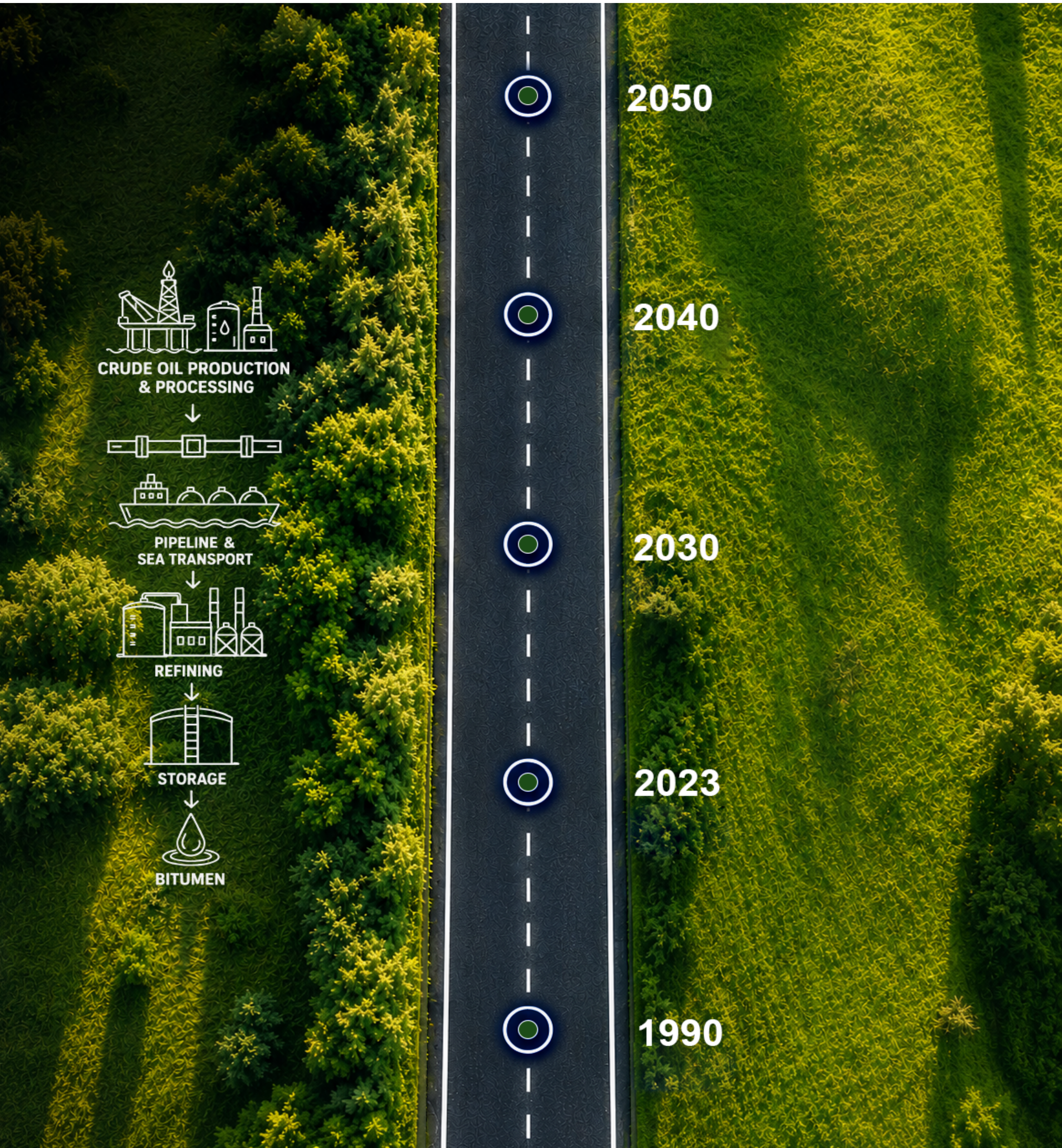
Decarbonisation Roadmap for Bitumen



This document has been developed through a joint work between Eurobitume and Deloitte. Deloitte has supported Eurobitume in developing a transparent decarbonisation pathway for bitumen production in Europe, targeting emissions reduction by 2050 with interim milestones for 2030 and 2040. This roadmap is part of Eurobitume's integrated Sustainability Roadmap initiative. The findings, interpretations and conclusions expressed herein are a result of a collaborative process facilitated and endorsed by Eurobitume but whose results do not necessarily represent the views of the entirety of its members, partners or other stakeholders.

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List of Acronyms

CCS	Carbon Capture and Storage
CH_4	Methane
CO_2	Carbon Dioxide
CO_2 eq.	Carbon Dioxide Equivalent
EAPA	European Asphalt Pavement Association
EPD	Environmental Product Declarations
EU-ETS	EU Emissions Trading System
GHG	Greenhouse Gas
GWP	Global Warming Potential
HFO	Heavy Fuel Oil
IEA	International Energy Agency
LDAR	Leak Detection and Repair
LNG	Liquified Natural Gas
OGMP	Oil and Gas Methane Partnership
VRU	Vapor Recovery Units

Executive Summary

This report presents a comprehensive decarbonisation roadmap demonstrating how the European bitumen industry can achieve substantial emission reductions by 2050. This roadmap reflects a data-driven approach across the entire bitumen supply chain, from crude oil extraction through to refinery gate. Rather than focusing on absolute sectoral emissions reductions, which would be highly sensitive to production volume assumptions, the roadmap is structured around emission intensity per tonne of bitumen (kg CO_2 eq. per tonne bitumen).

The analysis reveals that the cradle-to-gate carbon intensity of bitumen produced in Europe can decline by 73 % between 1990 and 2050, from 823 kg CO_2 eq. per tonne in 1990 to 223 kg CO_2 eq. per tonne in 2050. While this represents significant progress toward European climate neutrality, the projected reductions do not yet achieve net-zero emissions or full alignment with Paris Agreement targets, underscoring the need of continued innovation, supportive policy frameworks, and collaborative action to close the remaining decarbonisation gap.

The roadmap identifies specific interventions for each stage of the supply chain, recognising that success requires coordinated action across multiple fronts rather than dependence on any single breakthrough technology. Figure 1 shows the relative contributions of each supply chain step for reducing emission intensity for one tonne bitumen produced in Europe between 2023 and 2050.

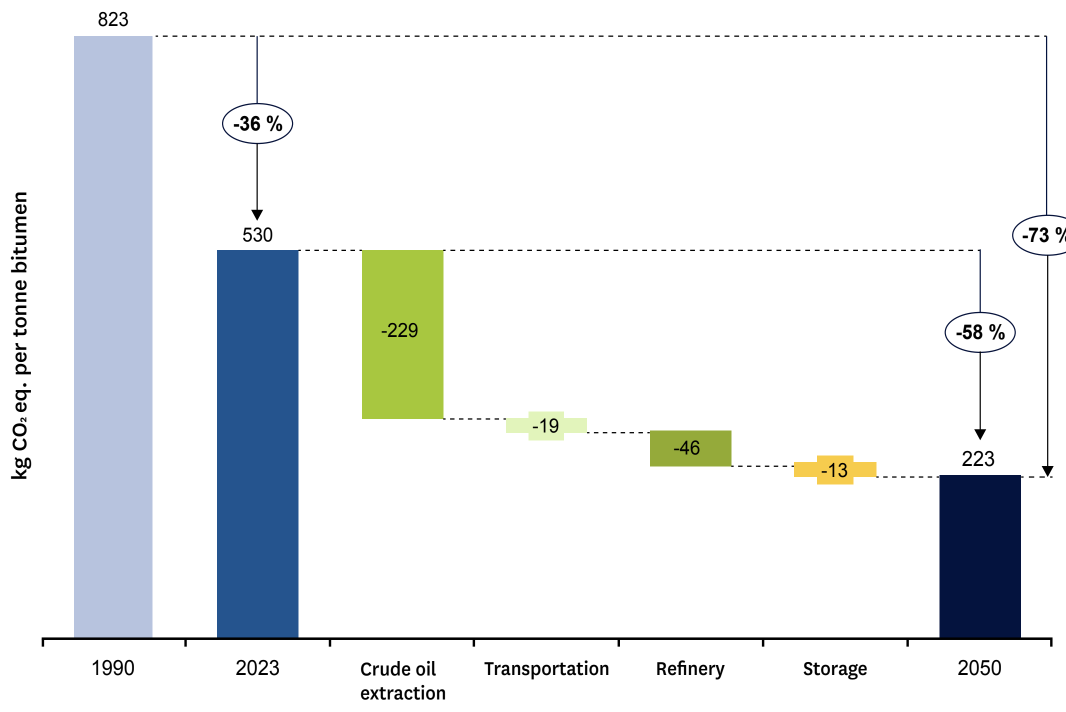

Figure 1. Emissions reductions by step in bitumen's cradle-to-gate supply chain towards 2050

Crude oil extraction can achieve a 75 % reduction in emission intensity from 1990 to 2050. The primary lever is electrification of auxiliary equipment such as pumps and compressors, which can reduce both carbon dioxide (CO_2) and methane (CH_4, i.e., avoiding "bleed") emissions. Implementation of vapour recovery units, gas utilisation technologies, blowdown capture systems, and replacement of gas-venting pumps and controllers with instrument air systems can capture otherwise vented emissions. Leak detection programmes, including the use of infrared cameras and monitoring systems, accelerate the identification and repair of fugitive leaks. Improved flaring practices contribute additional gains. Carbon capture and storage technologies provide a supplementary pathway for addressing residual CO_2 emissions. It is important to acknowledge that bitumen producers exercise limited operational control over crude oil extraction. Nonetheless, the industry can support these improvements through supplier engagement and collaboration with upstream operators.

