SOCIO-ECONOMIC ANALYSIS FOR A REACH RESTRICTION PROPOSAL ON PFAS IN THE UPSTREAM OIL & GAS, OIL REFINING AND FUEL DISTRIBUTION SECTORS, AND IN CARBON CAPTURE AND STORAGE

Final Report

For: Concawe and IOGP

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PREFACE BY CONCAWE AND IOGP-EUROPE

Concawe and the International Association of Oil & Gas Producers (IOGP) commissioned Ricardo AEA Ltd (Ricardo) to produce an independent Socio-Economic Analysis (SEA) for the potential EU REACH restriction of Per- and polyfluoroalkyl substances (PFAS), following the European Chemicals Agency's (ECHA) guidelines.

The scope of the proposed PFAS restriction is wide, covering several groups of substances and uses across many sectors. Given this breadth, the SEA presented in this report focuses on a prioritised subset of PFAS-containing materials that are critical to selected industrial activities. Specifically, the analysis focuses on fluoropolymers and fluoroelastomers used in sealants, coatings for wires, capacitors, and pipes; within upstream oil and gas operations, oil refining, fuel distribution, and carbon capture and storage (CCS).

This means that other PFAS groups, including fluorosurfactants, low-molecular-weight PFAS, fluorinated gases, and processing aids, are explicitly out of scope of this SEA.

Accordingly, references in this report to 'PFAS-containing equipment or materials' specifically relates to fluoropolymers and fluoroelastomers (and not, for example, to fluorosurfactants) unless otherwise stated. Understanding this distinction is essential to correctly interpret the findings. While certain non-polymeric PFAS have been reported to be persistent, mobile and/or bioaccumulative, and toxic, these hazards have not been scientifically demonstrated for polymeric PFAS such as fluoropolymers and fluoroelastomers. Whilst fluoropolymers and fluoroelastomers are also environmentally persistent, they are also reported to be biologically inert and non-toxic[1].

In the absence of comprehensive sector-specific emission and exposure data, this independent SEA adopts a precautionary and conservative analytical approach within the scope of this study which is consistent with our understanding of ECHA's guidelines.

Potential PFAS emissions from fluoropolymer- and fluoroelastomer-containing equipment during normal use are considered to be very low, although quantitative data are limited.

From a life-cycle perspective, PFAS emissions from fluoropolymer- and fluoroelastomer-containing equipment are likely during the manufacturing and end-of-life treatment of these polymers[2]. Available evidence indicates that 83.5% of industrial PFAS-containing materials (of all forms) is sent for incineration[3], which at high temperature destroys polymeric PFAS. However, Concawe and IOGP confirm that these activities are largely outside the operational control of oil and gas operators.

Whilst the scope of this SEA study is narrow (fluoropolymers and fluoroelastomers used in sealants, coatings for wires, capacitors, and pipes), this does not imply that fluoropolymers and fluoroelastomers represent the only critical PFAS uses within the oil and gas value chain.

The industry also relies on these and other PFAS in many additional applications, including (non-exhaustive list):

- Anti-foaming agents – used in fluids management
- Oil, gas and water tracers
- Batteries – in multiple large and small equipment sources and hand-held device
- Building and construction equipment
- Conveyor belt/roller systems – across a range of sizes/scales
- Electrical and electronic systems - well beyond the capacitor use explained
- Fastenings / fittings - a large range of simple equipment in this category
- Fire Suppression systems - (not foam in another restriction) but 'clean agent' mists

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[1] Améduri, B (2023). Fluoropolymers as unique and irreplaceable materials: Challenges and future trends. Molecules, https://doi.org/10.3390/molecules28227564

[2] Organisation for Economic Co-operation and Development (OECD) (2025). Synthesis Report on Understanding Fluoropolymers and Their Life Cycle. Available at: https://www.oecd.org/en/publications/synthesis-report-on-understanding-fluoropolymers-and-their-life-cycle_35b035df-en.html

[3] Concawe (2024). Review of end-of-life management options for refinery equipment and lubricants/greases potentially containing PFAS. Concawe report 12/24, Brussels. https://www.concawe.eu/wp-content/uploads/Rpt_24-12.pdf

- Hydraulic Fluids – in multiple systems fixed and mobile
- Environmental sampling and monitoring equipment
- Laboratory / testing equipment
- Lubricants / Greases – speciality needs in highly constrained environments
- Membranes and Filters – in chemicals / fuel processing / separation and water treatment
- Power management systems - UPS/switchgear etc
- Refrigerants & Gases – in process chillers, HVAC, compressors, heat exchangers, laboratory equipment etc
- Safety Equipment – specific items of use – providing resistance to chemicals/hazardous environments, including personal protective equipment (PPE)

In addition, while this study assesses impacts on industrial activities directly operated or influenced by Concawe and IOGP members, the potential impacts of restricting fluoropolymers and fluoroelastomers would extend well beyond the assessed applications.

These industrial impacts would propagate both up the value chain, affecting equipment manufacturers and service providers, and down the value chain, affecting users of oil and gas products and renewable fuels that underpin essential economic activities.

In sum, this means that the impacts quantified in this SEA represent only a subset of the potential socio-economic and environmental implications of a broad PFAS restriction.

Finally, Concawe and IOGP plans to use this study to support their response to European Chemicals Agency's (ECHA) consultation on their proposed EU REACH restriction on PFAS, as assessed by the European Chemicals Agency's (ECHA) Committee for Socio-Economic Analysis (SEAC).

EXECUTIVE SUMMARY

This Study has been commissioned by Concawe and the International Association of Oil & Gas Producers (IOGP) **to provide an independent Socio-Economic Analysis (SEA) for the potential EU REACH restriction of Per- and polyfluoroalkyl substances (PFAS)**[4]**.** This analysis focuses on upstream Oil & Gas (O&G), carbon capture and storage (CCS), refinery operations, renewable fuels and fuel distribution sectors.

Scope of the Assessment

The scope of this assessment is on PFAS that are relevant to the equipment/processes in scope, which are fluoropolymers and fluoroelastomers, as described in the following table. **Non-polymeric PFAS are out of scope of this SEA.**

The period of appraisal is 30 years (2026-2055) to capture the main implications of the restriction over time and consider also how technological change and market evolution will interact with the regulatory developments. The study assumes that the proposed restriction enters into force in 2028, with direct impacts delayed until 2041, after a 1.5-year transition period and a 12-year derogation period.

Table E1 Scope of this SEA

Scope	Details
Substance	Polymeric PFAS relevant to the products in scope, specifically fluoropolymers and fluoroelastomers
Sectors	Upstream O&G; CCS; refinery operations; renewable fuels; and fuel distribution
Equipment/ processes in scope	Sealants and sealing devices, coatings for wires and capacitors, flexible pipes and umbilicals, and their waste management
Categories of impact	Economic, social and environmental
Geographical scope	EEA (and qualitatively for United Kingdom and Switzerland)
Time period	2026 – 2055

The Baseline and the Proposed Restriction Scenario in scope

A baseline (‘do nothing’ scenario) and one restriction scenario have been assessed in this study. The restriction scenario selected for the assessment is the scenario that has been proposed by the Dossier Submitters (RO2) and is as a ban of PFAS with specific time-limited derogations. This includes derogations of 12 years after entry into force (EIF) plus 18 months transition period (i.e., a total of 13.5 years after EiF) for sealants, coatings for wires, capacitors, and pipes.

Method overview

The methodology used in this study consists of several steps, in line with ECHA’s SEA guidelines, and are summarised as follows.

- **Define and characterise the baseline scenario**, against which the impacts of the restriction scenario will be assessed for 2026-2055. This includes employing statistical techniques and publicly available sources (such as Eurostat’s Structural Business Statistics) combined with data reported by industry stakeholders.

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[4] ECHA (2025). Registry of restriction intentions until outcome – Per- and polyfluoroalkyl substances (PFASs). Available at: https://echa.europa.eu/registry-of-restriction-intentions/-/dislist/details/0b0236e18663449b

- **Consult industry stakeholders and gather evidence of the baseline and the potential impacts**. This involved a literature review, consultation (survey) of industry stakeholders, validation workshops with stakeholders and follow up interviews.
- **Assessment of the economic, social (including health) and environmental impacts of the restriction scenarios,** over the period 2026-2055 quantitatively, where possible (e.g., some economic impacts), or otherwise qualitatively (e.g., health and environmental impacts using a Multi-Criteria Analysis (MCA) method.

The quantitative and qualitative assessment methods employed to characterise and compare the impacts of the scenarios over the period of 2026-2055 are further described below.

- The impacts of the restriction scenario against the baseline have been quantified, where evidence was available. Quantitative analysis has been performed to estimate: i) the impact of the restriction on the Gross Value Added (GVA) and turnover for the in-scope sectors in the EEA; and ii) the impact of the restriction scenario on employment in the EEA. Three impact scenarios (high, medium, and low) have been applied to reflect the uncertainties regarding the substitution of PFAS-containing equipment with alternatives and the potential implications for the sectors within the scope of this analysis based on stakeholder insights. The high-impact scenario is considered the most likely scenario based on stakeholder consultation, which assumes that only 10-30% of PFAS-dependent components can be replaced upon the introduction of a restriction, leading to cessation of activities in the affected sectors. The medium-impact scenario (which stakeholders consider unlikely) assumes that 20-60% of PFAS-containing equipment can be substituted, resulting in widespread operational disruption. In contrast, the low-impact scenario (which stakeholders consider unlikely) assumes that at least 90% of PFAS-containing equipment can be replaced, limiting operational disruptions to a relatively minor level.
- The impacts of the restriction scenario against the baseline have been qualitatively assessed (including the direction and relative magnitude), where quantitative evidence was not available. Qualitative methods also allow for bringing the overall assessment together to develop conclusions. For example, the evidence available was considered to establish the magnitude and direction of impact for the EEA's industry's competitiveness in a global context relative to the baseline, considering the effects on costs of doing business and trade, drawing on the Commission's Better Regulation[5] and ECHA's guidelines. A qualitative analysis has also been conducted to conclude on the effects of the restriction scenario against the baseline for social impacts (excluding the impact on employment, which has been quantified) and the environment.

The outputs of the assessment were used to establish comparable and evidence-based 'scores', following a scale of -5 to +5 to reflect the direction (positive or negative) and the magnitude of impact (weakly: 1 to strongly: 5, limited: 0 or unclear impacts: N/A), which are illustrated in the Table below. This methodology, based on MCA principles, required an iterative and multidisciplinary approach that is detailed in Appendix 1. For illustrative purposes, the scores are presented for +/- 5, +/- 3, +/- 1 and 0 only; however, scores of +/- 2 and +/- 4 are possible. The assessment of impacts is affected by uncertainties inherent to an ex-ante assessment as well as driven by the lack of available evidence.

Table E2. Scoring and colour-coding framework used for the overall, qualitative assessment

Strongly negative	Negative	Weakly negative	No or limited impact	Weakly positive	Positive	Strongly positive	Unclear
-5	-3	-1	0	+1	+3	+5	N/A

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[5] European Commission (2024). Better regulation: guidelines and toolbox. Available from: https://commission.europa.eu/law/law-making-process/planning-and-proposing-law/better-regulation/better-regulation-guidelines-and-toolbox_en

Analysis of economic, social and environmental impacts

Economic impacts

- The proposed PFAS restriction (RO2) would likely result in a severe economic contraction when compared to the baseline, with the high-impact scenario indicating the complete cessation of upstream O&G operations by 2041, and partial closures in the medium- and low-impact scenarios. The estimated impact on turnover ranges from a loss of €4 billion per year (PV[6], € 2025) on average from 2041-2055 (low-impact scenario) to €26 billion per year (PV, € 2025) on average from 2041-2055 (in the more likely high-impact scenario), against the baseline scenario.
- The proposed restriction could have substantial negative impacts on the crude oil refining sector, projecting reductions in economic activity from 2041 ranging from 10% to 100%, depending on the impact scenario. Estimated impact on turnover ranges from a loss of €11 billion per year (PV, € 2025) on average from 2041-2055 (low-impact scenario) to €74 billion per year (PV, € 2025) on average from 2041-2055 (in the more likely high-impact scenario), against the baseline scenario.
- The proposed restriction could negatively disrupt the renewable fuels sector, ranging from widespread facility shutdowns in the high-impact scenario to moderate operational constraints in lower-impact cases, undermining the sector's role in decarbonising hard-to-abate transport modes. This translates to an estimated loss of turnover of €8 billion per year (PV, € 2025) on average from 2041-2055 (low-impact scenario) to a €53 billion per year (PV, € 2025) on average from 2041-2055 (in the more likely high-impact scenario), against the baseline scenario.
- The proposed restriction could also disrupt the fuel distribution sector, ranging from widespread facility shutdowns in the high-impact scenario to moderate operational constraints in lower-impact case. Estimated impact on turnover ranges from a loss of €2 billion per year (PV, € 2025) on average from 2041-2055 (low-impact scenario) to €12 billion per year (PV, € 2025) on average from 2041-2055 (in the more likely high-impact scenario), against the baseline scenario.
- Components based on polymeric PFAS (fluoropolymers and fluoroelastomers) are integral to operations in the CCS sector. The proposed restriction scenario would likely redirect CCS investment outside the EU due to increased Health, Safety, Security and Environment (HSSE) risks, potentially slowing CCS infrastructure deployment within the EEA and affecting progress towards the EU's CO_2 storage targets, though the magnitude of this impact remains uncertain and dependent on future technological and regulatory developments.
- Additional investment in R&D for developing PFAS-free alternatives could generate positive economic and environmental outcomes within the EEA. However, the regulatory drivers might also redirect resources towards compliance-driven substitution activities. This could, in some cases, reduce more productive investments or breakthrough innovation compared to the baseline, potentially affecting negatively the overall efficiency of innovation outcomes.
- **Overall, the restriction (RO2) could weaken the EEA's global competitiveness across the O&G value chain, with both direct and indirect effects limiting the region's ability to compete internationally, especially in upstream O&G production, oil refining, and renewable fuels production**.

Social impacts

- The adoption of the restriction scenario could lead to a direct net reduction in the number of jobs supported by upstream O&G operations in the EEA, ranging from a loss of 3,000 jobs (low-impact scenario) to 21,000 jobs (high-impact scenario), against the baseline scenario. Moreover, negative impacts on the CCS sector may diminish redeployment opportunities, which could increase the risk of deeper and more sustained employment losses than anticipated under the baseline trajectory.
- Across the 'downstream user' industry segments, including crude oil refining, renewable fuels and fuel distribution, the proposed restriction RO2 could also reduce jobs supported in the EU from 2041-2055. Estimated job losses when compared to the baseline range from an average of 38,000 jobs (low-impact scenario) to 250,000 jobs (high-impact scenario) by 2055.
- The proposed restriction could also lead to supply disruptions and higher refinery product prices, which could negatively affect downstream user industry segments, consumer and households. In the high-impact scenario where activities may cease entirely in the sectors under the scope of this study, the wider social

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[6] This refers to the Present Value, using a discount rate in line with EU guidelines.

and macroeconomic effects could be large, with extensive disruption spreading across multiple layers of the EEA economy.
- There is limited information available into the health risks associated with human and environmental exposure to fluoropolymers and fluoroelastomers. It is noted by OECD that life cycle assessment (for production to end of life) should also be taken into account for fluoropolymers[7]. This means that the magnitude of this impact is uncertain (see Section 5.2).
- There can be traces of monomeric PFAS in the components in scope, and such evidence offers a reference point for consideration as part of a qualitative assessment. Whilst monomeric PFAS are out of scope of this SEA, available studies highlight that exposure to these PFAS may be associated with adverse health effects.
- The PFAS restriction scenario could potentially lead to slight, positive effects on human health from lowering the potential for PFAS-related exposure at the end of life of the equipment in scope.
- **The adoption of the restriction scenario for both the upstream O&G and CCS as well as refinery, renewable fuels and distribution operations might lead to limited negative or neutral social impacts, with slightly positive health impacts potentially neutralised by negative to weakly negative job losses and consumer effects, at least in the short-to-medium term**.

