitumen**.

The air-blowing units consume a relevant amount of energy, which adds for the oxidation process about 86 kg CO_2 eq./t. Therefore, additional processing to tune product properties and meet specifications increases the GWP_{100} to **616 kg CO_2 eq./t of bitumen for oxidised bitumen** (~16 % increase).

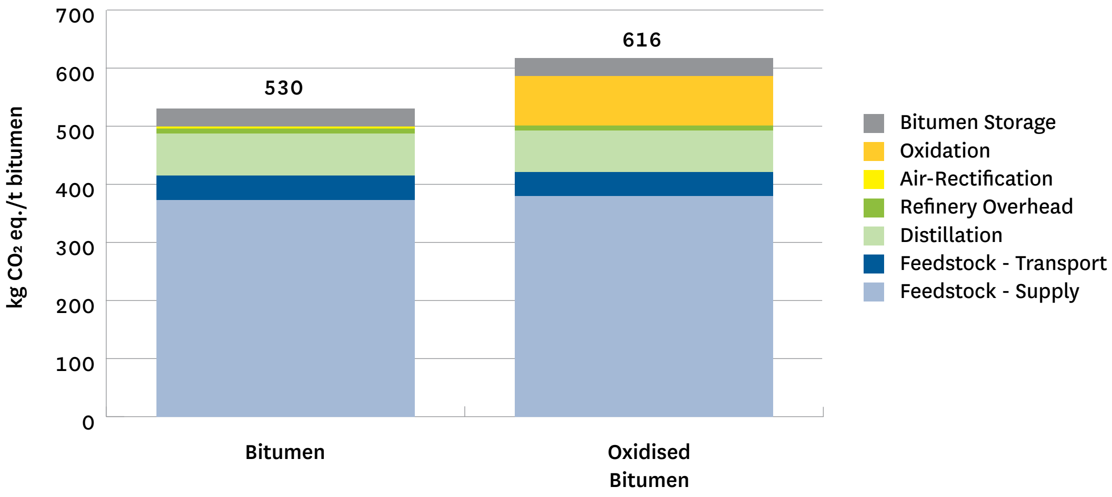

Figure 2. GWP_{100} (AR6) for bitumen products

The major contributor to GWP_{100} is the extraction of the crude oil and heavy fuel oil supplied to the refinery (70 % and 62 % for bitumen and oxidised bitumen, respectively). The transport of crude to the refinery contributes an additional 8 % and 7 %, for the respective products. Atmospheric and vacuum distillations of the crude oil contribute 14 % to GWP_{100} of bitumen, and 11 % in the case of oxidised bitumen products for which oxidation process contributes to a 16 % increase of the GWP_{100}.

Primary data collected in the study for the storage of the bitumen resulted in an energy consumption close to ~500 MJ of steam, fuels and electricity per tonne of bitumen, representing around 6 % of the GWP_{100} of bitumen.

Methane (CH_4) emissions contribute 46 % to bitumen GWP_{100}, while CO_2 emissions make up another 54 % (see Figure 3). The relevance of methane for bitumen GWP_{100} originates from its high share of GHG emissions (61 % of total feedstock supply's GWP_{100}) during crude oil extraction, mainly through venting, flaring and fugitives (VFF) emissions.

Emissions from nitrous oxide (N_2O) and other GHGs are negligible.