Crude oil transportation can achieve a 79 % reduction in CO_2 emissions intensity by 2050. The dominant lever is the adoption of alternative fuels for ship propulsion, which drives most of the transportation emissions reduction potential. This includes switching from heavy fuel oil (HFO) to liquefied natural gas, as well as replacing fossil fuels with low-carbon fuels such as green hydrogen, methanol, and ammonia. The latter is contingent on the development of sufficient supply and supporting infrastructure. Hybrid propulsion systems for deep-sea tankers provide additional but more modest contributions. In addition, a minor reduction is foreseen related to electrification of pipeline operations, due to limited applicability (i.e., regions with established infrastructure) and limited relative contribution of pipelines to transport emissions. As mentioned above, European bitumen producers exercise limited operational control over transportation.

Refinery operations can achieve a 61 % reduction in CO_2 emission intensity by 2050, though decarbonisation pathways vary materially depending on refinery configuration, complexity, and local infrastructure conditions. The dominant lever is associated with general improvements of process efficiency, including optimisation of heat recovery systems, process integration, and operational improvements, which are tailored to each refinery's specific configuration. Other key levers focus on fuel substitution, through either electrification of furnaces or using low-carbon fuels. These are the main levers where bitumen producers have the most direct impact. Both are considered long-term initiatives that need increased maturity of both technology and markets. Some emission reductions could still be achieved by transitioning from HFO to natural gas. Carbon capture and storage technologies address residual emissions that cannot be eliminated through efficiency or fuel switching.

Bitumen storage can achieve a 51 % reduction in CO_2 emission intensity by 2050 through process efficiency measures (e.g., reduced storage temperature) and electrification of storage heating. Replacing fossil-fuel-fired heaters with electric systems powered by low-carbon electricity is the key decarbonisation lever within the bitumen storage stage where bitumen producers have direct control.

The roadmap is not prescriptive but represents a collective realistic but ambitious objective for the European bitumen industry, recognising that individual actors within the supply chain will have different starting points and opportunities depending on their current processes, technologies, and geographic location. Furthermore, many of the most significant emissions reductions occur at stages of the supply chain where bitumen producers exercise limited direct control. Achieving the full potential of this roadmap therefore requires collaboration across the entire supply chain, including engagement with crude oil producers, shipping companies, refinery operators, and regulatory authorities.

This collaborative approach reflects the reality that climate action in complex global supply chains cannot be achieved through unilateral action.

Regulatory implementation is the linchpin of this roadmap's success. Without clear, consistent, and supportive regulatory frameworks, the decarbonisation measures outlined herein will remain insufficient to achieve the projected reductions. Beyond this critical foundation, the successful implementation of this roadmap depends on several external enablers that are beyond the direct control of bitumen producers. The potential of several measures will be dependent on the availability of sufficient low-carbon supply (e.g., low-carbon electricity, biomass, low-carbon fuels) and supporting infrastructure (e.g., electricity grid, pipeline connections). In addition, the industrial investments will only be realistic if policy makers provide sufficient supporting measures to create demand for low-carbon products, incentivize and derisk adoption of low-carbon technologies.

Importantly, this roadmap focuses exclusively on cradle-to-gate emission intensity and does not assess the full life-cycle climate performance of bitumen-based infrastructure. While decarbonising bitumen production is a necessary foundation, it is not sufficient on its own to minimise the overall climate impact of roads and other applications. Meaningful assessment of climate performance ultimately requires a life-cycle- and performance-based perspective at infrastructure level, accounting for service life, maintenance strategies, material efficiency, and end-of-life practices.

1. Introduction and Methodology

This study develops a data-driven decarbonisation pathway for bitumen production in Europe by 2050. The analysis encompasses the cradle-to-gate supply chain of bitumen, including the stages from crude oil extraction through refinery gate storage, covering the period from 1990 to 2050.

The starting point of the analysis is the recent Life Cycle Assessment (LCA) 4.0 executed by Sphera [1], specifically the Global Warming Potential (GWP_{100} AR6) of 530 kg CO_2 eq. per tonne of bitumen (EN 12591). The LCA 4.0 quantifies cradle-to-gate emissions to produce bitumen, from raw material extraction through the point where the finished product leaves the refinery gate.

As presented in Figure 2, European bitumen producers exercise varying degrees of operational control across the supply chain. Crude oil extraction and crude oil transportation are highlighted in grey, reflecting the bitumen industry's limited direct operational control over these upstream activities. This constraint reflects the heterogeneous nature of market participants creating variability in the industry's capacity to influence emissions at these stages. The extent of influence (operationally or commercially) depends on the specific actor's position and role within the supply chain. In contrast, the refinery and storage stages (shown in blue) represent areas where the bitumen industry exercises full direct operational control. However, bitumen producers of Eurobitume can strive to work, each within their own sphere of responsibilities and influence, towards the achievement of the collective objective presented in this report.

Throughout the report, emissions are expressed using a cradle-to-gate intensity metric (kg CO_2 eq. per tonne of bitumen), aligned with the supply chain boundaries presented below. A detailed description of the emission drivers for each stage in the supply chain is available in Annex 6.1: "LCA 4.0: Detailed overview of cradle-to-gate emissions".

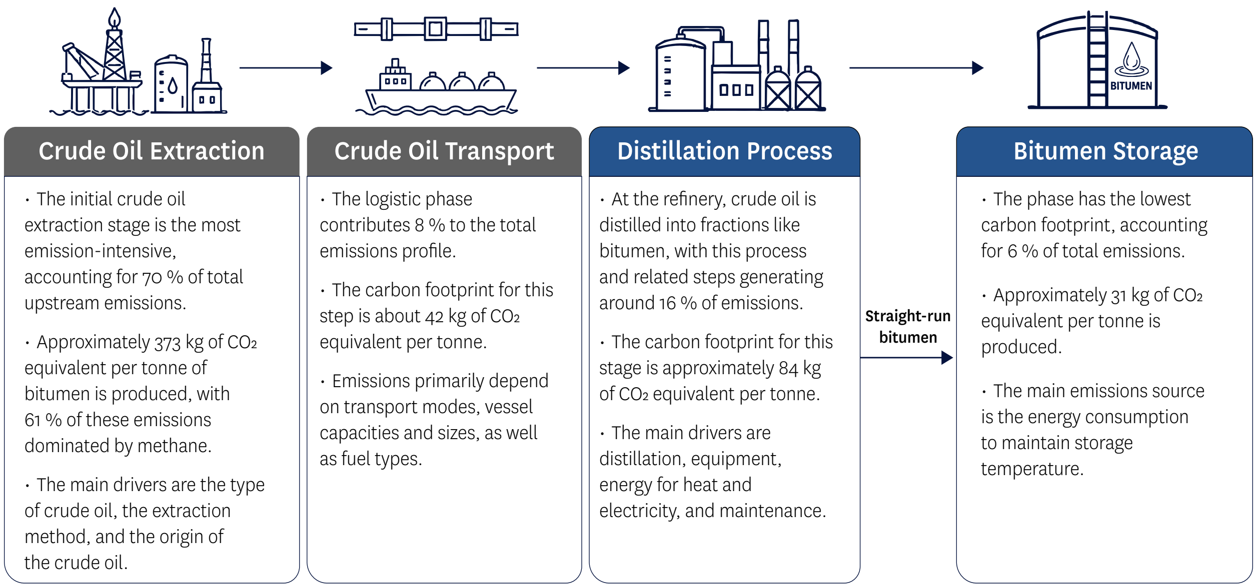

Figure 2. Overview of the cradle-to-gate supply chain of bitumen according to the LCA 4.0

To align with the European Union's climate objectives and other sector decarbonisation roadmaps, 1990 was designated as the reference baseline year. Given the absence of direct lifecycle assessment (LCA) data with consistent methodology for 1990, a retrospective analysis was undertaken to establish baseline conditions by back-casting from the 2023 footprint data. The year 2023 was selected as the reference point for the LCA 4.0 (published in 2025), as it aligns with the availability of crude oil basket data (2021-2023) and the corresponding crude oil database used in this assessment. This analysis was based on Deloitte research and interviews with industry professionals. The projections indicate that the emissions per tonne bitumen declined by 36 % over the 33-year period from 1990 to 2023. A detailed description of the retrospective analysis is available in Annex 6.2: "Evolution of emission intensity between 1990 and 2023".

The decarbonisation roadmap was developed based on extensive desktop research, stakeholder interviews, and several working sessions with Eurobitume's dedicated Taskforce. All these insights combined resulted in the quantification of identified decarbonisation levers across the bitumen supply chain. An overview of the decarbonisation levers is available in Annex 6.3: "Overview of decarbonisation levers per supply chain (incl. description)". The underlying assumptions for the calculation of the reduction potential for each of the levers is available in Annex 6.4: "Detailed overview of assumptions used to quantify the emission reduction potential".

2. The Supply Chain of Bitumen Produced in Europe

Bitumen is manufactured through the distillation of crude oil during petroleum refining. Bitumen possesses characteristics (e.g., adhesion, durability, and waterproofing properties) which make it an ideal construction and engineering material. In Europe, bitumen is predominantly used in the construction industry as a binder in asphalt for roads, runways, parking lots, bicycle path, and sidewalks. Bitumen is also used in the production of waterproofing membranes and other industrial applications.

2.1 Evolution of Cradle-to-Gate Bitumen Emission Intensity (1990-2023)

As established by the Eurobitume Life Cycle Assessment 4.0, 530 kg CO_2 eq. emission are associated to the production of one tonne bitumen. Emissions associated with crude oil extraction account for 70 % of the cradle-to-gate total, driven by methane originating from venting, flaring, and fugitive emissions during extraction operations, as well as by CO_2 from energy-intensive drilling, pumping, and associated infrastructure. Refining operations contribute the second largest share with 16 %, arising from energy-intensive conversion processes. Followed by transportation of crude oil with 8 %, primarily from fuel consumption in maritime transportation. Storage accounts for the smallest share with 6%, associated mostly with energy consumption.