Environmental impacts

- The environmental concerns for fluoropolymers and fluoroelastomers are related to their persistence.
- Many PFAS-containing components currently in use provide chemical resistance, thermal stability, and durability, which help prevent leaks, equipment failures, and accidental releases of process fluids and are required for safe operations. If substitute materials do not achieve comparable performance, there is potential for increased operational and environmental risks. These could include more frequent leaks, fugitive emissions, or accidental discharges of hydrocarbons, chemicals, or other hazardous substances. While these risks are not directly related to PFAS, they are an important environmental consideration.
- Under the restriction scenario, there could be a reduction of PFAS emissions across all relevant release media. However, the magnitude of both baseline emissions and scenario-based emission reductions cannot be quantified due to limited available information.
- Under the restriction scenario, there could also be moderate positive impacts for the quality of natural resources, waste production, generation, and recycling for the value chain. This positive impact could result from a decrease of PFAS-containing equipment at the end of life over time and potential recycling of PFAS-free alternatives. However, this effect is also dependent on the durability and recyclability of PFAS-free alternatives that could be adopted.
- **It is most likely that there could be net, slightly positive impacts on the environment that could result from the adoption of the restriction scenario for both the upstream O&G and CCS and refinery, renewable fuels and distribution operations.**

Balance of economic, social, and environmental impacts, costs and benefits

In addition, these and other outputs of the assessment were brought together across the broad economic and environmental impact categories and summarised in Table E2 below.

Table E3. Overview of the economic, social and environmental impacts on the oil and gas sector for the proposed restriction scenario (RO2)

Restriction Scenario	Economic impacts	Social impacts	Environmental impacts
Restriction Scenario 1 (against baseline)	-3	0	+2

*Source: Ricardo analysis based on the evidence presented in this Study. *Rounded figures*

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[7] OECD (2025) Synthesis Report on Understanding Fluropolymers and Their Life Cycle, OECD Series on Risk Management of Chemicals. OECD Publishing, Paris. Available from: https://doi.org/10.1787/35b035df-en

The assessment concludes that the restriction scenario is likely to have negative economic impacts (-3), limited social impacts (0) and positive environmental impacts (+2 respectively). The scale of the potential, positive environmental impacts is concluded to be lower than that of negative economic impacts. Thus, the restriction scenarios appear to have a likely negative balance of economic, social and environmental impacts.

Finally, the analysis was grouped to consider the balance of costs and benefits to EEA society, which provides additional insights into the merits of the restriction scenario and whether it could contribute to addressing the problems outlined earlier, as well as meeting the EEA's general objective in a cost-effective way.

Table E4. Economic, social and environmental costs and benefits of the proposed restriction scenario (RO2) against the baseline

Restriction Scenario	Costs	Benefits	Benefit: Cost Ratio
Restriction Scenario 1 (against baseline)	-5.0	+3.0	<1

*Source: Ricardo analysis based on the evidence presented in this Study. *Rounded figures*

The scale of the potential benefits that might result from the restriction scenario has been assessed to be lower than that of potential costs. The assessment has highlighted a range of costs, such as for the conduct of business, and sectoral competitiveness, trade and investment flows, which could be incurred upon the introduction of the restriction. In addition, some potential benefits have been identified, such as for the potential for innovation, human health and the quality of natural resources and waste management. **These benefits of the restriction scenario are assessed to be of insufficient scale, which is represented by a benefit-to-cost ratio (BCR) lower than 1.**

Please refer to the method overview of this summary, and Section 2 and Appendix 1 of this Study for more details on the methodology employed.

Conclusions

The outputs of this assessment and the comparison of impacts of the restriction scenario suggest that for upstream O&G, CCS and refinery, renewable fuels and distribution operations:

- Costs that would potentially be incurred from the adoption the restriction scenario include negative impacts in economic and social categories. Benefits that would potentially occur under the restriction scenarios include potentially positive impacts on innovation, health and research and waste production, generation and recycling.
- Under the restriction scenario, the scale of economic and environmental benefits has been assessed to be lower than the costs. This has also been highlighted by estimates of the potential benefit: cost ratio, being below 1 for the restriction scenario.

These conclusions do not support the adoption of the restriction scenario (RO2) considered.

CONTENTS

1. INTRODUCTION

Several, individual and groups of per- and polyfluoroalkyl substances (PFAS) are regulated in the European Union, for example through the assignment of harmonised classifications under Regulation (EC) No 1272/2008 on classification, labelling and packaging, as Substances of Very High Concern under Regulation (EC) No 1907/2006 on the Registration, Evaluation Authorisation and Restriction of Chemicals (REACH), restriction of PFAS in fire-fighting foams in REACH under Regulation (EU) 2025/1988, and Regulation (EU) 2019/1021 on Persistent Organic Pollutants.

In addition, a proposal for a broad REACH restriction covering all PFAS (the ‘Universal-PFAS Restriction proposal’) is currently under evaluation by the European Chemicals Agency (ECHA)’s scientific committees and will subsequently be considered by the European Commission, reflecting concerns about the persistence of these substances in the environment.

In this context, Concawe and IOGP jointly commissioned Ricardo to provide an independent **Socio-Economic Analysis (SEA) of proposal for the EU REACH restriction on PFAS in the Upstream Oil & Gas, refinery operations, renewable fuels and fuel distribution sectors, and in Carbon Capture and Storage (CCS))**. The study follows the SEA guidelines produced by ECHA for REACH restrictions[8], subject to the limitations outlined in this report.

1.1 AIMS AND SCOPE OF THE SEA

The aim of this SEA is to assess quantitatively to the extent that is possible, or qualitatively where necessary, the **economic, social and environmental impacts** on **upstream oil and gas (O&G) and carbon capture and storage (CCS) and on the oil refining, renewable fuels and fuel distribution sectors.**

The scope of the study is described in the Table below.

Table 1-1: Scope of this SEA

Scope	Details
Substance	Polymeric PFAS relevant to the products in scope - fluoropolymers and fluoroelastomers.
Sectors	Upstream O&G; CCS; refinery operations; renewable fuels; and fuel distribution
Equipment/ processes in scope	Sealants and sealing devices, coatings for wires and capacitors, flexible pipes and umbilicals, and waste management
Categories of impact	Economic, social and environmental
Geographical scope	EEA (and qualitatively for United Kingdom and Switzerland)
Time period	2026 – 2055[9]

The period of appraisal of this study is 30 years (2026-2055), specified to capture the main implications of the restriction over time and consider also how technological change and market evolution will interact with the regulatory developments. The study assumes that the proposed restriction enters into force in 2028, with direct impacts delayed until 2041, after a 1.5-year transition period and a 12-year derogation period.

1.2 STRUCTURE OF THE SEA

The rest of this SEA is structured in five sections and followed by a set of complementary Appendices. The sections include:

- Section 2, providing an overview of the SEA methodology.
- Section 3, describing the baseline and restriction scenario.

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[8] ECHA. (2008). Guidance on Socio-Economic Analysis – Restrictions. Available from: https://echa.europa.eu/documents/10162/2324906/sea_restrictions_en.pdf/2d7c8e06-b5dd-40fc-b646-3467b5082a9d

[9] This timeline is discussed in further detail in Section 4.1.1.

- Section 4, summarising the analysis of economic, social and environmental impacts.
- Section 5, summarising the potential impacts of the restriction scenario, and considering any sensitivities to the assumptions employed in the assessment.
- Appendices, comprising a detailed description of the methodologies employed, the definition of the sectors analysed, monomeric PFAS, the outputs of an evidence review of alternatives, and the consultation synopsis.

2. OVERVIEW OF THE METHODOLOGY

A **five-step approach** has been employed to assess the socio-economic impacts of the restriction scenario, following ECHA's guidelines. These steps are:

- Step 1: Defining the baseline and restriction scenario under consideration.
- Step 2: Mapping and screening all potential impacts of the restriction scenarios, based on the estimated absolute and relative magnitude of these impacts and their likelihood, based on the available evidence.
- Step 3: Gathering primary and secondary evidence to support the analysis.
- Step 4: Assessing the shortlisted socio-economic impacts, qualitatively and/or quantitatively.
- Step 5: Reviewing key uncertainties and conducting sensitivity analysis.

2.1 STEP 1: DEFINING THE BASELINE AND RESTRICTION SCENARIOS

Following ECHA's guidance on SEA for REACH restriction proposals[10], a baseline or 'do nothing' scenario has been defined, against which a REACH restriction scenario (RO2 scenario in the ECHA PFAS REACH restriction[11]) can be assessed. These scenarios were defined in discussions with Concawe and IOGP as follows:

- **Baseline scenario**: This scenario assumes that no new restrictions under REACH would be introduced. As a result, historical trends and external dynamics to REACH (such as Net Zero 2050 targets, decarbonisation plans, etc.) are used to characterise possible future pathways for the economic sectors in scope. The analysis characterises indicators such as Gross Value Added (GVA), sales turnover and employment in the EEA, imports into the EEA and exports out of the EEA. The baseline is characterised in more depth in Section 3.1.
- **Restriction scenario**: One restriction scenario was also defined, based on the scenario proposed by the Dossier Submitters for the EU PFAS REACH restriction (the 'RO2' scenario). The proposed restriction sets out a list of possible derogations on a range of products, which has been considered. This scenario is outlined in more detail in Section 3.2.

2.2 STEP 2: MAPPING AND SCREENING OF IMPACTS

A longlist of potential impacts for the restriction scenario, when compared against the baseline, has been mapped across three categories (economic, social and environmental impacts) using impact pathway and theory of change approaches.

This longlist of impacts was screened, using a qualitative framework, which considered their likelihood to materialise or occur, and the potential magnitude (and direction) of impact, based on the available evidence.

The output of this task is a shortlist of 10 categories (see Appendix 1) for an in-depth assessment of impacts of the restriction scenario against the baseline. This supports the effective prioritisation of the in-depth analysis of economic, health, social and/or environmental impacts, resulting in a proportionate SEA.

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[10] European Chemicals Agency (2008). Guidance on Socio-Economic Analysis – Restrictions. Available from: https://echa.europa.eu/documents/10162/2324906/sea_restrictions_en.pdf/2d7c8e06-b5dd-40fc-b646-3467b5082a9d

[11] ECHA. (2025). Background Document to the Opinion on the Annex VI dossier proposing restrictions on Per- and polyfluoroalkyl substances (PFAS). Available from: https://echa.europa.eu/documents/10162/cd583492-f5d4-e2e7-9938-a1d602084c72. RO2 is set out in pages 4-10.

2.3 STEP 3: GATHERING EVIDENCE

The study draws on evidence gathered through desk-based research and a targeted stakeholder consultation.

The **desk-based research** targeted published material, such as industry reports, scientific literature and official datasets, and assembled an evidence base capturing the size of upstream O&G, CCS, oil refining and fuel distribution sectors and the economic baseline (especially by drawing on Eurostat and published industry reports), the volume of equipment in scope and the presence of PFAS in this equipment, the performance of baseline and alternative products, health effects from PFAS exposure during production, use and end of life, waste and wastewater treatment, and the emissions of PFAS into the environment. Appendix 1 presents a detailed outline of the approach employed, and Appendix 3 summarises the outputs from the rapid evidence review of product alternatives.

The **targeted stakeholder consultation** comprised one online survey of Concawe and IOGP members, three follow-up workshops and five interviews. The survey asked companies to validate desk-based findings on the size of typical operations, equipment in scope (units used in a typical operation, criticality), presence of PFAS, alternatives to PFAS, end-of-life management, emissions of PFAS, and how they might respond to a restriction (e.g., adjustment, substitution etc.). The survey results were reviewed in an online, validation workshop, which was complemented by five follow-up interviews, and two additional workshops during which Concawe and IOGP members provided feedback on the baseline scenario and characterisation of the SEA's methodology. A brief consultation synopsis is presented in Appendix 4.

2.4 STEP 4: ASSESSING IMPACTS

The shortlisted impacts of the restriction scenario against the baseline have been assessed qualitatively and, where possible, quantitatively, to compare the costs and benefits and, ultimately, develop conclusions.

Qualitative and quantitative methods in alignment with the ECHA SEA restriction guidance were used to characterise the impacts. The study assumes that the proposed restriction enters into force in 2028, with its impacts beginning in 2041 following a 1.5-year transition period and a 12-year derogation period. More specifically:

- The impacts of the restriction scenario against the baseline have been quantified, where evidence was available. More specifically, baseline sectoral turnover, gross value added (GVA), and employment across the upstream oil and gas, refining, fuel distribution, and renewable fuels sectors in the EEA were quantitatively assessed and characterised over the appraisal period. The impacts of the restriction scenarios on these indicators were also quantified, thus presenting estimates of the economic damages of the restriction in monetary terms as well as potential job losses.
- Other impacts, especially health and environmental effects, have been qualitatively assessed (including the direction and relative magnitude), as sufficient evidence was not available. The evidence available was considered to establish a relative magnitude and direction of impact for the EU industry's competitiveness in a global context, considering the effects on costs of doing business and trade, drawing on the Commission's Better Regulation[5] and ECHA's guidelines, as well as health and environmental impacts.

Qualitative frameworks also enable us to bring together all the analysis conducted into overall assessment to develop conclusions. More specifically, the outputs of the impact analysis were used to establish comparable and evidence-based 'scores', following a scale of -5 to +5 to reflect the direction (negative or positive) and the magnitude of impact (weakly: 1 to strongly: 5, limited: 0 or unclear impacts: N/A), which are illustrated in Table 2-1. For illustrative purposes, the scores are presented for +/- 5, +/- 3, +/- 1 and 0 only; however, scores of +/- 2 and +/- 4 are possible. This methodology, based on Multi-Criteria Analysis (MCA), required an iterative and multidisciplinary approach that is detailed in Appendix 1.

Table 2-1 Scoring and colour-coding framework used for the overall, qualitative assessment

Strongly negative	Negative	Weakly negative	No or limited impact	Weakly positive	Positive	Strongly positive	Unclear
-5	-3	-1	0	+1	+3	+5	N/A

2.5 STEP 5: UNCERTAINTIES AND SENSITIVITY ANALYSIS

The evidence available and analytical outputs underpinning this assessment are subject to uncertainty. Ex-ante assessments inherently involve uncertainty, which in this case is compounded by evidence gaps. To address this, the sensitivity of the conclusions of the SEA was tested against key uncertainties by exploring possible 'low', 'medium' and 'high' sensitivity scenarios, and assessing how these variations may influence the SEA outputs.

Firstly, the distribution of responses to the stakeholder consultation was analysed to derive possible estimates corresponding to 'high', medium' and 'low' impact scenarios, which captured the uncertainties in the business responses to a REACH PFAS restriction proposal scenario. For example, this included analysis of the presence of the equipment in scope within their operations in the EEA; the presence of PFAS in the equipment; the potential for PFAS-free alternatives; and the operational implications of the restriction scenario with derogations across these industries. These estimates are presented in Sections 3 and 4.

Secondly, uncertainty in baseline sector projections for the period 2026-2055 was addressed through a review of multiple, publicly available studies and modelling approaches. A baseline scenario was selected that reflects the convergence across models and broadly aligns with the EU Net Zero 2050 targets[12]. Industry stakeholders (members of Concawe and IOGP) were also consulted, and this information was triangulated with external evidence to develop projections of sector scale within the EEA to 2055. This approach supports the robustness and proportionality of the baseline assumptions applied in this study. There is also uncertainty in the potential environmental and human health impacts from PFAS emissions, due to a lack of available evidence concerning environmental and human exposure for the sector and PFAS in scope (fluoropolymers and fluoroelastomers).

Finally, uncertainties in the available data for the baseline and each sectoral impact scenario were considered to develop 'upper', 'central' and 'lower' estimates, where applicable. This quantitative analysis primarily focused on the evolution of the upstream O&G, CCS, oil refining, renewable fuels and fuel distribution sectors under both the baseline and PFAS restriction scenarios. Where sector-specific data was unavailable, evidence-based assumptions were developed to construct reasonable parameter ranges. The resulting 'upper' and 'lower' bounds were used to evaluate the sensitivity of study conclusions to data uncertainty. The scale and direction of impacts were compared across these bounds, and the implications for SEA conclusions were documented.