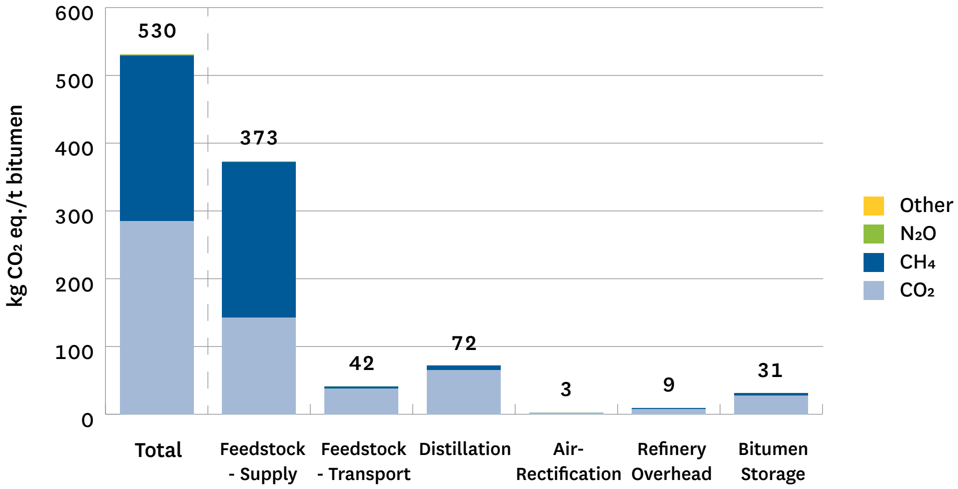

Figure 3. Individual GHGs for bitumen's GWP_{100} (AR6)

5 Comparison with Eurobitume LCI 3.1

5.1 Comparison of GWP_{100} between Eurobitume LCI 3.1 and LCA 4.0

A comparison of the GWP_{100} indicator between Eurobitume LCI 3.1 [7] and LCA 4.0 (based on assessment report 6 – IPCC 2021 [6]) is presented in Figure 4.

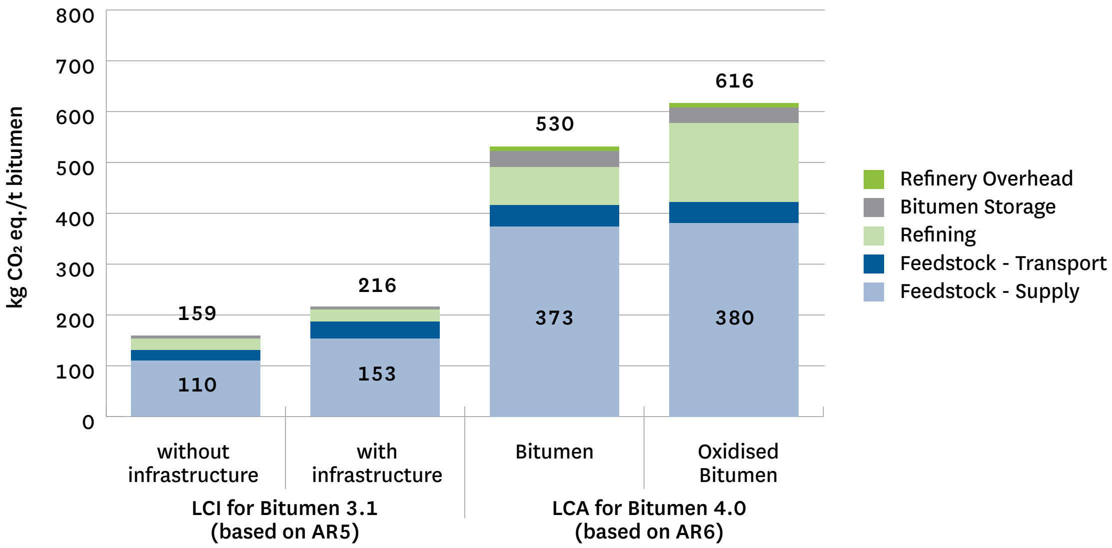

Figure 4. Comparison of GWP_{100} between Eurobitume LCI 3.1 and LCA 4.0

The bitumen GWP_{100} in LCA 4.0 is 145 % higher than the reference value with infrastructure of LCI 3.1.

The various assumptions explaining the significant differences are developed in the following sections.

5.2 Main differences in methodology between LCI 3.1 and LCA 4.0

An overview of the main differences in methodology between LCI for bitumen 3.1 (2020/2022) [7] and LCA for bitumen 4.0 (2025) is presented in Table 4.