Based on the retrospective analysis (Figure 3), emissions per tonne of bitumen declined by 36 % between 1990 and 2023, from 823 kg CO_2 eq. per tonne bitumen in 1990 to 530 kg CO_2 eq. in 2023. The decrease in emissions from crude oil extraction was primarily driven by reduced methane emissions and lower CO_2 intensity from extraction operations. Larger vessel sizes, enhanced ship design, and optimised operational speeds contributed to the reduction of crude oil transportation CO_2 emissions. The estimated reduction of CO_2 emissions for refining and storage operations was driven by process optimisation and heat recovery systems. A detailed description of the retrospective analysis is available in Annex 6.2: "Evolution of emission intensity between 1990 and 2023".

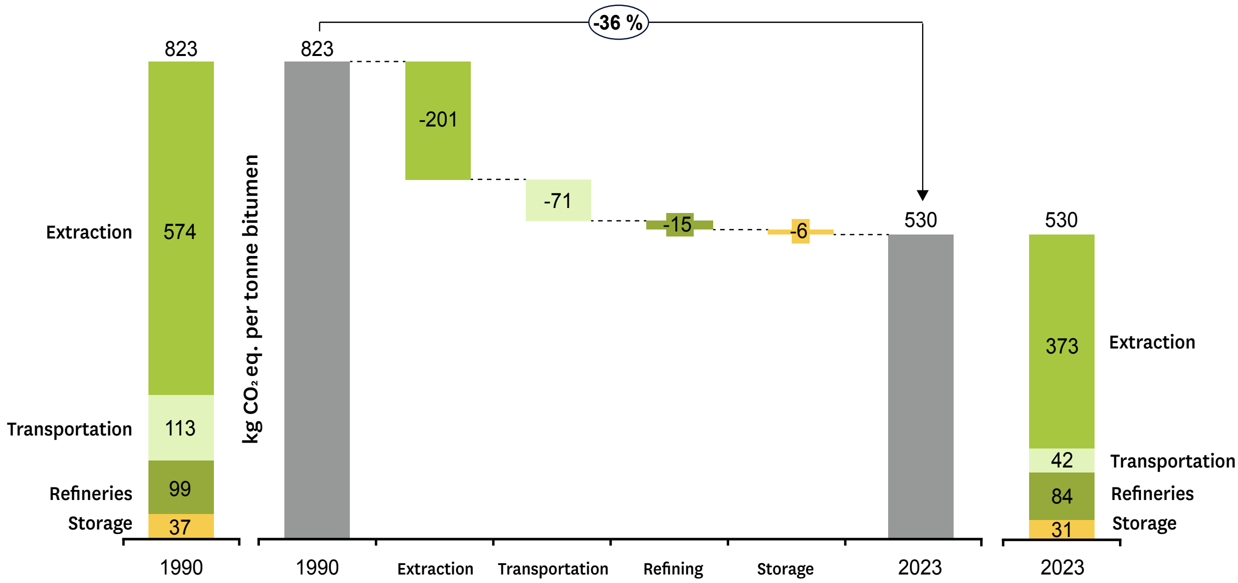

Figure 3. Evolution of cradle-to-gate emissions between 1990-2023 (kg CO_2 eq. per tonne bitumen)

2.2 Historical Trend and Evolution of European Bitumen Production

Production of bitumen in Europe has undergone significant structural transformation over the past three decades. From 1990 to 2023 [2], production output volumes declined by 31%, with the sector experiencing a production peak in 2006 before entering a sustained contraction phase. This decline reflects multiple concurrent factors, including the 2008 financial crisis which prompted rationalisation and facility closures in the European refining industry, and the impact of the COVID-19 pandemic and geopolitical disruptions between 2020 and 2023.

Looking ahead, bitumen production in Europe is commonly projected to continue to decline towards 2050, though the extent of this contraction remains uncertain. This decline will be shared by interconnected factors, including structural transformation of the refining sector, tightening legislative frameworks, and climate policy evolution. Simultaneously, bitumen demand is constrained by national infrastructure investment cycles.

Bitumen will remain strategically relevant to European infrastructure, as its irreplaceable properties make it essential for road construction, road maintenance, and roofing applications. To maintain strategic robustness across divergent production scenarios, this decarbonisation roadmap prioritises emission intensity per tonne of bitumen rather than absolute emissions targets. This approach is particularly critical given the risk that declining domestic production could drive increased reliance on imported bitumen. Imports from regions with less stringent environmental standards or less efficient production processes may carry significantly higher emission intensities, potentially offset domestic decarbonisation gains and undermine the roadmap's climate objectives.

3. 2050 Decarbonisation Roadmap for Bitumen

Implementation of identified decarbonisation levers is projected to reduce emissions per tonne bitumen by 2050 with 58 % from 2023-levels and with 73 % compared to 1990 baseline levels (Figure 4). This reduction represents an exploratory scenario for the European bitumen industry and demonstrates substantial potential for meaningful climate contribution. However, realising this ambition requires coordinated implementation of multiple levers across the entire supply chain and depends critically on factors beyond the industry's direct operational control.

The magnitude of achievable emissions reductions is constrained by inherent complexities in global supply chains. Uncertainty remains high because a significant proportion of upstream emissions, where direct operational control is limited, cannot be unilaterally addressed by individual producers. This structural limitation necessitates a broader engagement strategy. However, the projections presented in this roadmap are informed by the declared objectives and public pledges of upstream actors, supplemented by independent analysis of technological feasibility and market trends. While these commitments provide a credible foundation, their realisation depends on sustained policy support and continued investment in low-carbon infrastructure.

Limited direct operational control does not preclude meaningful influence. European bitumen producers can exercise commercial leverage through strategic supplier engagement, procurement standards, and transparent reporting mechanisms that cascade accountability through the supply chain. Regulatory frameworks establishing transparency expectations would reinforce these commercial incentives and create systemic pressure for upstream decarbonisation. Fundamentally, achieving industry-wide emissions reductions requires collaboration extending beyond individual actors. Individual actors in the supply chain will have different starting points and opportunities to adopt certain levers depending on their current processes, technologies, and geographic location. The roadmap below represents a realistic scenario selected as a target by the European bitumen industry, partly depending on critical external enablers. To illustrate, the reduction potential of electrification requires the availability of low-carbon electricity and an electricity grid capable to manage the increased demand. The adoption of hydrogen and other low-carbon alternative fuels will depend on its availability at competitive costs. These attention points are incorporated in the section below.

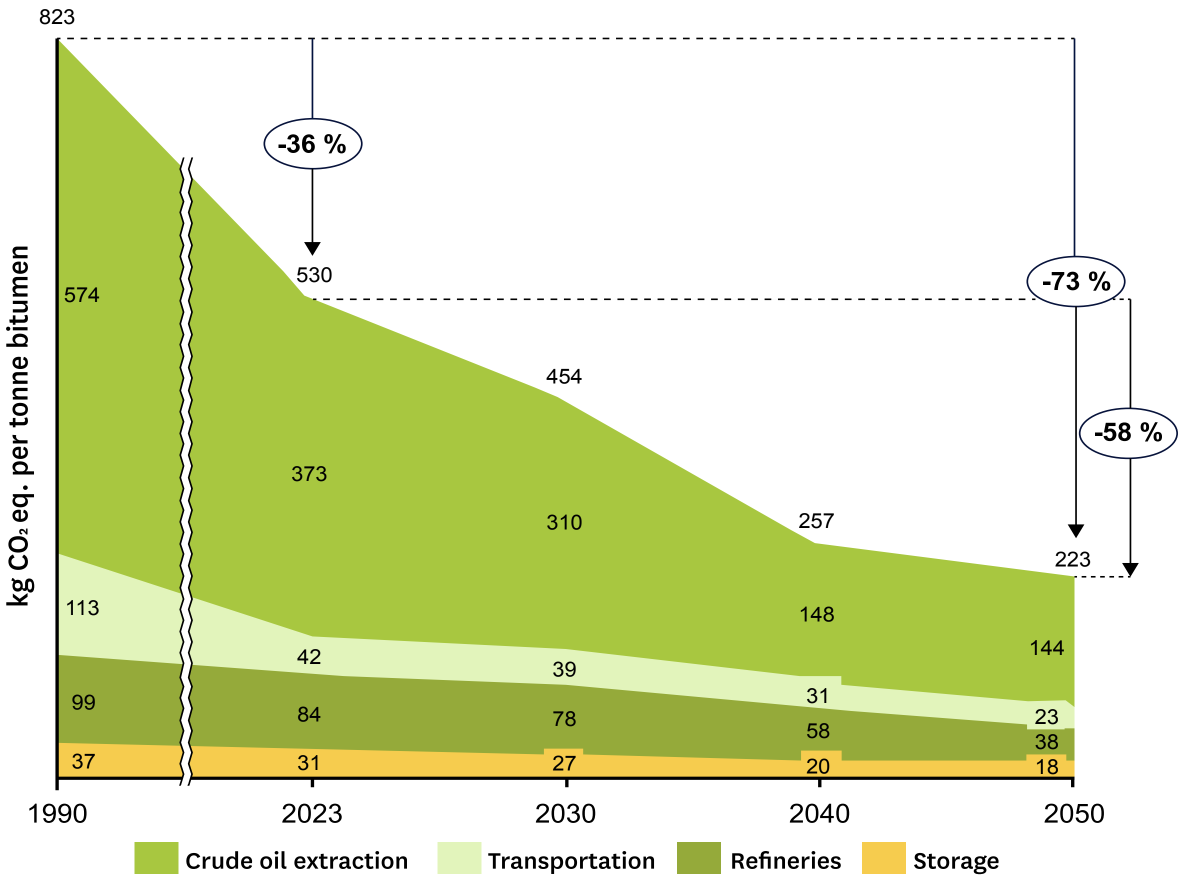

Figure 4. Decarbonisation roadmap of bitumen cradle-to-gate emissions intensity (1990-2050)

3.1 Reducing Emissions Associated With Crude Oil Extraction

The decarbonisation of crude oil extraction is essential to this roadmap, given its significant share of emissions per tonne bitumen. Industry pledges such as the Global Methane Pledge [3] and reporting standards including OGMP 2.0 [4] have advanced methane reduction efforts. The EU Methane Emissions Regulation (MER) [5], which entered into force in 2024, establishes a mandatory framework for measurement, reporting, and verification aligned with OGMP 2.0 Level 5 standards. Implementation challenges persist, including the absence of third-party verification protocols and pre-accredited verifiers. While concerns regarding supply availability have been raised [6],the high liquidity of the global oil market and EU refineries' operational flexibility to process diverse crude grades substantially mitigate supply shortfall risks [7].