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[12] European Commission (n.d.). European Climate Law. Available from: https://climate.ec.europa.eu/eu-action/european-climate-law_en

3. BASELINE AND PROPOSED RESTRICTION SCENARIOS

This section describes the baseline scenario and the proposed restriction scenarios considered in this SEA.

3.1 THE BASELINE SCENARIO

This section introduces PFAS, the products in scope of assessment, their market and value chain, and the current regulatory framework.

3.1.1 Introduction to PFAS

PFAS (polymeric and non-polymeric) are a large and diverse group of mostly man-made substances that contain carbon-fluoride (C-F) bonds. This C-F bond is one of the strongest bonds in organic chemistry[13]. OECD has defined PFAS as including "*fluorinated substances that contain at least one fully fluorinated methyl or methylene carbon atom (without any H/Cl/Br/I atom attached to it)*"[14]. This definition includes fluoropolymers and fluoroelastomers and is the definition used by ECHA for PFAS.

Fluoropolymers are typically defined as a polymer consisting of a carbon backbone with multiple carbon-fluorine bonds. They may sometimes be categorised as perfluoropolymers, to distinguish them from partially fluorinated polymers (fluoroelastomers) or other polymers that contain fluorine[15].

Fluoropolymers and fluoroelastomers are used due to their favourable technical properties, including resistance to mechanical stress, thermal stability, durability, chemical inertness, and resistance to biological, chemical and physical degradation. Sectors in which fluoropolymers are also used include aerospace, automotive, electronics, energy production, energy storage and medical equipment, amongst others.

However, due to the C-F bond, PFAS are highly resistant to degradation and are the subject of the proposed REACH restriction due to the persistence of the parent substance in water and soil compartments, with some PFAS substances also being toxic for both the environment and human health[4]. Persistence is considered by the restriction proposal submitters to be the only hazard applicable for all PFAS.

3.1.1.1 Current regulatory framework

Some PFAS are regulated under the current EU regulatory frameworks. Under Regulation (EU) 2019/1021 on persistent organic pollutants (POPs) which restricts the manufacturing, placing on the market and the uses of substances subject to the Stockholm Convention on POPs, PFAS substances which are listed include perfluorooctanoic acid (PFOA), its salts and PFOA-related compounds; and perfluorohexane sulfonic acid (PFHxS), its salts and PFHxS-related compounds. Under the REACH regulation, some PFAS are restricted such as C9-14 Perfluorocarboxylic acids (PFCAs) and there is a restriction for PFAS in firefighting foams. There is a limit value for the total PFAS concentration of 0.5 µg/L and 0.1 µg/L for the sum of twenty PFAS under the Directive 2020/2184 (Drinking Water Directive).

Under the Water Framework Directive (Directive 2000/60/EC) PFOS and PFOA are listed as priority hazardous substance[16]. Fluoropolymers and fluoroelastomers are however, not specifically regulated within the EU. When at the end-of-life, fluoropolymers and fluoroelastomers would be subject to the Waste Framework Directive (WFD). The production of fluoropolymers and fluoroelastomers is also subject to other regulatory frameworks, such as the Industrial Emissions Directive (IED).

3.1.1.2 EU REACH PFAS restriction

A proposal has been made to ECHA for a broad (group-based) restriction of PFAS under REACH[17] due to concerns about their persistence in the environment. The first call for evidence by Germany, Denmark, the

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[13] O'Hagan, D. (2008). Understanding organofluorine chemistry. An introduction to the C-F bond. Chem. Soc. Rev., 37, 308-319.

[14] OECD. (2021). Reconciling Terminology of the Universe of Per- and Polyfluoroalkyl Substances: Recommendations and Practical Guidance. Available from: https://www.oecd.org/content/dam/oecd/en/publications/reports/2021/07/reconciling-terminology-of-the-universe-of-per-and-polyfluoroalkyl-substances_a7fbcba8/e458e796-en.pdf

[15] Ebnesajjid. S. (2021). Introduction to Fluoropolymers: Materials, Technology and Applications. Second edition. Elsevier, UK

[16] Water Framework Directive. (2020). Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000 establishing a framework for Community action in the field of water policy. Document 02000L0060-20141120. Available from: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A02000L0060-20141120

[17] The OECD definition of PFAS is used for this restriction.

Netherlands, Sweden and Norway was launched in May 2020, followed by a second call for evidence launched in July 2021. In March 2023, an Annex XV dossier on PFAS was submitted by Germany, the Netherlands, Sweden, Norway and Denmark[18]. This was then followed by a consultation period for this proposed restriction, during which ECHA received over 5,600 comments from over 4,400 respondents.

In August 2025, ECHA published an update. This included the assessment of eight sectors, comprising broader industrial uses (i.e. catalysts and solvents), explosives, machinery applications, other medical applications (i.e. excipients and immediate packaging for pharmaceuticals), military applications, printing applications, sealing applications and technical textiles. In addition, an alternative restriction option (allowing the continued use of PFAS where the risk is controlled) has been considered for electronics and semiconductors, energy, machinery applications, PFAS manufacturing, sealing applications, technical textiles and transport[19]. Three restriction options (ROs) were considered by the Dossier Submitters, which are described in the following table.

Table 3-1: Restriction options considered by the EU REACH PFAS Restriction Dossier Submitters

Restriction Option	Restriction Details
Restriction Option 1 (RO1)	Full ban
Restriction Option 2 (RO2)	Ban with specific time-limited derogations
Restriction Option 3 (RO3)	Continued use under strict conditions which minimise the emissions over the full life cycle

The preferred RO of the Dossier Submitters is RO2 (ban with specific time-limited derogations) for sealants, coatings for wires, capacitors, and pipes[19] which is further described in Section 3.2.

3.1.2 Products containing PFAS

Fluoropolymers and fluoroelastomers are used in many applications in the sectors in scope. Applications in which PFAS are used include in antifoaming agents; oil, gas and water racers; batteries; building and construction equipment; conveyor belt/roller systems; electrical and electronic systems; fastenings/fitters; fire suppression systems; hydraulic fluids; environmental sampling and monitoring equipment; laboratory/testing equipment; lubricants and greases; membranes and filters; power management systems; refrigerants and gases; and safety equipment[20].

In the scope of this SEA are the following products that contain PFAS (fluoropolymers and/or fluoroelastomers): sealants and sealing devices, coatings for wires and capacitors, and in umbilicals and flexible pipes. Examples of identified PFAS[21] used in oil and gas sector operations are described in the following table for sealants and sealing devices, coatings for wires and capacitors, and umbilicals and flexible pipes.

Table 3-2: Examples of fluoropolymers and fluoroelastomers

Equipment (or 'uses')	Fluoropolymers/ fluoroelastomers
Sealants and sealing devices	FEPM (tetrafluoroethylenepropylene copolymer), FKM (Fluoroelastomers), FFKM (Perfluoroelastomer), PCTFE (Polychlorotrifluroethylene), PTFE (Polytetrafluoroethylene), PVDF (polyvinylidene fluoride), PFA (Perfluoroalkoxy alkane), FEP

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[18] ECHA. (2023). Annex XV Restriction Report. Proposal for a Restriction – Per- and polyfluoroalkyl substances (PFASs). Available at: https://echa.europa.eu/documents/10162/f605d4b5-7c17-7414-8823-b49b9fd43aea

[19] ECHA. (2025). ECHA publishes updated PFAS restriction proposal. Available from: https://echa.europa.eu/-/echa-publishes-updated-pfas-restriction-proposal

[20] Concawe (2023) PFAS Study in Refinery & Fuel Distribution Equipment. Available from: https://echa.europa.eu/comments-submitted-to-date-on-restriction-report-on-pfas (Table 105, ID 8916)

[21] (a) Concawe. (2023). PFAS Study in Refinery & Fuel Distribution Equipment; (b) Arcadis. (2023). Fluoropolymers in the Oil and Gas Industry. Report for the American Petroleum Institute; (c) Dalau. (2026). The Importance of Fluoropolymer Products in the Electronics Industry. Available from: https://dalau.com/company/blog/the-importance-of-fluoropolymer-products-in-the-electronics-industry/

Equipment (or 'uses')	Fluoropolymers/ fluoroelastomers
	(Fluorinated Ethylene Propylene), ECTFE (ethylene-chlorotrifluoroethylene)
Coatings for wires	FEP, PFA, PVDF, PTFE, FFKM, FKM, PCTFEM ECTFE
Coatings for Capacitors	PTFE, PFA
Flexible pipes and umbilicals	FEP, PFA, PTFE, PVDF, FFKM, FKM, PCTFE, ECTFE

Fluoropolymers and fluoroelastomers are used in these products for their technical properties, such as resistance to high temperatures, resistance to pressure, resistance to corrosive environments, reliability and stability. The following table describes these properties in more detail, which is further explored in Appendix 4. From stakeholder engagement, these PFAS-containing equipment are critical for operations.

Table 3-3: Technical properties of PFAS for the uses

Equipment	Key technical properties
Sealants and sealing devices	High temperature resistance, broad chemical compatibility, long term reliability
Coatings for wires	Flexibility, mechanical robustness, high dielectric strength, thermal resistance (typically from −55 °C up to 150 °C), and resistance to fuels, hydrocarbons, acids, alkalis, solvents, and biological contaminants.
Coatings for Capacitors	High dielectric strength, thermal stability, chemical inertness, operate under fluctuating temperatures and electrical load conditions.
Flexible pipes and umbilicals	Chemical inertness, high temperature resistance, corrosion resistance, flexibility, long-term creep resistance, and extended service life.

Within the upstream and downstream sectors, the volumes of these items of PFAS-containing equipment in typical operations have been estimated using desk-based research and responses to an online survey, which is further discussed in Appendix 4. The volumes of equipment are described in the following boxes. There is a lack of information on the quantities of PFAS used in this equipment; however, this is generally a value chain issue.

Box 3-1: Volumes of equipment required in a typical operation in upstream O&G and CCS operations

Volume of equipment required for a typical operation and the presence of PFAS in the EEA

The volumes of the equipment in-scope in this sector for the EEA were estimated based on the results of desk-based research and survey responses; followed by an analysis of the proportion of this equipment that might contain PFAS. The sizes of a typical upstream O&G and CCS operation is provided in Appendix 4. Briefly, a typical O&G operation produces 300k (boe/d) per field and a typical CCS operation captures and sequesters 3 million tons of CO_2 per year per field.

However, this potential prevalence of PFAS is subject to uncertainty, which can be seen in the estimated ranges. This is because the evidence on the presence of PFAS across different equipment is limited (>50% of respondents to the survey did not know or answered N/A).

Table 3-4: Volumes of equipment in a typical upstream operation and CCS operation and presence of PFAS in the EEA

Typical operation	Sealants and sealing devices (units)	Coatings for wires (km)	Capacitors (units)	Piping system and hoses (km)
Upstream O&G	26,000-52,000	40-80	1,000-3,000	400-550
CCS	3,200-4,600	5-10	570-2,200	460-620
% of equipment that might contain PFAS	45% (30-70%)	50% (20-60%)	40% (25%-70%)	40% (25%-70%)

Box 3-2: Volumes of equipment required in a typical operation in oil refinery and fuel distribution operations

Volume of equipment required for a typical oil refinery operation and the presence of PFAS

The volumes of the equipment in-scope in this sector were also estimated based on the results of desk-based research and survey responses; followed by an analysis of the proportion of this equipment that might contain PFAS. A typical oil refinery has a capacity for 10 million tonnes of oil equivalent per year (225,000 barrels of oil equivalent per day). The Table below sets out volumes estimated across the following stages of typical refinery activities: offloading/reception; feedstock storage and desalting; refinery processes (distillation, conversion, treatment, blending); storage and dispatch; and support systems.

Please note, again, that the potential prevalence of PFAS is subject to uncertainty, which can be seen in the estimated ranges. The provided midpoint values (50% and 70%) are typically aligned with the results of the desk-based research.

Table 3-5: Volumes of equipment in a typical oil refinery operation and presence of PFAS

Typical operation	Sealants and sealing devices (units)	Coatings for wires (km)	Capacitors (units)	Piping system and hoses (km)
Oil refinery (Total)	18,000-66,000	140-570	4,300-16,500	300-500

% of equipment that might contain PFAS	70% (30-90%)	50% (20-80%)	50% (20-80%)	70% (25-90%)

Volume of equipment required for a typical fuel distribution operation and the presence of PFAS

The volumes of the equipment in-scope in this sector were also estimated based on the results of desk-based research and survey responses; followed by an analysis of the proportion of this equipment that might contain PFAS. A typical fuel distribution operation has a pipeline network of 250 km, a road transport network of 72,000 truckloads per year, a rail transport network of 18,000 wagon loads per year, and a shipping transport network of 120 medium sized oil tanker trips per year. Table 3-6 below sets out volumes estimated across different distribution stages or types, such as road transport, rail transport, pipeline networks, and shipping/waterways.

Again, the potential prevalence of PFAS is subject to uncertainty, which can be seen in the estimated ranges. The provided midpoint values are typically aligned with the results of the desk-based research.

Table 3-6: Volumes of equipment in a typical fuel distribution operation and presence of PFAS

Typical operation	Sealants and sealing devices (units)	Coatings for wires (km)	Capacitors (units)	Piping system and hoses (km)
Total (all distribution)	1,740-3,450	153-256	3,650-6,840	186-346
% of equipment that might contain PFAS	60% (30-90%)	50% (40-80%)	60% (20-80%)	60% (25-90%)

3.1.3 Economic baseline

This section describes the size of the market for upstream O&G, CCS, crude oil refining, renewable fuels and fuel distribution sectors in the EEA, in terms of the turnover and GVA generated, and the employment supported. Appendix 1 provides a more detailed presentation of the methodology as well as data sources.

3.1.3.1 Upstream O&G and CCS

The size of the upstream O&G market

In 2024, Norway produced approximately 98 million tonnes of crude oil[22], while crude oil production in the EU amounted to 15.5 million tonnes, led by Italy (4.4 million tonnes), Denmark (2.9 million tonnes) and Romania (2.8 million tonnes)[23]. Norway also leads in natural gas production, with an output of 5.1 million terajoules (TJ), and the EU-27 produced 1.3 million TJ in 2024.[24] In the same year, sales turnover of the EEA's upstream oil and gas sector was estimated at €200 billion, with Gross Value Added (GVA) of €136 billion as shown in Table 3-7 overleaf.

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[22] IEA. (2026). Country Overview – Norway. Available at: https://www.iea.org/countries/norway/oil

[23] Eurostat. (2026). Supply, transformation and consumption of oil and petroleum products - nrg_cb_oil. Available from: https://ec.europa.eu/eurostat/databrowser/view/nrg_cb_oil__custom_20001024/default/table

[24] Eurostat. (2026). Supply, transformation and consumption gas - nrg_cb_gas. Available from: https://ec.europa.eu/eurostat/databrowser/view/nrg_cb_gas__custom_20570846/default/table

Table 3-7: Upstream O&G sector baseline economic estimates for the EEA in 2024

Indicator	Unit	Lower estimate	Central estimate	Upper estimate
Turnover	billion euros/year, 2025 prices	196	200	204
GVA	billion euros/year, 2025 prices	133	136	139

Source: Ricardo analysis based on Eurostat data.

Based on desk-research and the stakeholder consultation, a *typical* O&G field in the EEA was estimated to produce around 300,000 barrels of oil equivalent per day (boed). This corresponds to around 5% of total EEA production, for an estimated total O&G extracted per year in the EEA of around 1.9-2.3 billion barrels of oil equivalent (boe).

The upstream O&G production in the EU has exhibited a downward trend since 2004[25], with output declining on a year-on-year basis, while production in Norway has remained broadly stable since around 2010. These developments reflect a combination of geological maturity, limited new field development, and evolving policy and market conditions.

Forward looking scenarios aligned with net-zero objectives indicate a continuation of these underlying trends. Applying these scenario assumptions to the 2024 baseline suggests that upstream O&G sector's turnover in the EEA could decline to approximately €63 billion by 2040 and further to €34 billion by 2050 as shown in Figure 3-1 overleaf. GVA is projected to decline to €43 billion by 2040 and €23 billion by 2050.