Table 4. Overview of the main differences in methodology between LCI 3.1 (2020/2022) and LCI 4.0 (2025)

	Eurobitume LCI for bitumen 3.1 (2020 + 2022 update)	Eurobitume LCA for bitumen 4.0 (2025)
Crude production supply	Energy consumption and emission data published by IOGP (International Association of Oil and Gas Producers) per region/continent and combined with Ecoinvent background LCI data. Time reference for crude oil extraction emission based on rolling average for 2015-2019.	Sphera's Managed LCA Content (MLC) 2024.1 database. Technology mix of conventional and unconventional production methods for the crude oils (per country of production) assumed. Venting, flaring and fugitives based on the IEA (International Energy Agency) Global Methane Tracker.
Crude oil supply basket	Crude mix used for bitumen production estimated by Eurobitume members for the reference production year 2019.	Refinery specific crude supply data by country of origin collected and weighted by individual refinery bitumen production. Crude oil supply basket referring to a 3-year average (2021-2023).
Crude oil transport	Average transport distances between region/continent and hypothetical refinery in ARA (Amsterdam-Rotterdam-Antwerp) region, transport by ship. Pipeline only for crude from FSU until Baltic Sea.	Based on individual transport distances between country of origin and specific refinery distances.
Allocation refinery	Sensible heat method (energy to heat the bitumen fraction from the crude oil to the run-down temperature) used to assess the energy consumption. Refinery energy grid based on primary data from Eurobitume members.	Allocation by energy for the distillation steps based on the primary data of 17 refineries.
Fuel mix refinery	Literature (Concawe study resulting in 13,3 % HFO, 86,7 % refinery gas)	Based on primary data.
Emissions from fuel combustion	LCI background data (Ecoinvent)	Based on primary data + default IPCC EFs for CO_2.
Storage of bitumen	Energy consumption was calculated based on literature and defined storage parameters (tank volume, ambient temperature, throughput etc.).	Based on primary data.
LCI background data	Ecoinvent 3.5 database	Sphera's MLC 2024.1 database
Infrastructure	Included across the supply chain and results given with and without infrastructure.	The infrastructure for the crude oil production included in the used MLC datasets for the crude oil supply. Other infrastructures excluded and analysed in the sensitivity analysis.

5.3 Crude oil database

The major factor influencing the results is the method used to model the crude oil production, which represents the main part of the environmental impacts of bitumen (see Figure 5). The crude oil environmental data is now taken from Sphera's MLC (Managed LCA Content) database [4], based on average crude oil per country of origin, whereas the LCI 3.1 relied on the IOGP database [8] and average crude oil by region or continent.