European bitumen producers exercise limited operational control over crude oil extraction. Their ability to source compliant crude depends on upstream operators' successful implementation of MER's measurement and reporting requirements, making regulatory compliance across the supply chain critical to their operations.

The portfolio of levers for decarbonisation of crude oil extraction was developed using multiple sources. The methane abatement measures were based on the Methane Abatement model published by the International Energy Agency [8] and refined to the bitumen context with additional desktop research. Measures addressing carbon dioxide emissions, including electrification and CCS, were informed by additional IEA study [9] and relevant technical report [10], respectively.

The portfolio includes both mature, near-term measures, defined as technologies that are already widely available, proven, and can be implemented with existing infrastructure (such as technologies to improve flaring, use of equipment to minimise venting, and leak detection and repair programmes), as well as longer-term measures that depend on broader infrastructure transformation, technological maturity, and cost competitiveness (such as electrification and CCS). Implementation timelines vary accordingly, with most mature measures assumed by 2040 and transformational measures extending to 2050 (Table 1). The combined impact of all levers is estimated to reduce emissions associated with crude oil extraction by 75 % from 574 in 1990 to 144 kg CO_2 eq. per tonne bitumen in 2050 (Figure 5).

Electrification of auxiliary equipment (pumps, compressors) serves as the primary decarbonisation lever, assumed to be implemented where feasible by 2040, starting from 2030. By replacing gas-driven and diesel-powered auxiliary equipment with electric motors (using low-carbon electricity) could reduce carbon dioxide emissions by 18 % and methane emissions by 5 % by 2040. The latter is achieved by avoiding gas to “bleed” during its use.

Table 1. Decarbonisation levers for crude oil extraction, their implementation period, and their emissions’ reduction potential

Lever	Start	End	Reduction
Electrification of auxiliary equipment	2030	2040	-23 %
Minimise venting	2023	2040	-22 %
Leak detection and repair programmes	2023	2040	-11 %
Improve flaring	2023	2040	-3 %
Carbon Capture and Storage	2023	2040	-2 %

Methane management systems can significantly reduce methane emissions from venting through multiple technologies. Vapor recovery units (VRUs), which are small compressors that capture vented emissions accumulating in equipment (e.g., oil storage tanks), could reduce emissions by 16 % by 2040. Additionally, gas utilisation technologies (microturbines, mini-CNG, mini-GTL, mini-LNG), blowdown capture systems that recover gas for onsite use or sales, and replacement of gas-venting pumps and controllers with instrument air systems, could minimise venting practices and further reduce emissions by 6 % by 2040. Altogether, these technologies could achieve an overall reduction in vented emissions of 22 % by 2040.

Leak detection and repair (LDAR) programmes locate and repair fugitive leaks using techniques such as infrared cameras to make methane leaks visible. LDAR programmes vary in frequency (annually to quarterly) and can incorporate continuous monitoring systems based on remote or facility-based sensors. By 2040, LDAR programmes are expected to reduce emissions by 11 %.

Although not preferred, flaring is still considerably better than venting from a methane perspective, though this advantage depends on effective combustion efficiency and does not eliminate the climate impact of CO_2 emissions. By 2030, CH_4 emissions can be reduced by 3 % through improved combustion efficiency (e.g., automated controls and electronic ignition) and enhanced capture of vented gases (e.g., from tank and dehydrators).

Furthermore, Carbon Capture and Storage (CCS) technologies, which capture CO_2 emissions from upstream operations for either enhanced oil recovery or permanent underground storage, could reduce emissions by 2 % between 2030 and 2050.

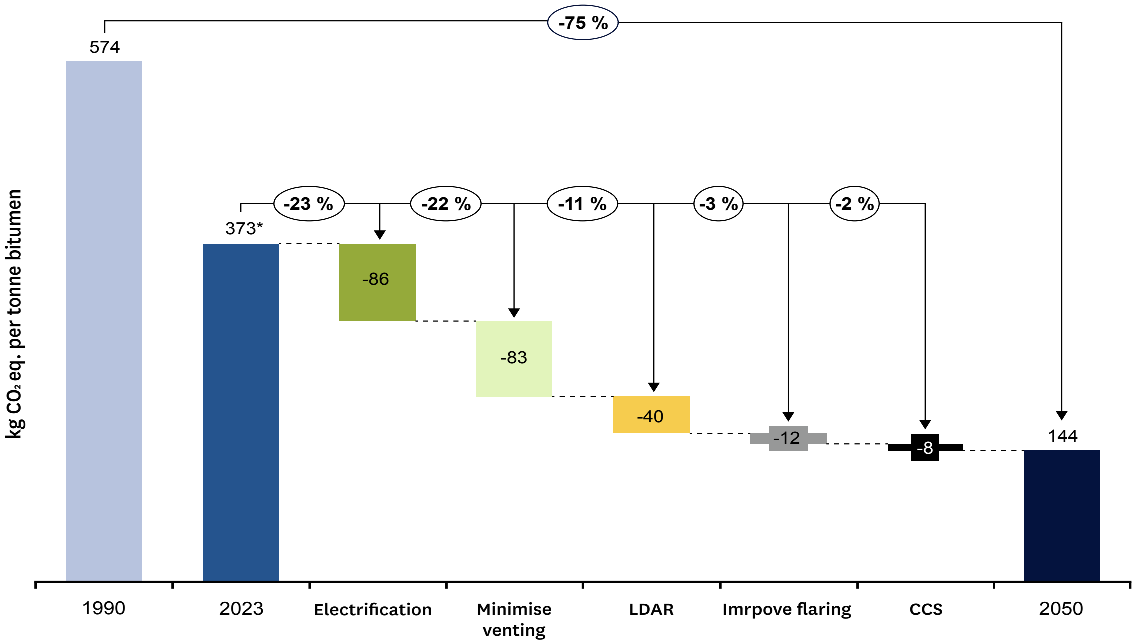

Figure 5. Decarbonisation levers in crude oil extraction and their impact on emission intensity between 1990-2050

**For 2023, 61 % of the total emissions during crude oil extraction are attributed to CH_4 and 39 % to CO_2, based on Eurobitume LCA 4.0.*

3.2 Reducing Emissions Associated With Crude Oil Transportation

Transportation of crude oil relies primarily on deep sea maritime transport (i.e., oil tankers) and pipelines. Besides transport mode, sourcing location (i.e., distance) is a key driver of transport emissions. This roadmap exclusively estimates the impact of emission intensity reductions, not potential changes in sourcing location. The crude oil basket composition and sourcing patterns depend on factors beyond the bitumen industry's control, including geopolitical developments, global energy markets, and refinery feedstock requirements, making reliable prediction infeasible.

Important international initiatives to reduce emissions from international shipping include the pledge by the International Maritime Organisation (IMO) to reduce Greenhouse gas (GHG) emissions in 2023 and the adoption of low-carbon fuels and clean energy technologies at European level, promoted through maximum limits for yearly average GHG intensity under the FuelEU maritime regulation [11]. Following the logic of both initiatives, this roadmap proposes several options to decarbonise leaving flexibility to individual operators to choose the most effective.

The portfolio of decarbonisation levers was derived from numerous studies and roadmaps on the maritime transport decarbonisation and refined to the context of bitumen (Table 2). The combined impact of all levers is estimated to reduce emissions associated with crude oil transportation by 79 %, from 113 kg CO_2 eq. per tonne in 1990 to 23 kg CO_2 eq. per tonne bitumen in 2050 (Figure 6).

Table 2. Decarbonisation levers during crude oil transportation, their implementation period, and their emissions' reduction potential

Lever	Start	End	Reduction
HFO/LNG to low-carbon fuels for tankers	2030	2040	-33 %
HFO to LNG for tankers	2023	2030	-6 %
Deep-sea shipping hybrid systems	2030	2050	-2 %
Pipeline electrification	2030	2040	-2 %
Optimisation of operations	2023	2050	-1 %

The adoption of alternative fuels for ship propulsion is the dominant decarbonisation lever, with two complementary pathways offering different timelines and reduction potentials. By 2030, the uptake of LNG-powered ships, replacing HFOs, could reduce emissions by 6 % from 2023, accounting for the adverse effects of potential methane slip. The adoption of low-carbon fuels (e.g., green hydrogen, methanol, and ammonia) would occur between 2030 and 2050, considering the efforts needed to ensure sufficient supply and supporting infrastructure. Of course, this does not exclude the possibility of early movers or pilots. By 2050, low-carbon fuels could reduce emissions associated with transportation by 33 % compared to 2030.