This projection is driven by the broader, Net-Zero policy framework and associated energy transition, aimed at reducing fossil fuel demand, increasing energy efficiency, and accelerating the deployment of low -carbon energy sources across the EEA.

For the CCS sector, which is considered qualitatively in this study, the EEA is projected to see substantial expansion of capacity over the coming decades, driven by at least partly by EU level targets and obligations designed to scale carbon management infrastructure. In 2024, there were only 5 operational projects in the EU and Norway, with total capture capacity of 2.7 $MtCO_2$ per annum.[26] Under the Net-Zero Industry Act, however, the EU aims to develop an annual injection capacity of at least 50 million tonnes of CO_2 per year by 2030[27]. Moreover, according to modelling used in the EU's 2040 climate target communication, some 280 million tonnes would need to be captured by 2040 and around 450 million tonnes by mid-century.[28] Announced projects in Europe as a whole (including Norwegian and UK continental shelves) are predicted to reach around 230 $MtCO_2$ per annum by the mid to late 2030s.[29]

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[25] Eurostat. (2025). Oil and petroleum products - a statistical overview. Available at: https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Oil_and_petroleum_products_-_a_statistical_overview

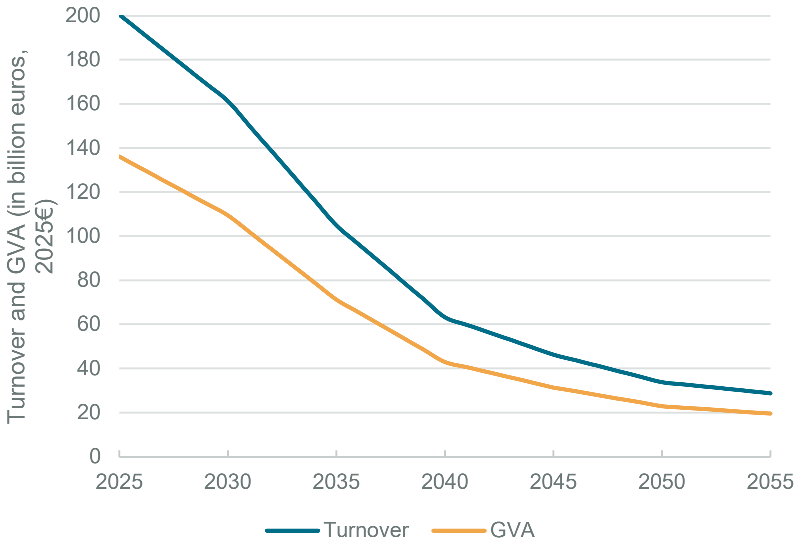
[26] IEEFA. (n.d.). EU carbon capture and storage policy - Fact Sheet. Available at: https://ieefa.org/sites/default/files/2024-11/CCSfactsheet11nov.pdf

[27] IEA. (2023). Net Zero Industry Act: CCUS. Available at: https://www.iea.org/policies/17545-net-zero-industry-act-ccus

[28] European Commission. (2026). About Industrial Carbon Management. Available at: https://climate.ec.europa.eu/eu-action/industrial-carbon-management/about-industrial-carbon-management_en

[29] IOGP, 2026. CO2 storage projects in Europe: CO2-Storage-Projects-in-Europe-poster_Feb2026-2.pdf

Figure 3-1: Baseline projections for O&G sector (2026-2055) based on a Net Zero 2050 Scenario



Source: Ricardo analysis based on Eurostat data and Net Zero 2050 scenario projections

Employment in upstream O&G

Employment in the upstream O&G sector reflects its capital and knowledge intensive nature, with a workforce composed predominantly of highly skilled technical, engineering, and operational roles. In 2024, the upstream O&G sector employed more than 106,000 (104,000-108,000) people directly across the EEA, including over 69,000 workers in Norway and more than 36,000 in the EU. These professionals are involved in exploration and appraisal activities, field development, drilling and production operations, asset integrity and safety management, and a range of other functions required to produce crude oil and natural gas and supply these products to customers in Europe and international markets.

In line with projected changes in sectoral activity, net-zero-aligned scenarios indicate there will be gradual long-term adjustments in employment levels in the EEA. Under these projections, direct employment in the upstream oil and gas sector is expected to decrease from 106,000 jobs in 2024 to approximately 56,000 jobs by 2035, and further to around 17,900 jobs by 2050. This is also driven by the background of decarbonisation and energy transition, including the replacement of fossil fuel for low-carbon energy technologies and opportunities for skills transfer, reskilling, and workforce redeployment within the wider energy system.

3.1.3.2 Crude oil refining sector

The size of the crude oil refining sector

In 2024, EU crude oil refineries produced an estimated 534 Mtoe (million tonnes of oil equivalent) of petroleum products, with Germany being the largest producer (97.6 Mtoe), followed by Italy (67.4 Mtoe), Spain (63.1 Mtoe), and the Netherlands (55.7 Mtoe)[23]. In the same year, refineries in Norway produced 10.1 Mtoe of petroleum products.

In 2024, the oil refining industry in the EEA recorded an estimated €563 billion in turnover and generated €50 billion in Gross Value Added (GVA) as shown in Table 3-8. This scale of refinery output reflects the continued importance of refining infrastructure for the European economy, supplying energy products and intermediates that underpin mobility, manufacturing activity, and cross-border energy trade at present.

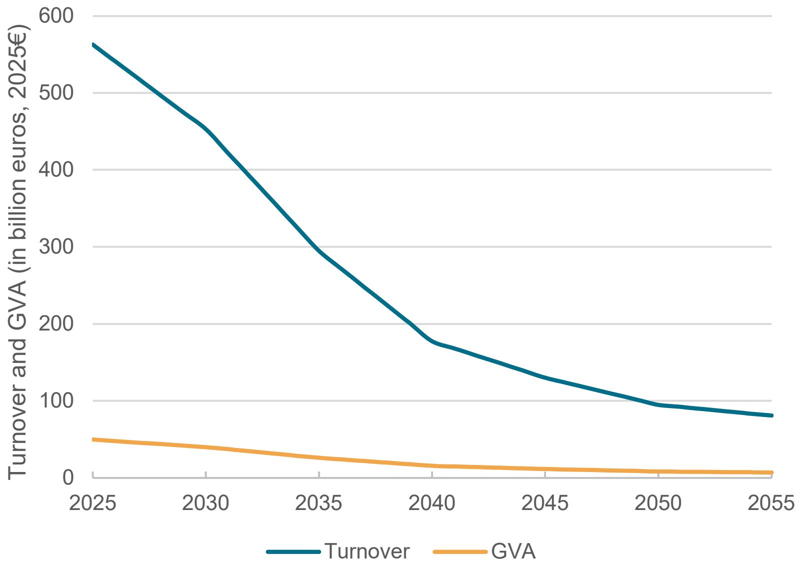
Table 3-8: Crude oil refining sector baseline economic estimates for the EEA in 2024

Indicator	Unit	**Lower estimate**	**Central estimate**	**Upper estimate**
Turnover	million euros, 2025 prices	551	563	574
GVA	million euros, 2025 prices	49	50	51

Source: Ricardo analysis based on Eurostat data.

Looking into the future and applying the Net Zero 2050 scenario trajectories would indicate a progressive reduction in crude oil refining activity. Turnover associated with conventional fuels is projected to decline to approximately €178 billion by 2040 and further to around €95 billion by 2050 as presented in Figure 3-2 below. GVA is projected to halve by 2035 to around €26 billion and decline further to €8 billion by 2050. This trend is driven by expected structural changes in fuel demand and product mix, with refining capacity expected to adapt through efficiency improvements, integration of low-carbon fuels, and diversification toward alternative and renewable feedstocks.

Figure 3-2: Baseline projections for crude oil refining (2026-2055) based on a Net Zero 2050 Scenario



Source: Ricardo analysis based on Eurostat data and Net Zero 2050 scenario projections

Employment in crude oil refining

Employment supported by the crude oil refining sector is shaped by the complexity and continuous-operation nature of refinery systems, requiring a diverse mix of specialised skills spanning process operations, engineering, maintenance, safety, quality control, and logistics.

In 2024, an estimated 161,000 (158,000-165,000) people were directly employed in crude oil refining across EEA. The workforce supports round--the-clock refinery operations, including process monitoring and optimisation, equipment maintenance and turnaround activities, laboratory testing and product certification, environmental compliance, and site-level health and safety management, alongside commercial and logistical functions necessary to deliver refined petroleum products to European and international markets.

Consistent with projected changes in refining throughput and product demand, net-zero-aligned pathways point to a gradual reconfiguration of employment in the sector over the long term. Based on these projections, direct employment in crude oil refining is expected to decline from approximately 161,000 jobs in 2024 to around 51,000 jobs by 2040, and further to about 27,000 jobs by 2050. These developments reflect broader shifts in refinery utilisation and product mix and underline the relevance of workforce transition measures, including skills adaptation and redeployment within the evolving energy and industrial landscape.

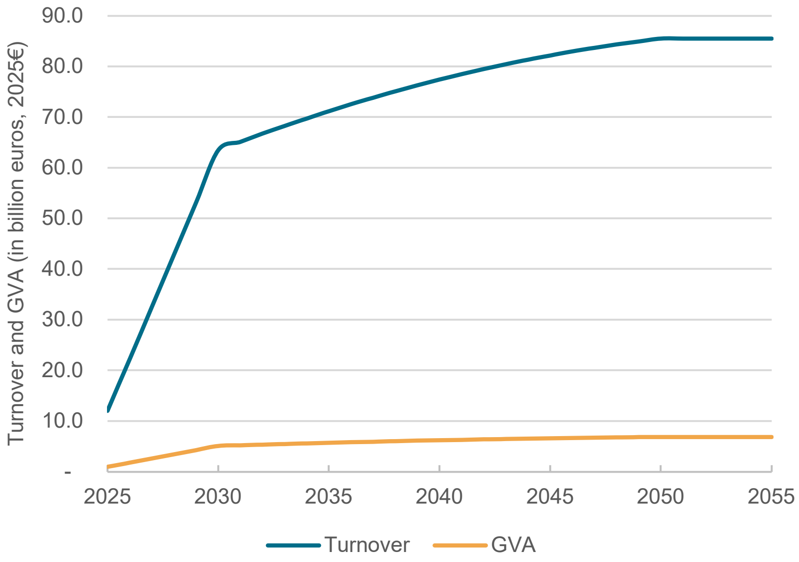
3.1.3.3 Renewable fuels sector

The size of the renewable fuels sector

As crude oil production declines, renewable fuel output, including conventional biofuels, drop-in advanced biofuels and e-fuels, is expected to increase. A 2024 European Commission study[30] highlights the essential role of renewable fuels in reducing transport-sector emissions and supporting the Fit-for-55 package and broader climate-neutrality objectives in the EU. Renewable fuels are identified as a key decarbonisation option for transport segments that are difficult to electrify in the short to medium term, such as aviation, maritime transport, and parts of heavy-duty road transport, while also contributing to diversification of energy supply and reduced reliance on imported fossil fuels.

According to this and a recent study from JRC[31], overall energy contribution from renewable fuels produced in the EU is projected to reach 27.4 Mtoe per year by 2030, from around 19-20 Mtoe per year in 2024; with industry turnover estimated to rise from €11.8 billion in 2024 to €63.5 billion in 2030 as presented in Figure 3-3 below. This contribution is expected to grow further as advanced renewable fuels become more widely available, supported by the full-scale commercialisation of technologies, supply chains, and processes driven by ambitious policies and sectoral targets. By 2050, the energy contribution from renewable fuels is projected to rise to 48.54 Mtoe per year reflecting a more mature market characterised by increased integration with existing refining and distribution infrastructure and a broader role for renewable fuels within the evolving European energy system

Figure 3-3: Baseline projections for renewable fuels sector in the EEA (2025-2055), on a Net Zero 2050 Scenario



Source: Ricardo analysis based on European Commission (2024) and Eurostat data.

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[30] European Commission. (2024). *Development of outlook for the necessary means to build industrial capacity for drop-in advanced biofuels—Research and innovation*. Available from: https://research-and-innovation.ec.europa.eu/news/all-research-and-innovation-news/development-outlook-necessary-means-build-industrial-capacity-drop-advanced-biofuels-2024-02-07_en

[31] JRC. (2026). Advanced Biofuels in the European Union - 2025 Status Report on Technology Development, Trends, Value Chains and Markets. Available from: https://setis.ec.europa.eu/advanced-biofuels-european-union-2025-status-report-technology-development-trends-value-chains-and_en

Norway currently meets almost all its liquid biofuel needs through imports[32]. While the country has declared a mandate to increase renewable fuels blending in the short-term[33], a long-term strategy to increase domestic liquid biofuel production could not be identified.

Employment in renewable fuels sector

The 2026 JRC study[31] estimates, based on EurObserv-ER data, that the renewable fuels sector supports around 150,000 direct and indirect jobs in the EU. The expansion of renewable fuels is associated with significant direct and indirect employment benefits. It is estimated that more than 50,000 new direct jobs could be created by 2030, with the potential to exceed 190,000 by 2050 in the baseline scenario[30]. These jobs support feedstock preparation, industrial processing, and transportation of feedstock and intermediate products.

Please note that the estimates concerning renewable fuels presented in this section cover only conventional and advanced biofuels and exclude e-fuels and other alternative feedstocks. While e-fuels are currently at a nascent stage of development, they are expected to play an important role in the EU's long-term decarbonisation strategy. Under the ReFuelEU Aviation Regulation, a minimum share of synthetic aviation fuels, produced from renewable hydrogen and captured carbon, is set at 1.2% of fuel supplied at EU airports by 2030, increasing to 35% by 2050.[34] The FuelEU Maritime Regulation also promotes the use of renewable fuels of non-biological origin (RFNBOs), with the potential introduction of binding targets contingent on future developments in supply availability and cost.[35] The role of alternative technologies such as pyrolytic liquefaction using plastic feedstock may grow in the future, potentially prolonging the lifecycle of refinery operations.[36] Given the early stage of development of the e-fuels sector and alternative technologies, it is not currently possible to construct a robust quantitative baseline. As a result, the projections for the renewable fuels sector presented in this assessment should be interpreted as an underestimation of the sector's overall long-term potential.

3.1.3.4 Fuel distribution sector

The size of the fuel distribution

Typical distribution practices were identified for each transport mode. Refined fuel products are distributed through four main networks: pipeline transport, road transport (trucks), rail transport, and shipping. These modes serve different functions within the distribution system, reflecting variations in distance, volume, flexibility, and end use. Pipelines are generally used for high-volume continuous transport between refineries, storage terminals, and major demand centres; road transport provides flexibility for shorter distances and final delivery to retail sites; rail transport is typically used for medium to long-distance inland distribution where pipeline infrastructure is not available; and shipping supports both coastal distribution and international movements of refined products.

Based on typical refinery production capacities and the proportion of products allocated to each transport mode, the volumes handled by each distribution network was estimated. These volumes were then used to derive key transport activity parameters, such as tonnes, kilometres and number of transport movements, as presented in Table 3-9 overleaf. The resulting parameters were discussed and validated through multiple stakeholder workshops, ensuring that they reflect current industry practices and operational realities.

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[32] Government.NO (2025). *Bioenergy*. Available from: https://www.regjeringen.no/en/topics/food-fisheries-and-agriculture/skogbruk/innsikt/bioenergi/id2001102/

[33] Government of Norway. (2025). Increased blending mandate for biofuels. Available from: https://technical-regulation-information-system.ec.europa.eu/en/notification/27045

[34] European Commission. (2026). ReFuelEU aviation. Available from: https://transport.ec.europa.eu/transport-modes/air/environment/refueleu-aviation_en

[35] European Commission. (2026). Questions and answers on Regulation (EU) 2023/1805 on the use of renewable and low-carbon fuels in maritime transport, and amending Directive 2009/16/EC. Available from: https://transport.ec.europa.eu/transport-modes/maritime/decarbonising-maritime-transport-fueleu-maritime/questions-and-answers-regulation-eu-20231805-use-renewable-and-low-carbon-fuels-maritime-transport_en

[36] Kumagai, S., Fujiwara, K., Nishiyama, T., Saito, Y., & Yoshioka, T. (2025). Chemical Feedstock Recovery Through Plastic Pyrolysis: Challenges and Perspectives Toward a Circular Economy. ChemSusChem, 18(16), e202500210. Available from: https://chemistry-europe.onlinelibrary.wiley.com/doi/10.1002/cssc.202500210

Table 3-9: Fuel distribution sector typical operation by mode

Distribution mode	Value	Unit
Pipeline network	250	km
Road transport network	72,000	truckloads/year
Rail transport network	18,000	wagonloads/year
Shipping network (Medium-sized oil tankers)	120	trips/year

Source: Ricardo analysis based on stakeholder consultations.