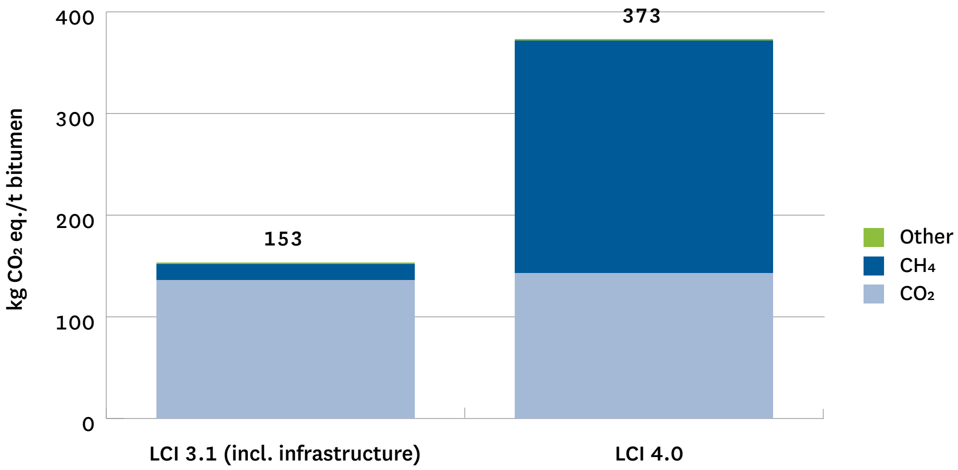

Figure 5. Comparison of the individual GHGs between LCI 3.1 and LCA 4.0

The quality of the crude oil modelling is increased in the LCA 4.0 compared to LCI 3.1, considering the level of detail of crude oil origin averaging, but also the method used to account for venting, flaring and fugitive emissions associated with crude oil production. Particularly, the amounts of flared and vented associated gas, and fugitive methane emissions from the equipment used to produce and transport well fluids and crude oil, can be quite different across countries.

The range of carbon intensity from country-specific crude oil production, taken from the Sphera's MLC 2024.1 database, is wide. The major factors influencing this large range are the venting, flaring and fugitive (VFF) emissions associated with crude oil production. Particularly, the amounts of flared and vented associated gas, and fugitive methane emissions from the equipment used to produce and transport well fluids and crude oil, can be quite different across countries. The data basis for the VFF emissions in the MLC database is using the International Energy Agency (IEA) Global Methane Tracker [5].

The calculation or measurement of VFF emissions is affected by uncertainty, regardless of whether a bottom-up (emission factors and equipment), top-down (satellite-based) or hybrid approach is used. Therefore, an update of this study with the updated cycle already adopted by Eurobitume is important to cover possible improvements, especially regarding the measurement of methane emissions during crude oil production as well as to take into account possible mitigation measures for VFF emissions.

5.4 Crude oil basket

The crude oil basket also has a significant influence on the results. In the LCA 4.0, it is calculated on the basis of refinery specific crude supply data by country of origin collected and weighted by individual refinery bitumen production. The share of countries from which crude oil is imported can vary over time. A 3-year average (2021-2023) has been used as the reference scenario for feedstock supply mix weighted by bitumen output of the included refineries, to flatten possible fluctuations over time. In the LCI 3.1, the crude oil basket was estimated by Eurobitume members for the reference production year 2019.

The impact of the crude oil basket cannot be compared directly on the GWP_{100} between LCI 3.1 and LCA 4.0 as the crude oil database used for the calculations are different between both studies. However, to better understand the impact that possible changes in the average feedstock supply mix might have on the environmental burdens associated with the production of bitumen products, a sensitivity analysis was performed in LCA 4.0 in which the baseline 3-year average feedstock was compared with (a) a 5-year average 2019-2023, and (b) the 2023 average feedstock supply basket. As the information about the country of origin for the crude slates are very sensitive information for the refineries, the weighted averaged feedstock supply has been aggregated to a continental/regional breakdown (see Table 5). The evolution of the crude oil basket over the 2019-2023 period is presented in Figure 6, as well as the crude oil basket taken from the LCI 3.1 based on the reference year 2019.

Table 5. Weighted feedstock supply mixes by continent/region

Origin of crude oil	**LCI 3.1 2019 [%]**	**LCA 4.0 3-year average [%]**	**LCA 4.0 5-year average [%]**	**LCA 4.0 2023 [%]**
Africa	-	5	5	6
Europe	10	28	27	29
Former Soviet Union (FSU)	30	18	22	5
Middle East	45	27	26	33
North America	-	6	4	11
South America	15	2	3	3
Other feedstock (HFO)	-	14	13	14
Total	**100**	**100**	**100**	**100**