Electrification in the context of crude oil maritime transportation is limited to the use of hybrid propulsion systems and replacement of onboard power generation. This measure could reduce emissions intensity by 2 % between 2030 and 2050. The cost of batteries per unit of energy and their accommodation on ships make fully electric crude oil tankers implausible.

Likewise, electrification in pipeline operations could reduce emissions by 2 % between 2030 and 2040 by replacing diesel-powered generators with electric motors, provided that low-carbon electricity is available.

As recognition of the industry's continuous efforts to optimise operations, the roadmap considers a modest 1 % reduction by 2050 associated with speed reductions, vessel utilisation and size, as well as alternative routes.

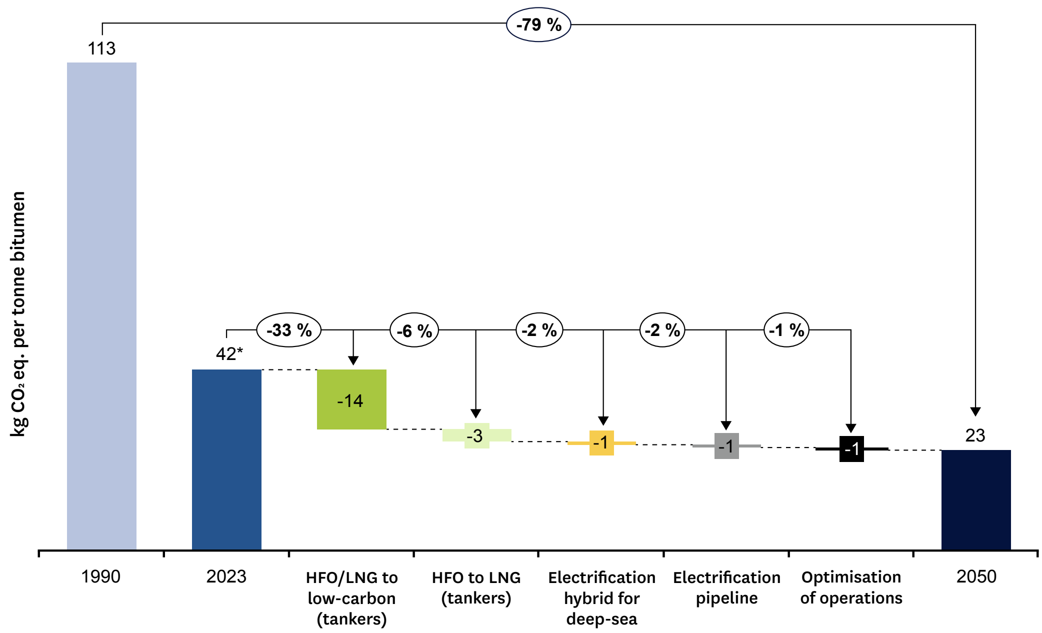

Figure 6. Decarbonisation levers in crude oil transportation and their impact on emission intensity between 1990-2050

**For 2023, 92 % of the total transport emissions are attributed to oil tankers and 8 % to pipelines, both estimated using relative distance calculations from Eurobitume LCA 4.0 and emission factors.*

3.3 Reducing Emissions Associated with Refinery Operations

Refining crude oil into bitumen involves atmospheric and vacuum distillation, where bitumen is only one of the many products produced. As an energy-intensive industrial sector, oil refineries are part of the EU Emissions Trading System (EU-ETS) [12] that seeks to reduce industrial GHG emissions by creating a carbon price via a cap-and-trade system. As EU-ETS tightens, European refineries are adapting by increasing energy efficiency, adopting alternative fuels.

The portfolio of decarbonisation levers was derived from numerous studies and roadmaps on the decarbonisation of refineries in Europe and refined to the specific context of bitumen (Table 3). Combined these measures are estimated to reduce the emission intensity of this stage by 61 % from 99 kg CO_2 eq. per tonne of bitumen in 1990 to 38 kg CO_2 eq. per tonne in 2050 (Figure 7).

Table 3. Decarbonisation levers at refinery level, their implementation period, and their emissions' reduction potential

Lever	Start	End	Reduction
Process efficiency	2023	2050	-21 %
Electrification of furnaces	2030	2050	-15 %
Low-carbon fuels for heating	2030	2050	-14 %
Carbon Capture and Storage	2030	2050	-3 %
Fuel oil to natural (or refinery) gas-fired furnace	2023	2050	-2 %

The roadmap assumes improvements related to process efficiency to reduce emissions by 21 % between 2023 and 2050. Process efficiency in refineries encompasses optimisation of process control and process integration in major energy-consuming processes (e.g., distillation), often targeted to reduce overall energy consumption. Although process efficiency measures are typically considered cost-effective, significant efforts are required in terms of operational change and important financial investments.

Electrification, in terms of replacing fossil-fuel-fired heaters in high-temperature refinery processes with electric heaters powered by low-carbon electricity, could reduce emissions by 15 % between 2030 and 2050. Beyond availability of sufficient low-carbon electricity, the potential for electrification is typically dependent on the refinery's internal energy mix, fuel gas and steam balance, process configuration, and electricity supply and distribution.

As an intermediary measure, the roadmap considers phasing out HFO use in favour of natural gas (or refinery gas), reducing emissions by 2 % between 2023 and 2050. Low-carbon fuels (e.g., green hydrogen) serve as a long-term alternative pathway for where electrification is not suitable, reducing emissions by 14 % between 2030 and 2050. In this context, low-carbon fuels serve as alternative fuels. Important, the uptake of low-carbon fuels will be dependent on supply availability and related investment and operational costs.

CCS technologies provide end-of-pipe emissions reduction through solvent-based systems that capture CO_2 from refinery emissions sources and either store it permanently underground or utilise it for other applications. They address residual emissions that cannot be eliminated through increased efficiency or phasing out fossil fuels. CCS is estimated to reduce emissions by 3 % towards 2050.

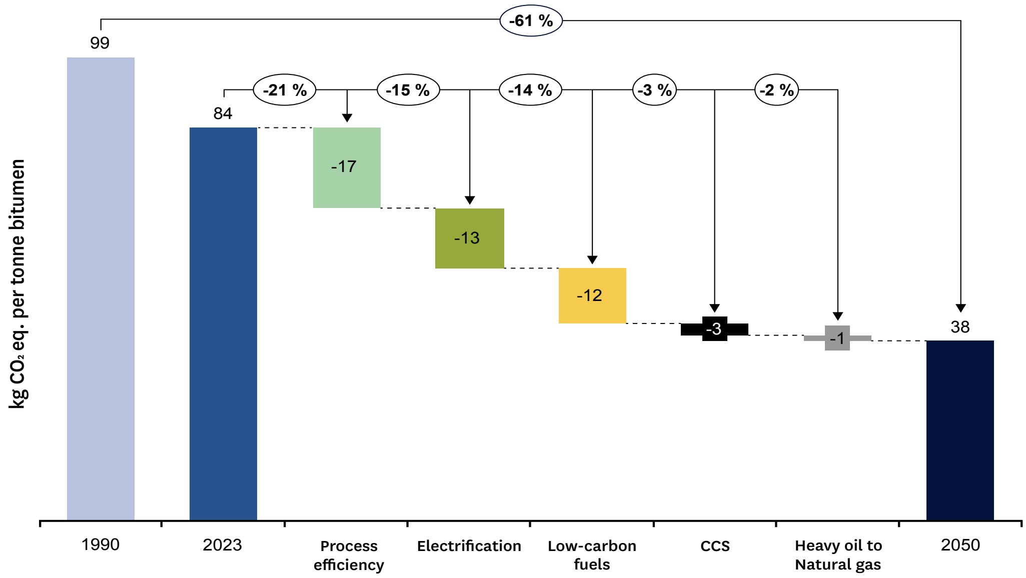

Figure 7. Decarbonisation levers in refinery process and their impact on emission intensity between 1990 - 2050

3.4 Reducing Emissions Associated with Bitumen Storage

The measures related to bitumen storage reflect targeted interventions related to efficiency improvements and electrification (Table 4). Combined, these measures are estimated to reduce the emission intensity by 51 %, from 37 kg CO_2 eq. per tonne of bitumen in 1990 to 18 kg CO_2 eq. per tonne in 2050 (Figure 8).

Table 4. Decarbonisation levers in bitumen storage, their implementation period, and their emissions' reduction potential

Lever	Start	End	Reduction
Process efficiency	2023	2050	-21 %
Electrification of storage heating	2023	2040	-21 %

Process efficiency in storage covers a range of interventions focused on reducing energy consumption, for example, through lower temperatures, reducing the thermal energy required to maintain bitumen at appropriate storage temperatures (e.g., insulation, temperature management and fine-tuning heating systems) [13]. Process efficiency is considered a continuous measure resulting in a cumulative emission reduction of 21 % in 2050.

Electrification of storage heating provides additional emission reductions by replacing fossil-fuel-fired heaters with electric heaters powered by renewable energy. This directly eliminates carbon dioxide emissions from fuel combustion in storage heating operations, reducing emissions by 21 % by 2040.