For the economic assessment, Eurostat enterprise statistics were used as a reference point. Given the limited availability of disaggregated data specific to fuel distribution, five economic sectors defined by the statistical classification of economic activities (NACE)[37] that capture key distribution-related activities were selected to represent the sector. For each economic sector (i.e., NACE code), a share was estimated or developed to capture the proportion of these economic sectors capturing fuel distribution activities (spanning logistics, wholesale trade, storage, and supporting services). These assumptions are summarised in Table 3-10 below.

Table 3-10: Assumed shares of fuel distribution sector in each economic sector (by NACE code)

Economic sector (NACE codes)	Fuel distribution % – 'Low' scenario	Fuel distribution % – 'High' scenario
Transport via pipeline (NACE 49.50)	80%	90%
Freight transport by road (NACE 49.40)	2%	4%
Freight rail transport (NACE 49.20)	1%	3%
Sea and coastal freight water transport (NACE 50.20)	10%	15%
Warehousing and storage (NACE 52.10)	2%	4%
Support activities for transportation (NACE 52.20)	0%	1%

Source: Ricardo analysis.

Based on this approach, turnover in the fuel distribution industry in the EEA is estimated at €69 billion in 2024, with corresponding Gross Value Added (GVA) of €20.5 billion, as shown in Table 3-11 below.

Table 3-11: Fuel distribution sector baseline economic estimates for the EEA in 2024

Indicator	Unit	Lower estimate	Central estimate	Upper estimate
Turnover	million euros, 2025 prices	54.6	68.9	83.3
GVA	million euros, 2025 prices	16.8	20.5	24.2

Source: Ricardo analysis based on Eurostat data.

Looking into the future, the fuel distribution sector is projected to experience two opposing trends: deliveries of conventional fuels are projected to decline, and supplies of liquid renewable fuels are projected to rise. The contraction in the conventional fuels sector is estimated to be much larger in magnitude compared to the

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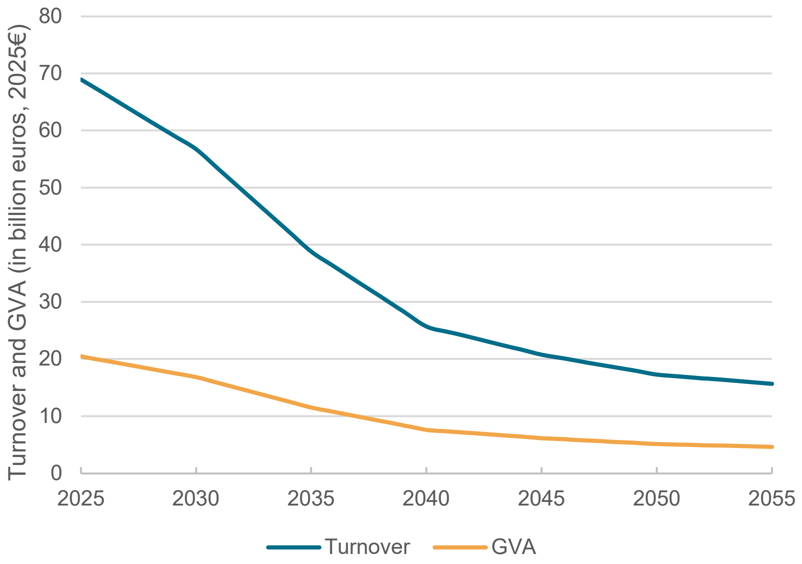
[37] Eurostat. (2008). Statistical classification of economic activities in the European Community. Available from: https://ec.europa.eu/eurostat/documents/3859598/5902521/KS-RA-07-015-EN.PDF.pdf/dd5443f5-b886-40e4-920d-9df03590ff91?t=1414781457000

expansion in liquid renewable fuels supply[38] because of the expansion of the EV vehicle fleet. This could result in a gradual net reduction in projected activity levels in the fuel distribution sector. Under these assumptions, sectoral turnover is projected to decline to approximately €26 billion by 2040 and further to €17 billion by 2050, while GVA is projected to reach around €5 billion by 2050 as illustrated in Figure 3-4 below. These projections reflect broader structural changes in fuel demand and composition and provide a reference baseline for assessing the incremental impacts of the restriction scenarios.

Figure 3-4: Baseline projections for fuel distribution in the EEA (2026-2055), on a Net Zero 2050 Scenario



Source: Ricardo analysis based on Eurostat data, Net Zero 2050 scenario and European Commission (2024).

Employment in fuel distribution

Employment in the fuel distribution sector reflects its operationally intensive and service-oriented nature, requiring a mix of skilled and semi-skilled roles spanning logistics, transport operations, infrastructure management, safety compliance, and commercial coordination. In 2024, the sector is estimated to employ more than 170,000 (123,000-218,000) people directly across the EEA. These professionals are involved in the operation of pipelines, terminals, storage facilities, and transport fleets; scheduling and dispatch of fuel deliveries; maintenance and inspection of distribution infrastructure; health, safety, and environmental management; and administrative and commercial activities required to manage fuel flows, ensure regulatory compliance, and deliver liquid fuels efficiently to end users.

In line with projected changes in sectoral activity, including a gradual shift in the composition of conventional fuels and an increasing share of renewable fuels in distribution networks, net-zero aligned scenarios indicate a long-term adjustment in employment levels. Under these projections, direct employment in the fuel distribution sector[39] is expected to decline to around 64,000 jobs by 2040 and further to approximately 43,000 jobs by 2050.

3.1.4 Health baseline

Establishing a health baseline for fluoropolymers and fluoroelastomers within the O&G supply chain is challenging due to the very limited evidence available on emission, exposure pathways, and associated health impacts specific to these substances.

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[38] Total petroleum product supply in the EU is expected to decline from 578 Mtoe in 2024 to between 60 to 72 Mtoe by 2050 (S&P 2025), a decline of between 506 to 518 Mtoe from 2024 to 2050. Total energy contribution from domestic biofuels production in the EU is expected to rise from 19 Mtoe in 2024 to 48.5 Mtoe in 2050, an increase of 29.5 Mtoe over this period (European Commission 2024).

[39] Please note that this refers to a net evolution in employment, which captures the declining role of conventional fuel sector, and the increasing role of biofuels, supporting fuel distribution employment in the EU/EEA.

Fluoropolymers can contain trace quantities of residual monomeric PFAS[,18,40]. While monomeric PFAS are known to contribute to human health effects, as discussed in Appendix 3, the extent to which fluoropolymers and fluoroelastomers used in this sector contribute to human health and exposure cannot be quantitatively determined from the existing literature. There is also a fragmentation of information which hinders the understanding of health impacts from exposure to fluoropolymers[40].

Generally, fluoropolymers and fluoroelastomers have low bioavailability due to their large molecular size and therefore, they are not considered bioavailable[18]. Evidence from the Commission's recent 'Cost of PFAS' report[41] indicates that fluoropolymers are generally regarded as safe in their polymer form due to their high molecular weight and chemical inertness, and currently no health effects have been reported from exposure to fluoropolymers themselves. However, human exposure concerns arise because the manufacture, processing, use, and end-of-life treatment of fluoropolymers can release monomeric PFAS (e.g., PFAAs)[40], which could affect human health. However, no specific human exposure data was found in the literature for fluoropolymers and fluoroelastomers.

The use of appropriate personal protective equipment, closed systems, and ventilation in the O&G supply chain suggests that occupational exposure to fluoropolymers and fluoroelastomers is minimal. Potential human exposure to fluoropolymers and fluoroelastomers could result from emissions at the product end-of-life/waste stage, which are not directly linked to the use of equipment containing these substances.

At end-of-life, wastes containing fluoropolymers and fluoroelastomers are typically managed through landfilling and incineration. Effective destruction of PFAS requires elevated temperature (>860 ^{o}C)[42] incineration, therefore incineration at lower temperatures may result in incomplete degradation. Landfilling may also lead to releases over time. Consequently, both incomplete incineration and landfill-related releases could indirectly contribute to human exposure. While manufacture and disposal may lead to releases of other PFAS, no studies quantify fluoropolymers and fluoroelastomers release.

Due to limited data and the complexity of this supply chain, this study has not estimated: 1) total number of workers who could be potentially exposed to PFAS from the products in scope; 2) to what extent workers might be exposed to these substances as a result of their work in the sectors in scope; nor 3) emissions into the environment contributing to indirect human exposure. Thus, it has not been possible to attribute baseline burden to this specific sector.

3.1.4.1 Conclusions

Overall, the available evidence suggests that there is health burden attributable to human exposure to PFAS. It has not been possible to attribute a proportion of the health burden to the O&G supply chain due to a lack of available evidence to human exposure to PFAS from fluoropolymers and fluoroelastomers. Evidence on emissions, exposure pathways and worker populations across this supply chain is limited, and no studies have isolated PFAS-related health impacts from fluoropolymers and fluoroelastomers for this sector. Consequently, attribution to the sector of a part of the overall PFAS-related health burden cannot be established, and a qualitative approach is therefore used in this SEA to describe potential health effects under the restriction scenario.

3.1.5 Environmental baseline

This section describes the emissions of PFAS to the environment for the equipment and sectors in scope in the EEA and the current environmental effects. Emissions of PFAS could occur during their manufacture (out of scope for this SEA), use and their end of life.

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[40] OECD (2025) Synthesis Report on Understanding Fluoropolymers and Their Life Cycle, OECD Series on Risk Management of Chemicals. OECD Publishing, Paris. Available from: https://doi.org/10.1787/35b035df-en.

[41] European Commission: Directorate-General for Environment, Ricardo, Trinomics and WSP. (2026). *The cost of PFAS pollution for our society – Final report*, Publications Office of the European Union. Available from: https://data.europa.eu/doi/10.2779/9590509

[42] Gehrmann H-J et al (2023) Pilot-Scale Fluoropolymer Incineration Study: Thermal Treatment of a Mixture of Fluoropolymers Under Representative European Municipal Waste Combustor Conditions. Available at: https://fluoropolymers.eu/wp-content/uploads/2023/10/8.-Preliminary-report-Pilot-Scale-Fluoropolymer-Incineration-Study-June-2023.pdf

3.1.5.1 Baseline emissions of PFAS and their associated environmental concerns

PFAS emissions can occur throughout the entire life cycle of these chemicals and products containing these chemicals. Releases begin during manufacturing and processing, continue during the manufacturing of PFAS-containing products (both out of scope for this SEA), and persist during the use phase and at the end of a product's life. The rate at which PFAS enter the environment depends heavily on their physical form and how they are used. Fluorinated gases are released quickly and directly, while solid PFAS, such as fluoropolymers and fluoroelastomers, may leach out very slowly over decades or centuries at the end of life in landfills [20,51] .

Emissions of PFAS from fluoropolymers and fluoroelastomers from sealings and sealing devices, coatings for wires, and pipes into the environment could occur at end-of life. The literature acknowledges the possibility that equipment may release small amounts of fluoropolymers and fluoroelastomers under certain conditions; however, it also reports that fluoropolymers and fluoroelastomers are specifically selected for their mechanical resistance, chemical stability, and very low propensity to degrade or leach, under normal operational conditions. As a result, any releases during use are expected to be minimal.

There is currently no quantitative information regarding emission of fluoropolymers and fluoroelastomers;. Identified emission pathways include[11]:

- Abrasion and general wear during the use phase, although evidence remains limited.
- Degradation of fluoropolymers and fluoroelastomers include the potential formation of microplastics[43].
- End-of-life treatment of the PFAS-containing products.

PFAS mobility in soil is dependent on the chain length, with short carbon chains resulting in higher mobility[44]. The risk to soil quality is not merely from the presence of PFAS but is also related to site-specific hydrogeology (i.e. soil and the release scenario for the contaminants to enter the environment). For example, the solid phase of soils contains numerous surfaces that could retain contaminants, which influences on whether these then leach to ground water and become bioavailable[45].

Emission estimates are generally based on the annual amount of PFAS placed on the market and include emissions expected during the waste management phase[11]. While the literature recognises the possibility of small releases of fluoropolymers and fluoroelastomers during use (e.g., through abrasion of equipment, linings and joint sealants) or at end-of-life (e.g., landfill), quantitative data are lacking, creating significant uncertainty regarding their magnitude. This was also confirmed with a survey conducted for this study, where respondents reported not having information on polymeric PFAS emissions due to the lack of monitoring, the absence of standardised methods, and the general understanding that polymeric PFAS emissions are likely minimal. As a result, estimating quantitative emissions of PFAS for the sectors and equipment in scope is not possible.

Baseline emission data has been supplied by the Dossier Submitters as part of the proposed EU REACH PFAS restriction for various sectors (for the petroleum and mining sector, see Table 3-12)[11]. These estimates reflect releases associated with the manufacturing and use of PFAS-containing articles in 2020. The Background document provides emissions estimated for the "petroleum and mining" sector, which is not in line with the oil and gas sector in scope of this SEA, but was considered the closest analogue used by ECHA. The petroleum and mining sector discussed by ECHA has been used simply for a discussion point; however, it is important to mention that it does not include or directly reflect any oil and gas sector-specific data. For very limited uses, industry specific emission factors were available and applied in the ECHA background document; however, for many applications such information was lacking, which included the petroleum and mining sector. In these cases, ECHA used default environmental release parameters from the ECHA Guidance on Information Requirements and Chemical Safety Assessment (Chapter R.16), which rely on Environmental Release Category (ERC) factors describing broad use conditions and default assumptions about service life. The background document presents separate low, mid, and high annual emission estimates from the use phase for PFAS manufacture and major PFAS use sectors in 2020. The document does not clearly specify the underlying data sources or assumptions used for each sector, leaving considerable uncertainty regarding how

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[43] Concawe. (2023). PFAS Study in Refinery & Fuel Distribution Equipment; (b) Arcadis. (2023). Fluoropolymers in the Oil and Gas Industry.

[44] Brunn H et al (2023) PFAS: forever chemicals - persistent, bioaccumulative and mobile. Reviewing the status and the need for their phase out and remediation of contaminated sites. *Environ Sci Eur* **35**, 20 https://doi.org/10.1186/s12302-023-00721-8

[45] Petruzzelli G et al (2025) The Fate of Chemical Contaminants in Soil with a View to Potential Risk to Human Health: A Review, Environments, 12(6), 183.

these estimates were derived, particularly for the petroleum and mining sector, where ECHA explicitly stated that no emission data are available for polymeric PFASs (Table 1 in the ECHA Background Document, 2025).

The lack of oil and gas sector-specific data and the uncertainties related to this calculation means that it was not possible to derive oil and gas sector-specific emission estimates in this study. Within refineries, effluents are treated in accordance with the EU Industrial Emissions Directives Requirements[46]. Refinery effluents are treated by biological methods (most commonly by the activated sludge process), physical/mechanical methods, physical/chemical methods and by tertiary treatment[47]. There is potential for PFAS in waste effluents; however, the industry stakeholder consultation suggested this could be from the use of firefighting foams containing PFAS rather than fluoropolymers and fluoroelastomers.

Table 3-12: Estimated annual emissions attributable to PFAS manufacture and PFAS use associated with the petroleum and mining sector in 2020, based on the ECHA Background Document (2025)

Estimate	Total PFAS Emission (t/y)
Low Scenario	1.1
Medium Scenario	1.6
High Scenario	2.1

Additionally, the Dossier Submitters calculated emissions of polymeric PFAS from sealing and sealing applications. These modelled emissions represent potential releases over the full lifecycle of sealing materials, including installation, use, maintenance, removal and end-of-life handling. These emissions from PFAS have been estimated as 345 t/year under the low scenario, 392 t/year under the medium scenario and 439 t/year under the high scenario. However, this is a cross-sectoral estimate with granularity at the sector level not included, and it is not possible to determine what proportion of these emissions relates specifically to fluoropolymers and fluoroelastomers. No further information was obtained from our stakeholder activities.