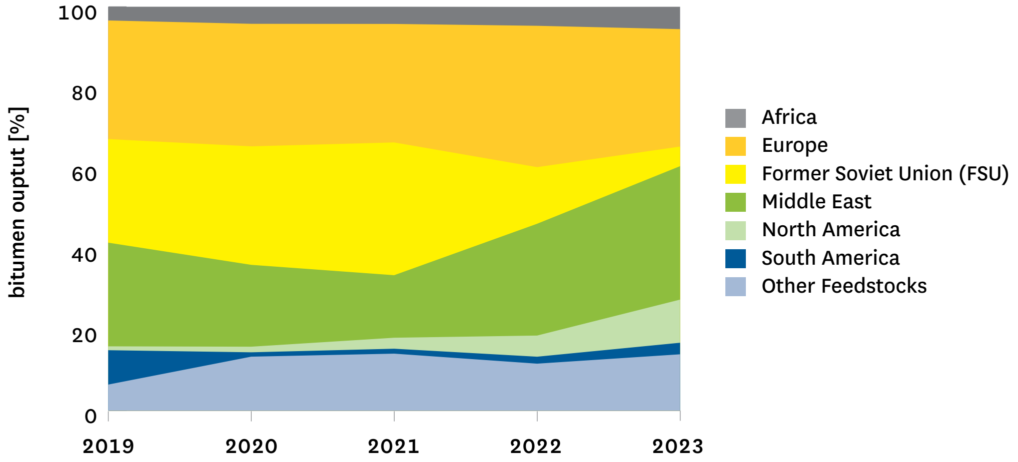

Figure 6. Evolution of the crude oil basket over the 2019-2023 period, weighted by bitumen output

The impact of time averaging of crude oil basket on the GWP_{100} indicator is shown in Figure 7. The time averaging method has a significant impact on the GWP_{100}. It is mainly due to the substitution, from 2022, of the Former Soviet Union (FSU) crude by crudes from other regions, e.g., Middle East, Europe or North America. Carbon Intensity (CI) of FSU crude is not so high (in the middle of the spectrum) but it is substituted by crudes from e.g., Europe or Middle East having lower carbon intensities.

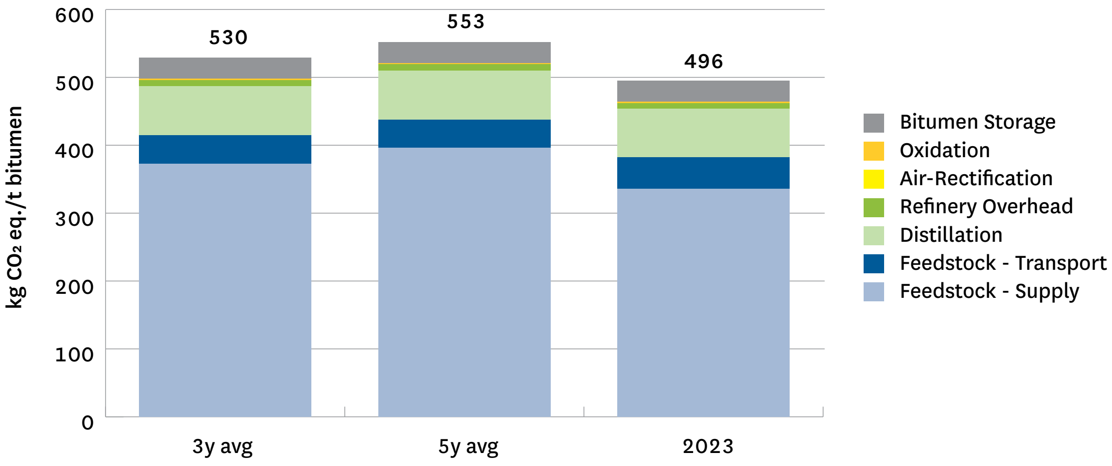

Figure 7. Impact of the time averaging on the GWP_{100} indicator

The 5-year average is only partially representative of the recent years when FSU crude is no longer used in the crude oil basket. The year 2023 crude mix is not representative of the past years before geopolitical change and may be not representative of the coming years. Therefore, the 3-year average was considered to be a good balance and was retained as the baseline scenario.