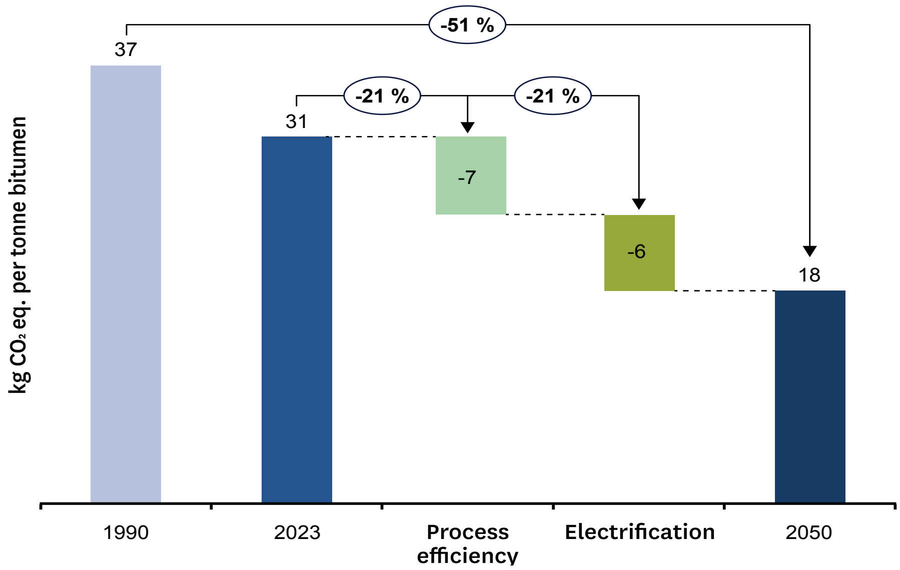

Figure 8. Decarbonisation levers in bitumen storage and their impact on emission intensity between 1990-2050

3.5 Exploring the Potential of Biomaterials in Bitumen Binders

Beyond cradle-to-gate improvements, the incorporation of bio-based materials blended with bituminous binders can further reduce emissions [14]. However, the net climate impact of biomaterials in bitumen binders depends significantly on production methods and accounting approaches. The net climate impact ranges from negative values, indicating net carbon sequestration, to positive values, depending on the specific production pathway and feedstock source.

The climate benefits of biomaterials in bitumen derive from their biogenic carbon through partial substitution. Current accounting frameworks (e.g., EN 15804) restrict the possibility to account for biogenic emissions in products such as bitumen. This underscores an important policy recommendation: aligned and amended accounting standards would enable more accurate quantification of climate benefits, facilitate market development for bio-based materials, and ensure that climate policies appropriately credit the carbon sequestration potential of renewable feedstocks. Without such clarity, the full potential of biomaterials to contribute to emissions reductions in bitumen-based applications may remain unrealised.

While accounting frameworks are essential for recognising climate benefits, equally important is verifying that bio-based binders deliver genuine sustainability gains across multiple dimensions. The end-product must not negatively affect the usable life, re-useability, or occupational health of asphalt workers. Therefore, it is essential to consider the factors of durability, circularity, and HSE impacts when adding biomaterials. Only through comprehensive verification of these factors can the full sustainability potential of bio-based materials be secured, ensuring that climate benefits are not offset by performance degradation or occupational health risks.

This complementary pathway works in conjunction with cradle-to-gate decarbonisation to achieve deeper overall emission reductions in bitumen-based applications.

4. Key Success Factors for Roadmap Implementation

Successful implementation of this roadmap requires coordinated action across five critical enabler categories spanning the entire supply chain.

The policy and regulatory framework must provide clarity and consistency to facilitate adoption of decarbonisation technologies. Effective implementation will need to go beyond enforcement, ensuring a level playing field and incentivising investment in decarbonisation technologies. Key policy instruments include EU Methane Regulation, FuelEU Maritime, EU ETS, CCS directive [15], and demand-side procurement. Additional regulatory clarity is needed through harmonised standards, supportive measures for emerging technologies and demand creation mechanisms for low-carbon products. These measures must be complemented by targeted financial incentives such as investment tax credits, accelerated depreciation, and support for early-mover projects to offset the capital intensity of decarbonisation investments and reduce technological risk.

Supplier engagement and collaboration are essential given the European bitumen industry's limited operational control over crude oil extraction and transportation. Long-term partnerships between European bitumen producers and upstream operators facilitate technology transfer and knowledge sharing on decarbonisation best practices. Joint investment mechanisms or risk-sharing arrangements can support capital-intensive deployment of decarbonisation technologies, particularly where individual operators face financing constraints. Multi-stakeholder platforms enable coordinated decarbonisation efforts and ensure incentive alignment across the supply chain.

Reliable access to low-carbon electricity and low-carbon fuel at competitive costs is critical. This also means the infrastructure to supply low-carbon energy will need to be adapted and scaled to the needs of the industry. Similarly, expansion of CCS infrastructure and permanent storage capacity will be necessary to support CCS deployment. In short, there is need for rapid deployment of supporting infrastructure for electricity, low-carbon fuels and CCS to unlock key investment decisions.

Investment and financing mechanisms must mobilise both public and private capital to support the transition. Mobilisation of public and private capital through green bonds, concessional financing, and risk-sharing mechanisms is necessary to support the transition. Support for early movers and first-of-a-kind projects reduces technological risk and accelerates cost reductions through learning-by-doing and economies of scale.

Research, development, and innovation must be sustained to enable further decarbonisation. Sustained investment in research and development develops next-generation technologies for enhanced decarbonisation beyond 2050. Support for pilot projects and demonstration facilities validates emerging technologies at commercial scale. Knowledge sharing and technology transfer mechanisms ensure rapid dissemination of innovations across the industry, preventing duplication of effort and accelerating progress.

5. Conclusion

This decarbonisation roadmap demonstrates that the European bitumen industry can achieve substantial emissions reductions through systematic deployment of proven and emerging technologies across the entire supply chain. The analysis projects cradle-to-gate emission intensity could decline by 73 % between 1990 and 2050, from 823 kg CO_2 eq. per tonne to 223 kg CO_2 eq. per tonne bitumen. These reductions position the bitumen industry as a significant contributor to the European climate neutrality objective by 2050, as well as supporting decarbonisation efforts in downstream sectors.

This roadmap does not yet demonstrate reductions fully aligned with the trajectory of the Paris Agreement. Substantial decarbonisation opportunities remain in the use and end-of-life phases of bitumen products. The industry intends to extend this roadmap into the downstream supply chain to capture these additional emission reductions. This expanded perspective reflects the reality that achieving climate neutrality requires coordinated action across multiple sectors and throughout product lifecycles, extending further beyond the bitumen industry's direct operational scope.

The roadmap represents a collective realistic but ambitious objective for the European bitumen industry, recognising that individual actors face different starting points, technological opportunities, and geographic constraints. Implementation will be neither uniform nor simultaneous. Some companies will lead; others will follow. Some regions will transition faster than others. This heterogeneity reflects a market reality and an acknowledgement of the diverse circumstances facing industry participants. Success therefore demands unprecedented collaboration across the entire supply chain, from upstream oil producers through to downstream users.

Across all identified actions, three key enablers determine the success of this roadmap. First, policy support through regulatory frameworks must create clear, long-term incentives for decarbonisation while ensuring competitive parity across suppliers and geographies. Second, infrastructure to supply low-carbon electricity and low-carbon alternative fuels, as well as CO_2 storage capacity at competitive costs is needed. Without them, even the most committed industry actors will face insurmountable barriers to decarbonisation. Third, collaborative action across the supply chain is necessary because no single company, sector, or even nation can decarbonise a global supply chain alone. Success requires sustained dialogue and coordinated investment across crude oil producers, shipping companies, refineries, bitumen producers, asphalt producers, end customers, and regulatory authorities.

The European bitumen industry stands ready to play its part in the continent's climate transition. This roadmap provides a data-driven pathway grounded in extensive stakeholder engagement and rigorous analysis. The challenge now is to translate ambition into action through policy support, infrastructure investment, and collaborative commitment to a decarbonised future.

6. Annexes

6.1 LCA 4.0: Detailed Overview of Cradle-to-Gate Emissions

The decarbonisation roadmap is developed using the Global Warming Potential (GWP_{100} AR6) for bitumen (EN 12591), from the Eurobitume Life Cycle Assessment 4.0. The cradle-to-gate emissions are estimated as 530 kg CO_2 eq. per tonne of bitumen, covering raw material extraction through the point where the finished product leaves the refinery gate.

The GHG composition of bitumen production reveals distinct emission profiles across the cradle-to-gate supply chain, with methane (CH_4) and carbon dioxide (CO_2) representing 46 % and 54 % of total GWP_{100}, respectively. The concentration of CH_4 and CO_2 emissions during crude oil extraction, combined with CO_2 emissions distributed across transportation, refining, and storage operations, necessitates a multi-faceted approach with targeted actions at each stage to achieve meaningful emission reductions.

Crude oil extraction represents 70 % of total cradle-to-gate emissions in bitumen's lifecycle, encompassing both CH_4 and CO_2. CH_4 contributions originate from venting, flaring, and fugitive emissions during crude oil extraction, while CO_2 emissions arise from energy-intensive extraction operations including drilling, pumping, and associated infrastructure. Approximately, 61 % of the total emissions during crude oil extraction are attributed to CH_4 and 39 % to CO_2.

The transportation phase represents 8 % of the total cradle-to-gate emissions, with most primarily associated with fuel consumption in the movement of crude oil. Approximately 92 % of the total transport emissions are attributed to oil tankers and 8 % to pipelines, both estimated using relative distance calculations and emission factors.

Refining operations represent 16 % of cradle-to-gate emissions, arising from energy-intensive processes required to convert crude oil into bitumen and other refined products.

Storage represents 6 % of the total emissions across the cradle-to-gate supply chain, with CO_2 emissions primarily driven by energy requirements for maintaining bitumen at the required temperature.

6.2 Evolution of Emissions Intensity Between 1990 and 2023

To align with the European Union's climate objectives and other sector decarbonisation roadmaps, 1990 was designated as the reference baseline year. Given the absence of direct lifecycle assessment (LCA) data with consistent methodology for 1990, a retrospective analysis was undertaken to establish baseline conditions by back-casting from 2023 footprint data based on Deloitte research and interviews with industry professionals.