3.1.5.2 End of life (Waste Management)

Emissions of PFAS could occur during the end-of-life treatment of PFAS-containing sealants, coatings for wires, capacitors, and pipes. Recycling PFAS-containing materials presents major challenges. Thermoplastics can be melted and reused. However, fluoropolymers and fluoroelastomers are difficult to recycle because they are usually combined with other materials and fillers. Landfills do not destroy PFAS, and these substances may eventually escape through leachate or air emissions or remain sequestered until conditions change.

At standard incineration conditions (> 860 ^{o}C), fluoropolymers are converted to inorganic fluorides and carbon dioxide[48]. For metals that are coated with fluoropolymers, these can be sent to a high temperature smelter to recover the metal content, with the residue being either incinerated, with or without energy recovery; sent to landfill; or recycled[49].

Under the baseline scenario, the volume of equipment in scope (sealants and sealing devices; coatings for wires; capacitors; and piping system and hoses) reaching end of life has been estimated based on desk research and consultation. These are presented in the following table.

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[46] Whale GF et al (2022) Assessment of oil refinery wastewater and effluent integrating bioassays, mechanistic modelling and bioavailability evaluation. Chemosphere, 287, 132146.

[47] Concawe (2025) 2022 Survey of Effluent Quality and Water Use at European Refineries. Available from: https://www.concawe.eu/wp-content/uploads/2022-Survey-of-Effluent-Quality-and-Water-Use-at-European-Refineries-2.pdf

[48] Gehrmann H-J et al (2023) Pilot-Scale Fluoropolymer Incineration Study: Thermal Treatment of a Mixture of Fluoropolymers Under Representative European Municipal Waste Combustor Conditions. Available at: https://fluoropolymers.eu/wp-content/uploads/2023/10/8.-Preliminary-report-Pilot-Scale-Fluoropolymer-Incineration-Study-June-2023.pdf

[49] Concawe. (2024). Review of End-Of-Life Management Options for Refinery Equipment and Lubricants/Greases Potentially Containing PFAS. Available from: https://www.concawe.eu/publication/review-of-end-of-life-management-options-for-refinery-equipment-and-lubricants-greases-potentially-containing-pfas/

Table 3-13: Volume of equipment reaching end-of-life each year

Typical operation	Sealants and sealing devices (units)	Coatings for wires (km)	Capacitors (units)	Piping system and hoses (km)
Upstream O&G	8,500-17,500	4-9	150-500	25-40
CCS	1,050-1,550	0.5-1.5	90-370	3-5
Refinery operations	3,000-15,000	10-40	450-1,800	5-25
Fuel distribution	530-1,200	15-30	575-895	11-27

Previous research has indicated that in 2020, 83.5% of fluoropolymer waste was incinerated, 13.1% was landfilled, and 3.4% was recycled[49]. For the baseline for this SEA from desk-based research and consultation, the following has been derived for end-of-life treatment for the PFAS-containing sealants, coatings for wires, capacitors, and pipes:

- 80-85% of equipment is incinerated.
- 10-15% of equipment is landfilled.
- 5-10% of equipment is recycled

The end-of-life management of PFAS-containing equipment has important implications for the environmental baseline. Because PFAS are extremely persistent and resistant to degradation, neither landfilling nor incineration when performed at lower temperatures fully eliminates them.

In practice, refinery and oil and gas sector-related waste streams are typically managed as hazardous waste and routed through controlled systems aligned with the Industrial Emissions Directive and Best Available Techniques (BAT)[11]. Thus, PFAS-containing wastes tend to be directed to high-temperature hazardous-waste incineration or, where appropriate, cement kiln co-processing, rather than municipal waste incineration. This distinction is important because destruction efficiencies vary significantly across technologies: high-temperature hazardous-waste incineration (>1,100 °C) and cement kilns are reported to achieve near-complete PFAS destruction, Recent evidence (e.g., Gehrmann et al., 2024)[50] also indicates no significant PFAS emissions from modern high-temperature incineration systems.

Recycling rates remain very low due to the technical challenges of separating fluoropolymers and fluoroelastomers from other materials, meaning most PFAS-containing equipment ultimately enters industrial hazardous-waste streams. In the oil and gas sector, these waste streams are typically routed through controlled, BAT-aligned hazardous-waste pathways with established monitoring and regulatory-compliance frameworks under the Industrial Emissions Directive, strengthening confidence in the robustness of these waste-handling systems[51].

Given that many of the in-scope equipment have relatively long operational lifetimes but require periodic replacement due to wear, corrosion, or safety standards, a continuous turnover of PFAS-containing equipment can be expected[49]. This creates an ongoing flow of materials entering waste management systems each year, contributing to PFAS emissions in the baseline scenario.

As highlighted in the recent Commission publication into the 'Cost of PFAS pollution'[41], these pathways contribute to long-term environmental accumulation and may lead to ecosystem impacts, even though the magnitude of these impacts cannot be quantified. Consequently, the baseline scenario reflects a waste management system in which PFAS emissions could continue to occur and persist in the environment from the landfilling of PFAS-containing equipment (10-15% of equipment is landfilled) and the potential of

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[50] Gehrmann et al. (2024) Mineralization of fluoropolymers from combustion in a pilot plant under representative European municipal and hazardous waste combustor conditions. Chemosphere. Volume 365, 143403, ISSN 0045-6535. https://doi.org/10.1016/j.chemosphere.2024.143403.

[51] Concawe. (2024). Review of End-Of-Life Management Options for Refinery Equipment and Lubricants/Greases Potentially Containing PFAS. Available from: https://www.concawe.eu/publication/review-of-end-of-life-management-options-for-refinery-equipment-and-lubricants-greases-potentially-containing-pfas/

incineration of PFAS-containing equipment at lower temperatures, reinforcing the importance of considering these releases qualitatively in this SEA.

3.2 THE RESTRICTION SCENARIO

The Dossier Submitters (Denmark, Germany, the Netherlands, Norway and Sweden) for the EU REACH PFAS restriction have published a proposed restriction, which is Restriction Option 2 (RO2) for the 'petroleum and mining' sector. This option is a ban of PFAS with specific time-limited derogations. Two other restriction options were considered by the Dossier Submitters, RO1 and RO3. RO1 is a blanket ban with a transition period of 18 months with no derogations. RO3 allows continued use under strict conditions which minimise emissions throughout the life cycle.

RO2, summarised in the Table below, has been selected as the restriction scenario for assessment in this SEA, as this has been proposed by the Dossier Submitters. Derogations were also proposed for anti-foaming agents, however these were not included for derogation in the SEAC draft opinion. However, how this restriction option will be taken forward remains uncertain. Thus, the policy assumptions have been quality assured to ensure they reflect the ongoing policy debate. As discussions are ongoing, the assumptions in this assessment may not accurately reflect the restriction that might enter into force in the near future, including derogations that may or may not be included. The assessment performed and its outputs are highly dependent on these assumptions and, therefore, are a source of uncertainty.

Table 3-14: Proposed derogations for the equipment or products in scope under RO2

Equipment (or 'product')	Proposed derogation
Sealants	Derogation of 12 years after entry into force (EIF) plus 18 months from entry into force of the restriction.
Coatings for wires	Derogation of 12 years after EIF plus 18 months from entry into force of the restriction
Capacitors	Derogation of 12 years after EIF plus 18 months from entry into force of the restriction
Pipes	Derogation of 12 years after EIF plus 18 months from entry into force of the restriction
Spare parts	Derogation 4(e): "Spare parts intended to replace PFAS-containing articles in articles or complex objects until 20 years after the last date when the complex article was allowed to be placed on the market for the first time or until the end of service life for the specific object, when it is shorter than 20 years."
	Derogation 4(f): "Spare parts used in articles or complex objects for which legal obligations related to the use of specific spare parts exist until the end of service life of the complex object."

Industry stakeholder engagement indicated that these PFAS-containing equipment described in the table above are mostly critical for their operations.

4. ANALYSIS OF IMPACTS

This section presents the economic, social and environmental impacts across the shortlisted impact categories and concludes on the overall costs and benefits associated with RO2.

A brief description of the methodology has been provided in Section 2, and a more detailed outline of the analytical methods and outputs used in the SEA can be found in the Appendices.

4.1 ECONOMIC IMPACTS

This subsection presents the estimated economic impacts of the restriction scenario in scope (RO2), structured in eight parts as follows:

- Section 4.1.1 – An overview of the economic impact pathways: provides a description of three impact scenarios which have been assessed for the restriction scenario.
- Section 4.1.2 – Business impacts on upstream operations: estimated impacts of the restriction for sales turnover and GVA of the sector and a qualitative description of the impacts for CCS.
- Section 4.1.3 – Business impacts on refinery operations: estimated impacts of the restriction for sales turnover and GVA for conventional refinery operations.
- Section 4.1.4 – Business impacts on renewable fuels: estimated impacts of the restriction for sales turnover and GVA for renewable fuel refinery operations.
- Section 4.1.5 – Business impacts on fuel distribution: estimated impacts of the restriction for sales turnover and GVA of the sector.
- Section 4.1.6 – Innovation and research: investigation of the potential alternatives to the use of PFAS-containing alternatives, including availability, technical feasibility, and performance of alternatives.
- Section 4.1.7 – Global competitiveness, trade and investment: qualitative assessment of competitiveness impacts under RO2.
- Section 4.1.8 – Overall economic impacts in the EEA: provides a summary of impacts presented in above sub-sections along with a qualitative assessment for the restriction scenario against the baseline.

The analysis and results presented in this Section are based on publicly available evidence and literature, including Eurostat datasets such as PRODCOM[52] and Structural Business Statistics (SBS)[53], as well as an online survey and follow-up interviews with companies in the upstream O&G, CCS, oil refining and fuel distribution sectors. A detailed consultation synopsis is presented in the Appendices. The evidence presented in the following sections is thus based on analysis of the evidence from these sources.

4.1.1 Economic impact pathways

The restriction scenario RO2 is expected to affect a broad range of stakeholders if implemented, including the businesses operating in the sectors within scope, as well as downstream users and other actors in the wider economy.

The primary impact pathway from adopting RO2 arises from the requirement to remove or replace PFAS-containing equipment in the sectors, or to stop the sector's activities if PFAS-free alternatives that meet performance criteria cannot be developed. Compliance would require companies to modify existing systems or adopt PFAS-free alternatives (or stop the activities), potentially disrupting operations during transition periods and leading to temporary output reductions within the EEA, when compared to the baseline. The transition would also generate additional costs associated with identifying, testing, and validating alternative technologies to meet performance, safety, and regulatory requirements. In addition, there would also be requirements for the development of international standards and management of change to install replacement components. Even after implementation, PFAS-free solutions may involve higher capital or operational costs, which could affect long-term efficiency and competitiveness. Where suitable alternatives are unavailable, impacts may be more severe on the industry sector. Depending on the operational criticality of PFAS-containing components, businesses may face reduced production capacity, early facility closure, or relocation outside the EEA.

Additional compliance costs are likely to be passed through supply chains, contributing to higher refined product prices and potentially causing supply disruptions. Such disruptions may affect product quality and operational reliability for downstream users. Given the foundational role of oil and gas products in the wider economy, these effects could contribute to broader socio-economic consequences, including inflationary pressures, reduced economic activity and mobility, and potential employment losses. Increased reliance on imports from third countries may also occur. However, the restriction could also stimulate investment in PFAS-free technologies and innovation, which may generate longer-term competitiveness and market opportunities, which is discussed in Section 4.1.6.

An analysis of evidence gathered from a targeted stakeholder consultation and desktop research was conducted, focussing on PFAS use in sealants, coatings for wires, capacitors, pipes, and their waste

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[52] Eurostat. (2026). PRODCOM Database. Available from: https://ec.europa.eu/eurostat/web/prodcom/information-data

[53] Eurostat. (2026). Structural business statistics (SBS). Available at: https://ec.europa.eu/eurostat/web/structural-business-statistics

management. Results indicate that approximately 40-70% of equipment across upstream O&G, refining, and distribution sectors contains PFAS (Table 4-1 below), with most survey participants identifying this equipment as operationally critical. In addition, stakeholders indicated that, at present, only 10-30% of PFAS-containing equipment could currently be replaced with PFAS-free alternatives.

Table 4-1: Share of in scope equipment that contains PFAS across the sectors

Sector	Share of PFAS containing equipment
Upstream O&G and CCS	40-50%
Refinery sector	50-70%
Distribution sector	50-60%

Source: Ricardo analysis based on stakeholder consultation.

Based on this evidence, three impact scenarios were developed.

- The **high-impact** scenario assumes limited availability of suitable alternatives during the derogation period, allowing replacement of only 10-30% of PFAS-dependent components. Under this scenario, critical equipment shortages would lead to the cessation of upstream production, refinery operations, and fuel distribution across the EEA, resulting in a complete loss of baseline turnover, gross value added (GVA), and employment following expiry of the derogation. The majority of stakeholders consulted suggest that this is the most likely outcome.
- The **medium-impact** scenario assumes the increased development of alternatives in the transition period, enabling replacement of 20-60% of PFAS-containing equipment and allowing continued operations with substantial disruptions. Some facilities may close early due to unrecoverable replacement costs. Between 30% and 60% of installations could be affected, with sectoral turnover, GVA, and employment projected to decline by approximately 45% relative to baseline levels. This scenario is considered less likely by the stakeholders consulted.
- The **low-impact** scenario assumes rapid technological advancement during the transition period, allowing replacement of at least 90% of PFAS-containing equipment and limiting operational disruption largely to scheduled maintenance periods. Nevertheless, some facilities may still close due to upgrade costs, affecting 10-20% of operations and reducing turnover, GVA, and employment by approximately 15% against the baseline. This scenario is considered very unlikely, based on current evidence and the stakeholders consulted.

The timing of these impacts depends on regulatory implementation. ECHA's scientific committees are expected to submit a final opinion to the European Commission in 2026[54]. Assuming regulatory adoption in 2027, the restriction is expected to enter into force early in 2028, followed by an 18-month transition period ending in mid-2029. A 12-year derogation period is assumed to run from mid-2029 to mid-2041. Economic impacts, against the baseline, are therefore assessed from mid-2041 to 2055, although it is possible that they could crystalise earlier (e.g., by companies electing to invest elsewhere ahead of the end date of the derogation).).

Impacts could arise earlier if operators cease investment in PFAS-containing equipment or later depending on spare-part availability (also subject to a proposed derogation as described in Section 3.2) and maintenance cycles, insufficient evidence exists to model such variations reliably. For methodological consistency, the analysis assumes that full impacts materialise immediately after the derogation period ends, providing a transparent and consistent basis for economic impact assessment.