5.5 Distillation process at the refinery

The refinery's atmospheric and vacuum distillation units are multioutput processes that produce a significant number of petroleum fractions, each of them with a different functionality.

A modification of the distillation processes modelling has been introduced in the LCA 4.0:

- The baseline scenario of the LCA 4.0 approaches the multifunctionality issue through the application of allocation **by energy content, on the basis of primary data** collected for the 17 refineries.
- The LCI 3.1 used the **sensible heat method**. This method assumes that the fraction of crude oil corresponding to refined bitumen remains in the liquid phase and does not change state, allowing for its enthalpies of vaporisation and condensation to be disregarded. This assumption allows a simplified thermodynamic calculation approach to estimate the energy required in the production of straight-run bitumen, i.e. the sensible heat required to raise the temperature of the bitumen fraction within the crude oil from the initial crude oil temperature to the final storage temperature of bitumen.

Table 6 summarises the feedstock and energy inputs per tonne of bitumen applying the different approaches.

Table 6. Energy input per tonne of bitumen in the distillation process

Inputs per t of bitumen	Allocation by energy (LCA 4.0 - Baseline scenario)	Sensible heat method (LCA 4.0 – sensitivity analysis)
Electricity [MJ]	146	150
Steam [MJ]	128	-
Natural gas [MJ]	112	60
Refinery gas [MJ]	494	268
Light fuel oil [MJ]	27	14
Total [MJ]	**907**	**492**

Results of the sensitivity analysis on the GWP_{100} when the multifunctionality approach is varied are presented in Figure 8.

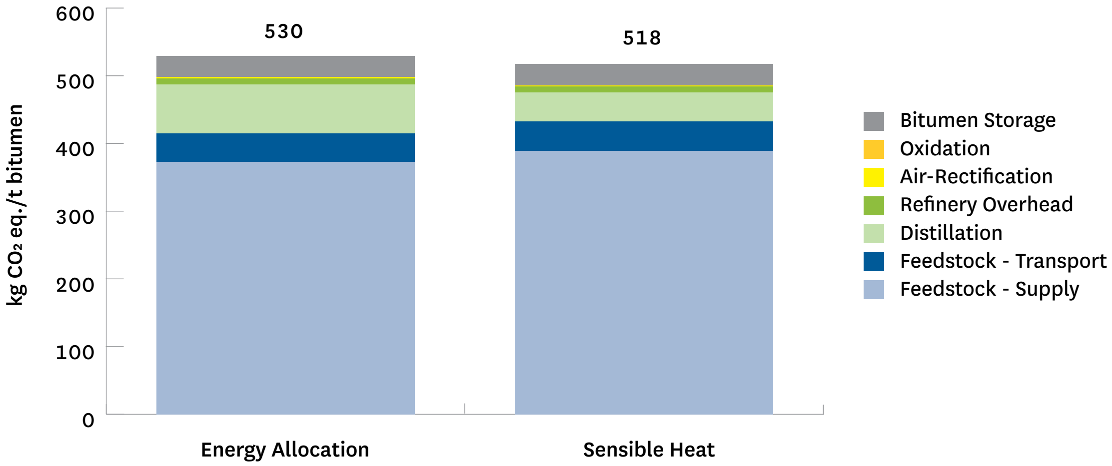

Figure 8. Sensitivity analysis on the GWP_{100} when the multifunctionality approach is varied

The allocation method at the refinery has a very limited impact on the bitumen's GWP_{100}: a reduction by 2 % for the sensible heat method compared with the baseline scenario based on energy allocation. However, on the distillation scope alone, the difference represents around -40 %.

The energy allocation method has been chosen in the LCA 4.0 as primary data for the various refinery processes are available, which was not the case for the LCI 3.1. The robustness of the sensible heat method is not questioned, but it could be assessed in greater detail in future studies.