The results suggest the emissions per tonne bitumen declined by 36 % over the 33-year period from 1990 to 2023. This estimated decrease is consistent with technological advancements, operational improvements, and enhanced energy efficiency across the entire bitumen supply chain. Each supply chain stage has experienced distinct technological and operational improvements that have contributed to the aggregate emission reduction.

Crude oil extraction

Crude oil extraction, the largest contributor to bitumen's lifecycle emissions, is estimated to have achieved an assumed 35 % reduction between 1990 and 2023, declining from an assumed 574 to 373 kg CO_2 eq. per tonne bitumen. This improvement stems primarily from two key factors: reduced methane emissions and lower CO_2 intensity from extraction operations.

Methane emissions have decreased significantly. Globally, methane emissions were estimated at approximately 83 million tonnes in 1990 and declined to approximately 70 million tonnes in 2023 [16], representing a 1,2 times reduction. When measured per unit of oil and gas global production [17], methane intensity fell from 492 kg CO_2 eq. per oil and gas tonne in 1990 to 253 kg CO_2 eq. per oil and gas tonne in 2023, representing approximately a two times reduction. However, to avoid overestimation of emission reductions, a conservative estimation was applied, namely 1,5 times higher emissions in 1990 compared to 2023, demonstrating substantial improvements in methane management across upstream operations.

CO_2 intensity from crude oil extraction has also improved significantly. Energy-related CO_2 emissions decreased by approximately 1,6 times, falling from 3,7 billion tonnes in 1990 to 2,4 billion tonnes in 2023 [18]. This reduction reflects enhanced energy efficiency and lower-carbon practices during crude oil extraction and processing. With extraction still accounting for the largest share of total emissions, methane management and energy optimisation remain significant factors in the bitumen supply chain's emission profile.

Crude oil transportation

Crude oil transport emissions are estimated to have declined by an assumed 63 % between 1990 and 2023, dropping from 113 to 42 kg CO_2 eq. per tonne of bitumen, with 1990 levels estimated to be approximately 2,7 times higher. The Energy Efficiency Operational Indicator (EEOI) improved dramatically from 13,5 g CO_2 eq. per tonne-kilometre [19] to 5 g CO_2 eq. per tonne-kilometre [20], reflecting larger vessel sizes, enhanced ship design, and optimised operational speeds. This transformation demonstrates that supply chain logistics can be fundamentally reshaped through efficiency gains, yet the sector's continued reliance on maritime transport means that further decarbonisation, through alternative fuels and model shifts, remains essential for achieving deeper emissions reductions in bitumen's lifecycle.

Refining and Storage of bitumen

Refinery emissions are estimated to have decreased from an assumed 99 to 84 kg CO_2 eq. per tonne of bitumen, while storage emissions fell from an estimated 37 to 31 kg CO_2 eq. per tonne. To estimate the evolution in emissions linked to distillation and storage, research indicates that between 1992 and 2010, EU refineries increased their energy efficiency by approximately 10 % [21]. From 2010 to 2023, EU refineries achieved an additional estimated 8 % reduction [22] in CO_2 emissions (adjusted for EU refined oil production). These improvements are associated with process optimisation, heat recovery systems, advanced refining technologies, energy-saving initiatives, better heat integration, and more efficient equipment. For the purposes of this analysis, emissions from distillation and storage are assumed to be 1,2 times higher in 1990 compared to 2023.

6.3 Overview of Decarbonisation Levers per Supply Chain (Incl. Description)

Bitumen Supply Chain Stage	Short Title / Lever Name	Technology
Crude Oil Extraction	Leak Detection and Repair LDAR	A process that uses infrared cameras and monitoring systems to identify and repair fugitive methane leaks across the oil and gas supply chain.
	Minimise Venting	Methane management systems, including compressors such as vapor recovery units (VRUs), capture and utilize associated gas, recover blowdown gases, and replace gas-venting equipment with air-based alternatives to minimize venting and uncontrolled releases.
	Electrification of Auxiliary Equipment	Electrification replaces gas-driven and diesel-powered auxiliary equipment with electric motors powered by grid or renewable electricity, reducing emissions from drilling, pumping, and compression operations.
	Carbon Capture and Storage - CCS	Capture carbon dioxide emissions from upstream oil and gas operations and either utilize the CO_2 for enhanced oil recovery or permanently store it underground, reducing direct emissions from crude oil extraction facilities.
	Improve Flaring	Automated controls and electronic ignition ensure complete combustion at flares. Routing equipment vents to flares and deploying portable flares for non-routine activities (well workovers, completions) prevents direct atmospheric release.
Crude Oil Transportation	Fuel Switching (HFO to LNG)	Replacing Heavy Fuel Oil with Liquified Natural Gas reduces carbon dioxide emissions due to LNG's lower carbon intensity.
	Fuel Switching (HFO/LNG to Low-Carbon Fuels)	Replacing HFO and LNG with low-carbon fuels reduces carbon dioxide emissions due to their lower carbon intensity.
	Electrification (Tankers)	Hybrid propulsion systems combine conventional engines with electric power to reduce emissions from deep-sea crude oil tankers, improving fuel efficiency and lowering overall operational emissions compared to conventional propulsion alone.
	Electrification (Pipeline)	Electrifying pipeline operations by replacing diesel generators with grid electricity reduced emissions.
	Optimisation of Operations	Reduces fuel consumption/fuel savings, lowering emissions during combustion.

Bitumen Supply Chain Stage	Short Title / Lever Name	Technology
Refineries	Electrification	Replacing fossil-fuel-fired heaters in high-temperature refinery processes such as distillation and cracking with electric heaters powered by renewable electricity.
	Fuel Replacement (HFO to Natural Gas)	Natural gas has lower carbon intensity per unit of energy produced compared to heavy fuel oil.
	Process Efficiency	Optimization of process control and process integration in major energy-consuming processes such as crude distillation.
	Low-Carbon Fuels	Optimization of process control and process integration in major energy-consuming processes such as crude distillation.
	Carbon Capture and Storage	Solvent-based systems capture CO_2 from refinery emission sources and store or utilize the captured carbon.
Storage	Electrification	Replacing fossil-fuel-fired heaters with electric heaters powered by renewable electricity.
	Process Efficiency	Optimisation aimed at reducing the thermal energy required to maintain bitumen at appropriate storage temperatures.

Colours in the first column indicate the level of operational control. Grey shading denotes upstream activities (crude oil extraction and transportation) where the bitumen industry has limited direct control, while light blue highlights refinery and storage stages where the industry exercises full operational control.

6.4 Detailed Overview of Assumptions Used to Quantify the Emission Reduction Potential

The reduction potential for each identified decarbonisation lever was calculated using a structured approach that combines baseline emissions quantification, technology-specific emission intensity improvements, and market adoption scenarios. This methodology ensures consistency across all levers and enables transparent comparison of their relative contributions to overall emissions reductions. The results from the Eurobitume Life Cycle Assessment 4.0 are the starting point of calculations for each specific supply chain stage and associated emission sources.

The reduction potential calculation follows a three-step multiplicative process. First, the emission intensity improvement of each lever is determined by comparing the emission intensity of the incumbent technology or practice against the emission intensity of the proposed decarbonisation solution. The improvement is expressed as a percentage reduction in emission intensity, reflecting the relative performance advantage of the decarbonisation technology. Second, the proportion of supply chain emissions covered by each lever is identified, as not all levers address all emission sources associated with the specific supply chain stage. The emissions covered by a lever are expressed as a percentage of total cradle-to-gate emissions, ensuring that the calculation reflects the actual scope of each intervention. Third, a realistic adoption rate is specified for each lever, representing the proportion of the relevant supply chain activity that transitions to the decarbonisation solution by 2050. The adoption rate reflects market dynamics, technological maturity, infrastructure availability, and implementation timelines. The three parameters are multiplied together to yield the estimated reduction potential for each lever.

Individual lever reduction potentials are aggregated to generate the overall roadmap reduction target. This approach enables transparent assessment of the cumulative impact of decarbonisation measures across the entire supply chain. Reduction potential is associated with specific implementation periods reflecting the time required for technology maturation, infrastructure development, and market deployment. Most decarbonisation levers are assigned implementation periods extending to 2050, recognising that substantial infrastructure investment and technological scaling are required. Levers with longer implementation periods are classified as long-term measures, reflecting their dependence on developing capacity and supporting infrastructure.

All assumptions underlying the reduction potential calculations for individual levers are documented in the technical annexes to this roadmap. The methodology acknowledges several inherent limitations. First, adoption rates are projections based on current understanding of market dynamics; actual adoption may differ significantly based on unforeseen technological breakthroughs, policy changes, or market developments.

Second, the methodology assumes that individual lever reduction potentials are additive and does not completely capture potential synergistic or antagonistic effects.

This methodology is designed to ensure transparency and enable reproducibility of results. All baseline data, technology performance parameters, and adoption rate assumptions are documented in the technical annexes. This documentation enables independent verification of calculations and facilitates scenario analysis under alternative assumptions.