4.1.2 Business impacts on upstream O&G operations

In 2024, the upstream oil and gas sector in the EEA generated €200 billion in turnover and €136 billion in GVA. Although the sector is expected to contract due to the EU's decarbonisation objectives, with turnover falling to €63 billion and GVA to €43 billion by 2040, it is projected to remain economically significant. Under the baseline

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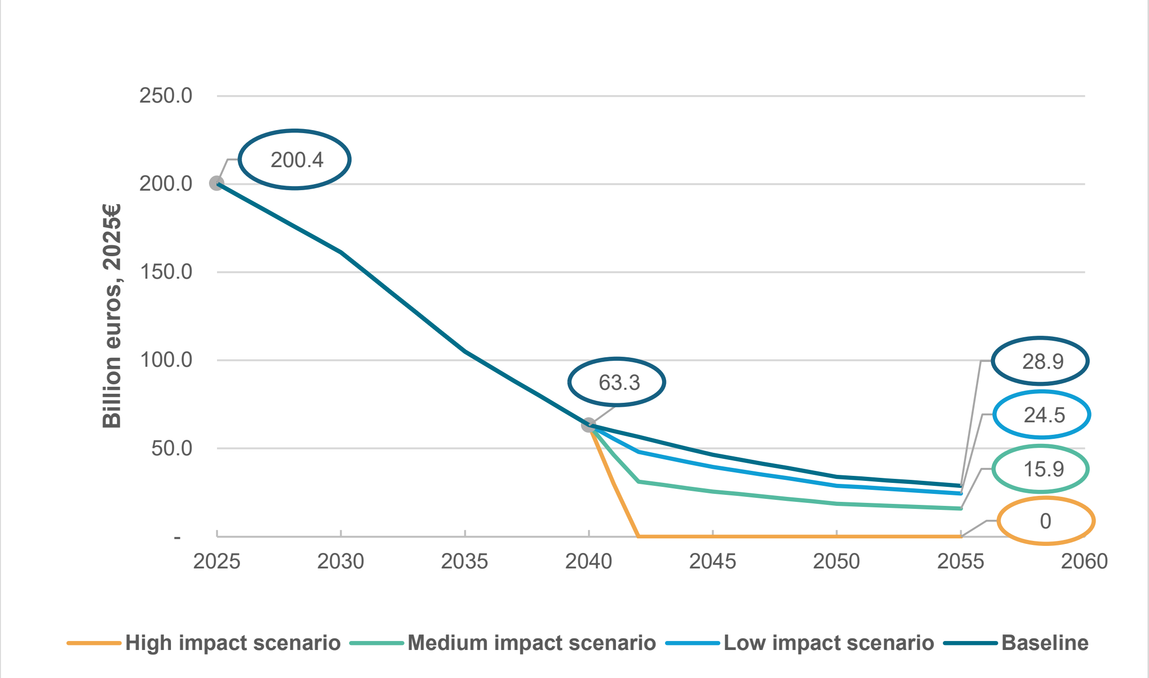
[54] ECHA. (2025). ECHA to consult on PFAS draft opinion in spring 2026. Available from: https://echa.europa.eu/-/echa-to-consult-on-pfas-draft-opinion-in-spring-2026

scenario, the sector is projected to generate on average €40 billion in turnover and €27 billion in GVA annually over 2041-2055 (in 2025 prices) (see Section 3.1.3).

The PFAS restriction (RO2) could result in a severe economic contraction when compared to the baseline, with the high-impact scenario indicating the complete shutdown of upstream O&G operations by 2041, and partial closures in the medium- and low-impact scenarios. Figure 4-1 below presents the estimated effects of RO2 on sales turnover of the upstream O&G sector in the EEA.

Figure 4-1: Sales turnover of upstream O&G sector in the EEA across the baseline and restriction impact scenarios (€ billion, 2025€)



In the **high-impact** scenario, the limited availability of suitable PFAS free alternatives for critical components[55] means that operators cannot maintain safe and legally compliant upstream O&G activity in the EEA once the PFAS-containing equipment in use in 2041 reaches its end of life. The absence of technically viable solutions results in a complete shutdown of upstream O&G extraction by 2041. The loss of all upstream activity from 2041-2055 corresponds to €40 billion/year (undiscounted) or €26 billion/year (discounted), against the baseline. Cumulatively over this period, this would mean a loss of €585 billion in turnover (undiscounted) or €305 billion (discounted), when compared to the baseline. The sector's contribution to GVA would also be reduced proportionally, by €27 billion/year (undiscounted) or €18 billion/year (discounted) from 2041-2055, which cumulatively would correspond to €400 billion (undiscounted) or €207 billion (discounted)[56].

In the **medium-impact** scenario, the emergence of PFAS free alternatives for some critical applications enables continued but materially disrupted operations. Facilities would face higher operating costs, shorter maintenance intervals, and reduced utilisation rates due to reliance on transitional equipment in parts of the system where no fully equivalent substitute exists. These pressures cause economically marginal assets to close earlier than planned, while remaining installations operate below optimal capacity. The stakeholder consultation indicates that a large proportion of upstream activity could be affected, resulting in a 45% reduction of baseline activity from 2041. From 2041-2055, this translates into a turnover loss of €12 billion/year (discounted) or a total of €135 billion (discounted) over the period; and a GVA loss of €8 billion/year (discounted) or a total of €93 billion (discounted) over the period. Alternatives for some critical applications enables the continuation of the materially disrupted operations. Facilities would face higher operating costs, shorter maintenance intervals, and reduced utilisation rates due to reliance on transitional equipment in parts

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[55] See Section 4.1.6 and Appendix 3.

[56] Undiscounted figures are presented in 2025 prices. Discounted values are calculated using a real discount rate of 3% in line with the European Commission's Better Regulation Toolbox #64. For further details on discounting, please see Appendix 1.

of the system where no fully equivalent substitute exists. These pressures cause economically marginal assets to close earlier than planned, while remaining installations operate below optimal capacity.

In the **low-impact** scenario, the rapid development and commercialisation of PFAS-free equipment allow for the majority of PFAS-containing equipment to be replaced during routine maintenance, limiting operational disruption. However, costs will still rise where substitutes remain less durable or more expensive, and a small number of specialised components may continue to lack fully equivalent alternatives. Therefore, some late-life or high-cost assets may close earlier than expected, though the overall scale of disruption remains modest. The available evidence and stakeholder consultation indicates that a smaller proportion of upstream activity could be affected, resulting in a 15% reduction of baseline activity from 2041. From 2041-2055, this translates into a turnover loss of €4 billion/year (discounted) or a total of €46 billion (discounted) over the period; and a GVA loss of €3 billion/year (discounted) or a total of €30 billion (discounted) over the period

The Table below provides a summary of the turnover and GVA impacts, relative to the baseline.

Table 4-2: Annualised impacts on the size of the EEA upstream O&G operators business from 2041-2055, against the baseline scenario (Discounted Present Value or PV, € 2025)

Scenario	Turnover impacts, average per year from 2041-2055, against the baseline	GVA impacts, average per year from 2041-2055, against the baseline
High impact	**Turnover loss of €26 billion per year** (PV, € 2025) on average from 2041-2055, against the baseline scenario.	**GVA loss of €18 billion per year** (PV, € 2025) on average from 2041-2055, against the baseline scenario.
Medium impact	**Turnover loss of €12 billion per year** (PV, € 2025) on average from 2041-2055, against the baseline scenario.	**GVA loss of €8 billion per year** (PV, € 2025) on average from 2041-2055, against the baseline scenario.
Low impact	**Turnover loss of €4 billion per year** (PV, € 2025) on average from 2041-2055, against the baseline scenario.	**GVA loss of €3 billion per year** (PV, € 2025) on average from 2041-2055, against the baseline scenario.

In addition to the impacts on conventional upstream oil and gas activities, the proposed PFAS restriction could also affect the emerging CCS sector. However, the magnitude of these impacts remains difficult to quantify due to the early stage of commercial deployment, limited availability of operational data, and uncertainty around future technology choices and infrastructure configurations. The box below provides a qualitative assessment of the likely implications for the sector based on stakeholder consultations.

Box 4-1 Potential impacts of the PFAS Restriction Option 2 on CCS

Impacts on CCS from the restriction

Stakeholder information provided by members of IOGP indicates that, although CCS deployment is expected to expand significantly in the coming decades, substantial uncertainty remains regarding the pace and scale of development. Deployment trajectories depend on investment decisions, permitting processes, regulatory frameworks, and the availability of enabling infrastructure.

Across the CCS value chain, several categories of PFAS-containing equipment, including sealants and sealing devices, wire coatings, capacitors and piping systems such as subsea umbilicals, are considered critical for safe and reliable operations. PFAS-based components are integral to CO_2 transport infrastructure because they provide the thermal resistance, chemical compatibility and sealing integrity required to prevent leaks and ensure system safety under high-pressure, high-density conditions.

CCS operations require the permanent and secure storage of CO_2 in deep geological formations. Maintaining CO_2 in a supercritical state typically requires injection and containment at depths greater than 800 metres below the seabed, where lithostatic pressures are sufficient to sustain supercriticality. PFAS-containing components, including high-integrity pipes, seals and capacitors, play a vital role in maintaining containment and preventing equipment failure under these conditions. Based on data supplied by IOGP members, planned CCS capacity in the absence of a PFAS restriction is estimated to increase to approximately 84 $MtCO_2$ per year within the EEA (including Norway) by the early-2030's, with further potential for currently planned projects to reach 220 $MtCO_2$ per year across Europe before 2050 (EEA and the UK).

In the event of a restriction, IOGP members have indicated that Health, Safety, Security and Environment (HSSE) risk management considerations would become a decisive factor in determining where CCS investments are directed. If PFAS-containing critical components cannot be replaced by technically equivalent PFAS-free alternatives, HSSE risks, and associated operator liability, are expected to be lower outside the EU.

Such outcomes could potentially slow the deployment of CCS infrastructure within the EEA and may affect progress toward policy objectives, including the EU target of achieving at least 50 million tonnes of annual CO_2 injection capacity by 2030 under initiatives led by the European Commission[57]. However, the extent of this potential impact remains uncertain and depends heavily on technological development, availability of substitutes, and future regulatory implementation.

4.1.3 Business impacts on crude oil refining

In 2024, the refining sector remained a major industrial contributor within the EEA, and although its long-term output is expected to decline due to lower fossil fuel demand, efficiency gains, and tightening climate policy, the sector retains a significant economic footprint. By 2040, turnover is projected at €178 billion, with €16 billion in GVA, reflecting continued demand for transport fuels, petrochemical feedstocks, and refinery-integrated products under the baseline scenario (Section 3.1.3). Under the baseline, refining activities from 2041-2055 remain economically significant, against which the impacts of the restriction are assessed.

The proposed restriction could have substantial impacts on the crude oil refining sector, projecting reductions in economic activity from 2041 ranging from 10% to 100%, depending on the impact scenario. In discounted terms, this could lead to cumulative turnover losses ranging from €128 billion to €855 billion over the period (or €11-€74 billion per year), while cumulative losses in GVA could range from €11-€76 billion (or €1-€7 billion per year). Figure 4-2 presents the estimated effects of RO2 on sales turnover of fuel refining in the EEA.

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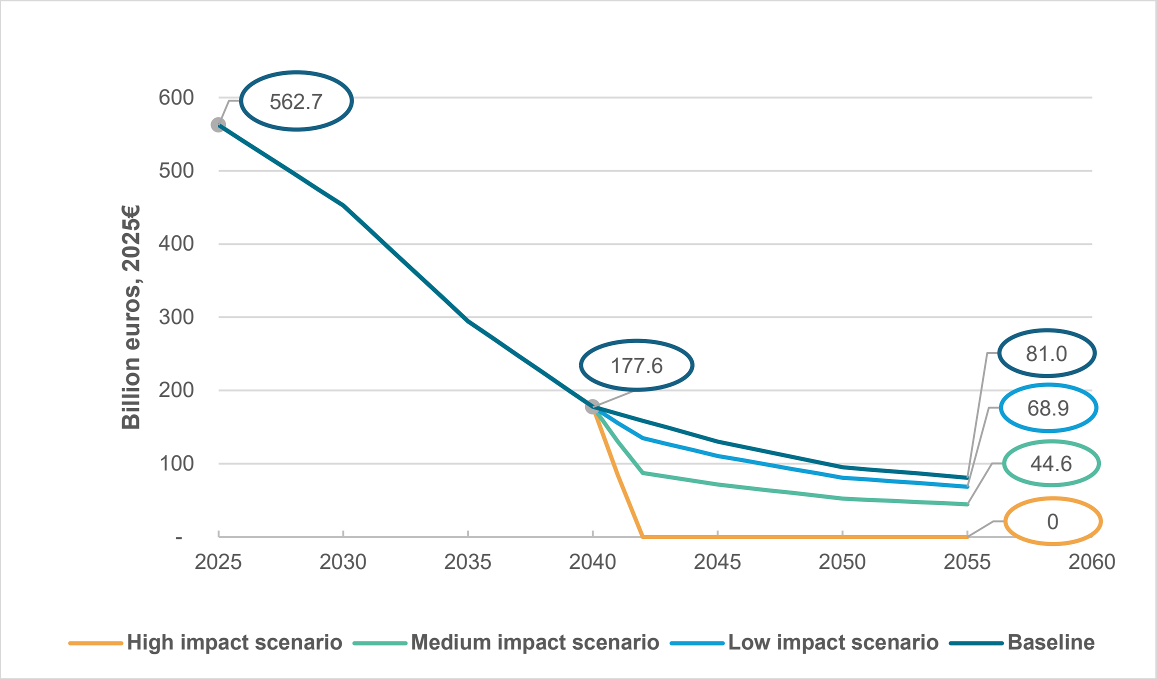
[57] European Commission. (n.d.). The EU's 2030 carbon storage target. Available from: https://climate.ec.europa.eu/eu-action/industrial-carbon-management/eus-2030-carbon-storage-target_en

Figure 4-2: Sales turnover of crude oil refining sector in the EEA across the baseline and restriction impact scenarios (€ billion, 2025€)



In the **high-impact** scenario, the absence of PFAS-free alternatives for essential components, such as high temperature gaskets, corrosion resistant seals, pump linings, reactor internals, and fluoropolymer based antifouling coatings, prevents refineries from operating safely and within regulatory compliance such as ISO and API standards. Many of these systems operate under extreme conditions of heat, pressure, and chemical reactivity, making the PFAS functionality difficult to replace. As the derogation period comes to an end, refineries are forced into full closure by 2041. The resulting loss of economic activity over 2041-2055 amounts to €1,640 billion in turnover and €145 billion in GVA (undiscounted). When discounted to 2025, the NPV of turnover losses is €855 billion (€74 billion per year), while GVA losses amount to €76 billion (€7 billion per year).

In the **medium-impact** scenario, partial substitution enables continued operation, but with materially constrained throughput and efficiency. Transitional PFAS-free components may be less durable or require more frequent replacement, resulting in raising unit operating costs. Some refineries, particularly older, less integrated, or financially marginal facilities, are expected to close earlier than planned, while others operate below optimum utilisation. Based on a 45% reduction in refining activity, undiscounted losses from 2041-2055 could reach €738 billion in turnover and €51 billion in GVA. Discounted figures imply turnover losses of €385 billion (€33 billion per year) and GVA losses of €34 billion (€3 billion per year).

In the **low-impact** scenario, widespread commercialisation of PFAS-free refinery grade materials allows for most of the baseline equipment to be replaced during standard maintenance cycles with only modest disruption. Some cost pressures persist, particularly where PFAS-free alternatives reduce asset lifetimes or increase maintenance intensity. A subset of smaller or less efficient refineries could become uneconomic. The resulting undiscounted losses amount to €246 billion in turnover and €22 billion in GVA over 2041-2055, with discounted values equivalent to €128 billion (€11 billion per year) for turnover and €11 billion (€1 billion per year) for GVA.

Table 4-3 overleaf provides a summary of the turnover and GVA impacts, relative to the baseline.

Table 4-3: Annualised impacts on the size of the EEA oil refining business from 2041-2055, against the baseline scenario (Discounted Present Value or PV, € 2025)

Scenario	Turnover impacts, average per year from 2041-2055, against the baseline	GVA impacts, average per year from 2041-2055, against the baseline
High impact	**Turnover loss of €74 billion per year** (PV, € 2025) on average from 2041-2055, against the baseline scenario.	**GVA loss of €7 billion per year** (PV, € 2025) on average from 2041-2055, against the baseline scenario.
Medium impact	**Turnover loss of €33 billion per year** (PV, € 2025) on average from 2041-2055, against the baseline scenario.	**GVA loss of €3 billion per year** (PV, € 2025) on average from 2041-2055, against the baseline scenario.
Low impact	**Turnover loss of €11 billion per year** (PV, € 2025) on average, from 2041-2055, against the baseline scenario.	**GVA loss of €1 billion per year** (PV, € 2025) on average from 2041-2055, against the baseline scenario.