5.6 Infrastructure

Infrastructure is often excluded in LCAs due to their mostly low influence. In addition, existing product category rules (PCR) for bitumen applications usually exclude infrastructure from the system boundaries.

Nonetheless, to get a better understanding of the possible influence of the infrastructure, a sensitivity analysis has been performed including as much as possible of the infrastructure for the bitumen production. This analysis remains partial as the infrastructure for the crude oil production is included in the used MLC datasets for the crude oil supply.

For the feedstock transport by pipeline and oil tanker as well as for the refinery dedicated infrastructure models have been set-up for this study. This contributes to an increase in the GWP_{100} less than 1 %. Therefore, infrastructure has finally been excluded from the system boundaries, except the infrastructure for the crude oil production which is included in the crude oil database.

5.7 Synthesis

The differences in GWP_{100} between LCA 4.0 and LCI 3.1 at the different stages of bitumen production are summarised in Figure 9.

The 3 majors factors influencing the GWP_{100} indicator increase are:

- the change in crude oil database and crude oil basket. The Managed LCA Content (MLC) 2024.1 database from Sphera used in the LCA 4.0 improves the quality of crude oil modelling, particularly the methane emissions assessment and the geographic accuracy for the crude oil data averaging. The crude basket now refers to a 3-year average (2021-2023) based on primary data of crude oil by country of origin. These choices contribute to a 102 % increase in GWP_{100};
- the modification of the allocation method at the refinery. The LCA 4.0 relies on the energy allocation method based on primary data of 17 refineries in Europe. This represents a 24 % increase in GWP_{100}.
- the change in bitumen storage model at the refinery, which is now based on primary data. This contributes to a 12 % increase in GWP_{100}.

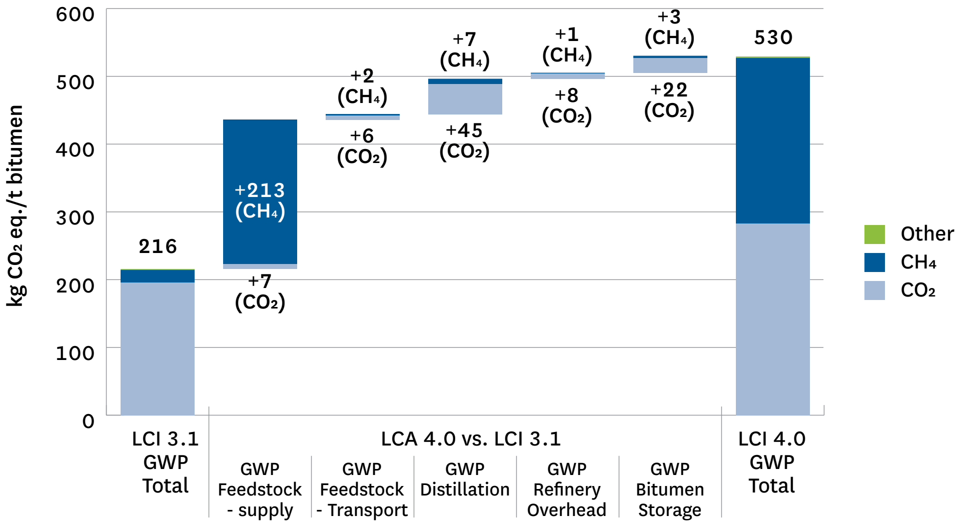

Figure 9. Differences in GWP_{100} between LCA 4.0 and LCI 3.1 at the different stages of bitumen production

The significant increase in GWP_{100} is clearly due to a change in the LCA methodology and is not related to the evolution of industrial processes.

The full report of this LCA 4.0 for bitumen is available on the Eurobitume website.

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Eurobitume
Boulevard du Souverain 165
B-1160 Brussels
Belgium
info@eurobitume.eu

eurobitume

www.eurobitume.eu
in www.linkedin.com/company/eurobitume
X www.x.com/eurobitume