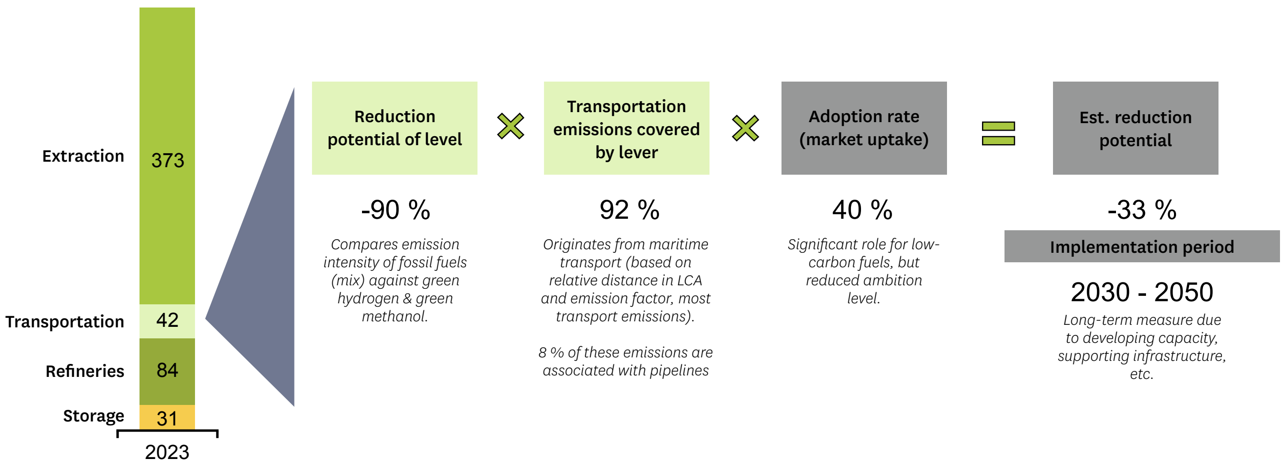

Figure 9. Decarbonisation levers assessment framework (example of a decarbonisation lever in crude oil transportation)

Crude Oil Extraction

Decarbonisation lever	Technical Reduction Potential	Justification Sources for Technical Reduction Potential	% Supply Chain Step Emissions Covered by Lever*	Uptake of Lever	Uptake Justification	Reduction Applied to Value Chain Step
Use equipment designed to minimize leaks and conduct regular leak detection and repair (LDAR)	-18 %	Derived from IEA Methane Tracker "Annual, Biannual, Quarterly and Continuous LDAR", "Replace compressor seal or rod and pumps" methane abatement levers for offshore and onshore oil operations corrected for regions (Africa, Middle East, North America, South & Central America) Link	61 %	100 %	Reduction potential of IEA methane tracker already accounts for market uptake. Regions included: Europe, Africa, Middle East, North America, Central & South America.	-11 %
Implement methane management systems to minimize venting and uncontrolled gas releases	-36 %	Derived from IEA Methane Tracker "Vapor recovery units", "Associated gas utilisation", "Blowdown capture", "Replace with instrument air systems" methane abatement levers for offshore and onshore oil operations corrected for regions (Europe, Africa, Middle East, North America, South & Central America) Link	61 %	100 %	Same as Above	-22 %
Electrification of auxiliary equipment (e.g., pumps, compressors) [Methane impact]	-8 %	Derived from IEA Methane Tracker "replace with electric motor" methane abatement lever for offshore and onshore oil operations corrected for regions (Europe, Africa, Middle East, North America, South & Central America) Link	61 %	100 %	Same as Above	-5 %

Decarbonisation lever	Technical Reduction Potential	Justification Sources for Technical Reduction Potential	% Supply Chain Step Emissions Covered by Lever*	Uptake of Lever	Uptake Justification	Reduction Applied to Value Chain Step
Electrification of auxiliary equipment (e.g., pumps, compressors) [Carbon dioxide impact]	-46 %	Derived from IEA Emissions from Oil and Gas Operations in NZE Transitions on the role of electrification of facilities in upstream oil and gas operations, adjusted for increased production output. Link, Link	39 %	100 %	Same as Above	-18 %
Application of CCS technologies	-53 %	CCS deployment in upstream oil operations can reduce approximately 40-65 % of operational emissions, depending on CO_2 concentration, infrastructure availability, and capture deployment strategy. Link	39 %	10 %	Uptake is expected to be limited or non-existent due to high cost versus low abatement potential.	-2 %
Improve flaring to avoid incomplete combustion	-5 %	Derived from IEA Methane tracker “improve flaring” methane abatement lever Link	61 %	100 %	Reduction potential of IEA methane tracker already accounts for market uptake. Regions included: Europe, Africa, Middle East, North America, Central & South America.	-3 %

** Share of methane (61 %) and carbon dioxide (39 %) in emissions related to crude oil extraction based on LCA 4.0. Applies to the whole crude oil basket excluding share from Russia based on LCA 4.0.*

Crude Oil Transportation

Decarbonisation lever	Technical Reduction Potential	Justification Sources for Technical Reduction Potential	% Supply Chain Step Emissions Covered by Lever*	Uptake of Lever	Uptake Justification	Reduction Applied to Value Chain Step
Switch tankers from Heavy Fuel Oil (HFO) to Liquefied Natural Gas (LNG)	-14 %	Compares emission intensity of HFO against LNG, considering methane slip. Link	92 %*	50 %	Short term mix of fuel use will be predominately fossil, but lower share of HFO. Long term it will be in competition with other alternative fuels.	-6 %
Switch tankers from HFO/LNG to low-carbon fuels (e.g. ammonia, hydrogen)	-90 %	Compares emission intensity fossil fuels against green hydrogen & methanol. Link	92 %*	40 %	Significant role for low carbon fuels, but comparatively lower to high ambition.	-33 %
Electrification hybrid systems for deep-sea (short-sea & inland not included)	-20 %	Compares emission intensity of hybrid systems against conventional use. Link, Link	92 %*	10 %	Very limited adoption. Likely to apply only to specific use cases.	-2 %
Electrification in pipeline operations	-68 %	Compares emission intensity of diesel generators against the EU grid average in 2023 (divided by 2 to account for renewables uptake). A.070.10.105 from ldemat2016 database Link	8 %**	31 %	Grid electrification relevant for EU & North America. More challenging for remote pipelines in Africa & Middle East. Based on table 3-2 in LCA	-2 %
Optimisation of operations	-8 %	Derived from abatement potential for speed reduction and is assumed minimal driven by marginal fuel saving. Link	92 %*	20 %	Very limited possibilities. Today's freight assumed to be price sensitive and thus seeking for such marginal gains.	-1 %

**Applies to cells referring to 92 %: Estimated for tankers based on relative distance in Eurobitume LCA 4.0 and emission factor. Majority of transport emissions originates from maritime transport. Lever applies globally.*

***Estimated for pipelines based on relative distance in Eurobitume LCA 4.0 and emission factor. Majority of transport emissions originates from maritime transport. Lever applies globally. Only applicable to "oil field to terminal/refinery" distance, based on table 3-2 in Eurobitume LCA 4.0.*

Refinery Operations

Decarbonisation lever	Technical Reduction Potential	Justification Sources for Technical Reduction Potential	% Supply Chain Step Emissions Covered by Lever*	Uptake of Lever	Uptake Justification	Reduction Applied to Value Chain Step
Electrification of furnaces (heat)	-55 %	Compares traditional fossil-fuel-fired heaters in high-temperature refinery processes, such as distillation and cracking, with highly efficient electric heaters powered by renewable/green electricity. Link	92 %*	30 %	Fork: Electrification, low carbon fuels and CCS. Technology is available but uptake dependent on location and installation.	-15 %
Replacement of heavy oil with natural gas-fired furnace	-25 %	Compares emission intensity (CO_2e/MWh based on CO_2e/tonne fuel & MWh/tonne) of heavy fuel oil against natural gas. Link, Link, Link	6 %**	100 %	Short term measure, is considered a intermediary step to evolve to low carbon fuels.	-2 %
Continued improvements in overall energy efficiency	-21 %	Drawing on Concawe (report 8/19, high elect scenario of Appendix 4) and the FPS low-carbon roadmap for Belgium, process efficiency improvements are projected to reduce refining energy use between 2023 and 2050 with an annual reduction rate of approximately 0,77 %. Link, Link	100 %	100 %	Energy efficiency is assumed to be common across the market. All companies look for process efficiency inherently.	-21 %
Use of low-carbon fuels for heating purposes	-55 %	Compares emission intensity (CO_2e/MWh based on tonne CO_2e/ tonne fuel & MWh/ tonne) of refinery gas against with hydrogen. Link, Link, Link (Table 2,2 in p. 6), Link	84 %***	30 %	Fork: Electrification, low carbon fuels and CCS. Technology is available but uptake dependent on competitive operational cost	-14 %

Decarbonisation lever	Technical Reduction Potential	Justification Sources for Technical Reduction Potential	% Supply Chain Step Emissions Covered by Lever*	Uptake of Lever	Uptake Justification	Reduction Applied to Value Chain Step
Application of CCS technologies in refineries	-24 %	Derived from Concawe (report 8/19) "CCS in refineries" reduction lever by 2050 under the high max-ccs scenario. Link	84 %***	15 %	Limited deployment due to high cost, applicability and infrastructure constraints (pipelines, storage, etc.)	-3 %

** Estimated based on LCA 4.0. Approximately 8 % of energy consumption in refineries is generated by onsite combined heat and power (CHP) plans.*

*** Estimated based on LCA 4.0. Heavy fuel oil only covers a small share of the fuel mix in LCA 4.0.*

**** Estimated based on LCA 4.0 to exclude electricity energy inputs for refinery processes.*

Bitumen Storage

Decarbonisation lever	Technical Reduction Potential	Justification Sources for Technical Reduction Potential	% Supply Chain Step Emissions Covered by Lever*	Uptake of Lever	Uptake Justification	Reduction Applied to Value Chain Step
Electrification of storage heating	-55 %	Compares traditional fossil-fuel-fired heaters for heated and insulated tanks at refineries with highly efficient electric heaters powered by renewable/green electricity. Link	95 %*	40 %	Technology is commercially available. Considering low abatement in overall footprint, it may not be the focus area for investment.	-21 %
Continued improvements in overall energy efficiency (e.g., lower temperature)	-26 %	Lower storage temperatures result in significant reductions in thermal losses and related emissions. Link	100 %	80 %	Energy efficiency is assumed to be common across the market.	-21 %

** Estimated based on LCA 4.0 to exclude electricity energy inputs generated onsite.*

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