4.1.4 Business impacts on renewable fuels

Advanced and conventional renewable fuels play a strategic role in the EEA's decarbonisation pathway, particularly in hard-to-electrify segments such as aviation, maritime transport and heavy-duty road freight. Although renewable fuels production, especially advanced renewable fuels production, currently remains in nascent stages, the sector is expected to expand in response to the Renewable Energy Directive, ReFuelEU Aviation, and national decarbonisation policies[58]. Renewable fuels are considered an essential pillar of the EU's energy transition, both as a direct emissions reduction tool and as a feedstock source for emerging sectors such as sustainable aviation fuels (SAF) and renewable marine fuels[59].

The proposed restriction could disrupt the renewable fuels sector, ranging from widespread facility shutdowns in the high-impact scenario to moderate operational constraints in lower-impact cases, undermining the sector's role in decarbonising hard-to-abate transport modes. Figure 4-3 presents the estimated effects of RO2 on sales turnover of the renewable fuels sector in the EEA.

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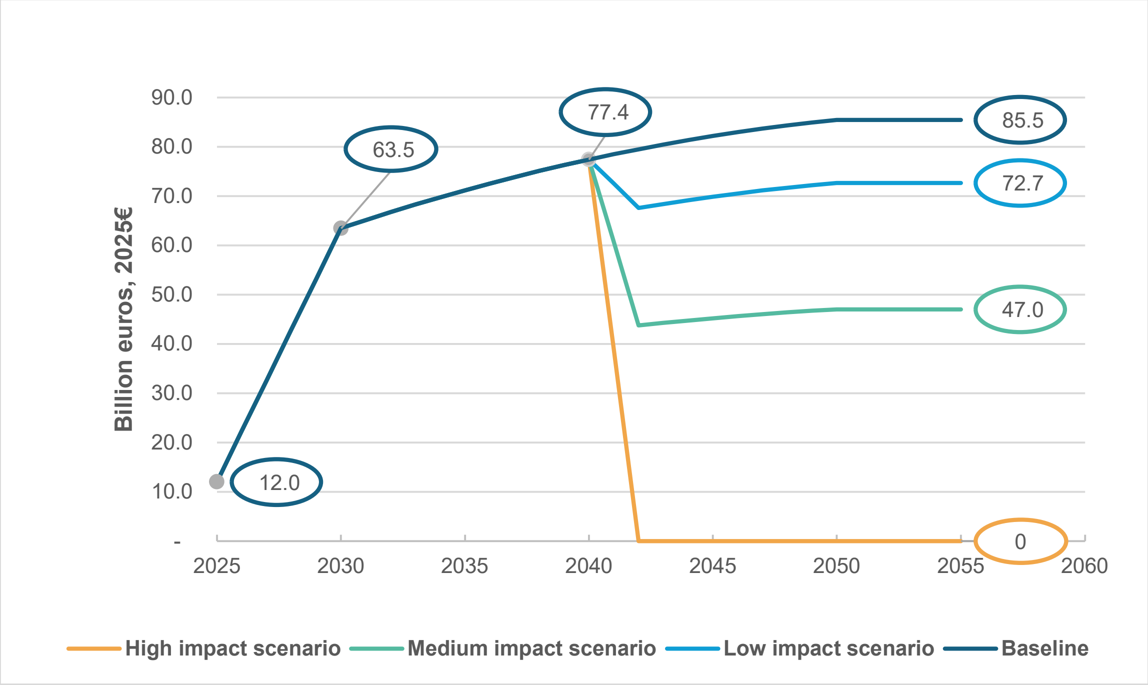
[58] European Commission (n.d.) Biofuels. Available from: https://energy.ec.europa.eu/topics/renewable-energy/bioenergy/biofuels_en

[59] European Commission (2025) Commission unveils the Sustainable Transport Investment Plan: a strategic approach to boost renewable and low-carbon fuels for aviation and waterborne transport. Available from: https://transport.ec.europa.eu/news-events/news/commission-unveils-sustainable-transport-investment-plan-strategic-approach-boost-renewable-and-low-2025-11-05_en

Figure 4-3: Sales turnover of renewable fuels sector in the EEA across the baseline and restriction impact scenarios (€ billion, 2025€)



The **high-impact** scenario assumes that PFAS-free alternatives for critical process components, such as high temperature seals, reactor linings and corrosion resistant gaskets, do not become available at the required technical standard by the end of the derogation period. Biofuel production processes, including transesterification, hydro-processing and gasification pathways, rely heavily on equipment operating under corrosive, high temperature or high-pressure conditions, making these components essential to safe and efficient operation. Without suitable replacements, production capacity cannot be sustained, leading to widespread shutdowns of biofuel facilities in the EU from 2041 onwards. Alternatives for critical process components, such as high temperature seals, reactor linings and corrosion-resistant gaskets, do not become available at the required technical standard by the end of the derogation period. In addition, these components are currently essential for safe and efficient biofuel production, especially in processes such as transesterification, temperature or high-pressure conditions. Without suitable replacements, production capacity cannot be sustained, leading to widespread shutdowns of biofuel facilities

The resulting loss of economic activity over 2041-2055 is estimated at €1,212 billion in turnover (undiscounted) with an annual average of €84 billion/year, while GVA losses total €97 billion (€7 billion per year). Discounted to 2025 prices, the turnover NPV amounts to €612 billion (€53 billion per year) and GVA losses amount to €49 billion (€4 billion per year). Such a large-scale contraction would directly undermine the EU's ability to meet its Net Zero targets, as renewable fuels are a key bridging solution for sectors where renewable electricity or hydrogen cannot be deployed rapidly.

In the **medium-impact** scenario, PFAS-free alternatives emerge for some, but not all, critical components. This allows production across the sector to continue, albeit with substantial operational constraints. Plants may experience shorter maintenance intervals, lower conversion efficiencies and reduced availability of key process units, leading to a notable decline in aggregate output. Economically marginal facilities may be forced to close earlier than planned due to rising maintenance and equipment replacement costs.

Under this scenario, the undiscounted turnover losses over 2041-2055 amount to €545 billion (€38 billion per year), and GVA losses total €44 billion (€3 billion per year). Discounted losses equal €276 billion (€24 billion per year) for turnover and €22 billion (€2 billion per year) for GVA. At this level of disruption, biofuel deployment slows materially, placing additional pressure on other decarbonisation levers such as electrification, green hydrogen and efficiency measures.

In the **low-impact** scenario, rapid commercialisation of PFAS-free refinery grade and biofuel grade equipment enables most critical components to be replaced during routine maintenance cycles, minimising operational disruption. Some cost increases still arise where PFAS-free materials exhibit lower durability or inferior performance, and a limited number of older or smaller plants may nonetheless face economic viability challenges. The scale of sectoral impact would be moderate, with undiscounted turnover losses of €182 billion (€13 billion per year) and GVA losses of €15 billion (€1 billion per year) over 2041–2055. Discounted PVs correspond to €92 billion for turnover (€8 billion per year) and €7 billion for GVA (€1 billion per year.

Table 4-4 provides a summary of the turnover and GVA impacts, relative to the baseline.

Table 4-4: Annualised impacts on the size of the EEA renewable fuels business from 2041-2055, against the baseline scenario (Discounted or PV, € 2025)

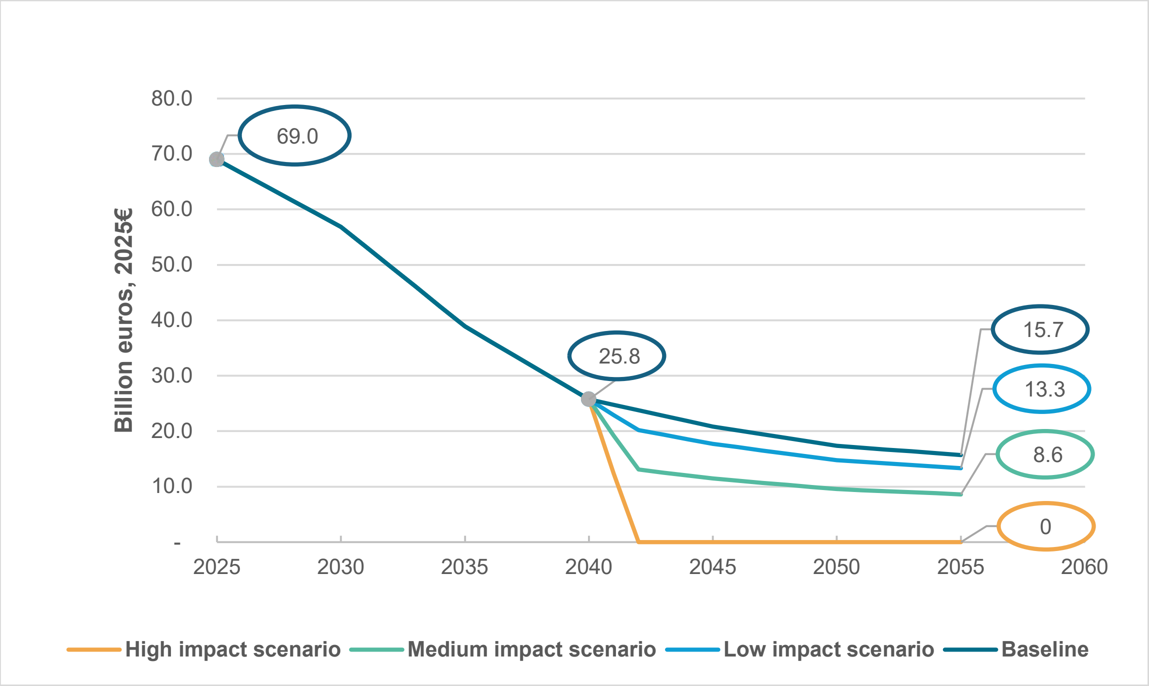
Scenario	Turnover impacts, average per year from 2041-2055, against the baseline	GVA impacts, average per year from 2041-2055, against the baseline
High impact	**Turnover loss of €53 billion per year** (PV, € 2025) on average from 2041-2055, against the baseline scenario.	**GVA loss of €4 billion per year** (PV, € 2025) on average from 2041-2055, against the baseline scenario.
Medium impact	**Turnover loss of €24 billion per year** (PV, € 2025) on average from 2041-2055, against the baseline scenario.	**GVA loss of €2 billion per year** (PV, € 2025) on average from 2041-2055, against the baseline scenario.
Low impact	**Turnover loss of €8 billion per year** (PV, € 2025) on average, from 2041-2055, against the baseline scenario.	**GVA loss of €1 billion per year** (PV, € 2025) on average from 2041-2055, against the baseline scenario.

4.1.5 Business impact on fuel distribution

The fuel distribution sector represents a critical link between upstream supply, refineries and final consumers, ensuring the safe and reliable transportation of liquid fuels across pipelines, road tankers, rail wagons and coastal tankers. In 2024, the sector's turnover in the EEA was estimated at €69 billion, and GVA equivalent to €20.5 billion. The sector is expected to contract structurally as conventional fuel demand declines significantly and renewable fuel uptake increases, although to a lower extent in terms of scale. By 2040, therefore, sectoral turnover is projected to fall to €25.8 billion, and GVA to €7.6 billion (see Section 3.1.3.4).

The proposed restriction could also disrupt the fuel distribution sector, ranging from widespread facility shutdowns in the high-impact scenario to moderate operational constraints in lower-impact cases, with broader indirect implications in the functioning of the EU's single market. Figure 4-4 presents the estimated effects of RO2 on sales turnover of the fuel distribution sector in the EU.

Figure 4-4: Sales turnover of fuel distribution sector in the EEA across the baseline and restriction impact scenarios (€ billion, 2025€)



In the **high-impact** scenario, the absence of PFAS-free replacements for critical distribution system components, such as seals, hoses, joint packings and corrosion-resistant linings, prevents continued safe operation of the distribution network. Fuel distribution assets, particularly pipelines and shipborne systems, rely on PFAS-based materials for chemical resistance, fire safety and durability under continuous operation. As PFAS-containing- components reach the end of their service life and cannot be replaced, operations across the pipeline, road, rail and shipping networks face progressive shutdowns.

The consequent reduction in economic activity from 2041-2055 is equivalent to turnover losses of €277 billion (undiscounted) or €19 billion per year; and GVA losses of €82 billion or €6 billion per year over this period. When discounted, turnover losses reach a PV of €143 billion (or €12 billion per year) and GVA losses reach a PV of €42 billion (or €4 billion per year). These disruptions extend beyond direct logistics firms: fuel retailers, airports, industrial consumers and emergency services would face significant supply reliability constraints.

Under the **medium-impact** scenario, viable PFAS-free alternatives emerge for some, but not all, of the system-critical components. This allows the distribution system to function, though with lower reliability and higher operating costs. Pipelines may require more frequent pressure management and integrity checks; road and rail operators may face shorter replacement intervals for hoses and couplings; and coastal tanker operations may experience higher maintenance downtime. These pressures force lower overall throughput and the retirement of older assets. As a result, undiscounted turnover losses for 2041-2055 equal €125 billion (€9 billion per year), with GVA losses of €37 billion (€3 billion per year). Discounted losses amount to €64 billion (€6 billion per year) for turnover and €19 billion (€2 billion per year) for GVA.

In the **low-impact** scenario, PFAS-free distribution components become widely available and can be integrated during routine maintenance cycles, limiting operational disruption. Some cost increases remain where non-PFAS materials offer reduced durability or require more frequent inspection, and some minor regional networks may still shut down early. Nonetheless, system reliability is largely preserved. The resulting undiscounted losses over 2041-2055 amount to €42 billion in turnover (€3 billion per year) and €12 billion in GVA (€1 billion per year). Discounted losses correspond to €21 billion for turnover (€2 billion per year) and €6 billion for GVA (€1 billion per year).

Table 4-5 provides a summary of the turnover and GVA impacts, relative to the baseline.

Table 4-5: Annualised impacts on the size of the EEA fuel distribution sector from 2041-2055, against the baseline scenario (Discounted or PV, € 2025)

Scenario	Turnover impacts, average per year from 2041-2055, against the baseline	GVA impacts, average per year from 2041-2055, against the baseline
High impact	**Turnover loss of €12 billion per year** (PV, € 2025) on average from 2041-2055, against the baseline scenario.	**GVA loss of €4 billion per year** (PV, € 2025) on average from 2041-2055, against the baseline scenario.
Medium impact	**Turnover loss of €6 billion per year** (PV, € 2025) on average from 2041-2055, against the baseline scenario.	**GVA loss of €2 billion per year** (PV, € 2025) on average from 2041-2055, against the baseline scenario.
Low impact	**Turnover loss of €2 billion per year** (PV, € 2025) on average, from 2041-2055, against the baseline scenario.	**GVA loss of €1 billion per year** (PV, € 2025) on average from 2041-2055, against the baseline scenario.

4.1.6 Innovation and research

In response to increasing regulation and growing environmental and health concerns associated with PFAS, industries that rely on PFAS-containing equipment are increasingly investing in assessing PFAS-free alternatives. Due to their position in the supply chain, the sectors in scope of this study are heavily reliant on equipment manufacturers and material suppliers to develop and provide viable PFAS-free alternatives.

Evidence collated through stakeholder engagement of companies (*via* the survey and follow-up interviews) has suggested that alternatives are available for 10-30% of the PFAS-containing equipment (with caveats such as technical feasibility for some applications, safety requirements etc.). A breakdown per equipment is supplied in the following table. There is uncertainty associated with the availability of alternatives with a number of stakeholders unable to provide information on the availability of PFAS-free alternatives. This is a general value chain issue, as there is a lack of information on alternatives.

Table 4-6: Availability of PFAS-free alternatives

Equipment	Availability of alternatives (% of baseline equipment)
Sealants and sealing devices	30% (15-90%)
Coatings for wires	20% (10-60%)
Capacitors	10% (0-10%)
Piping systems and hoses	10% (5-40%)

The findings from a rapid review of this evidence for alternatives, complemented by the outputs of a literature review, are summarised in the Box overleaf.

Box 4-2 Alternatives to PFAS

In response to the restriction scenarios, users of products containing PFAS are likely to consider two principal response strategies:

- **Substituting of PFAS-containing equipment,** replacing PFAS-containing sealants, coatings for wires, capacitors, pipes with PFAS-free equipment with similar performance if available as indicated by 70% of respondents.
- **Delocalisation of operations to other jurisdictions and/or closure of operations in the EEA** as indicated by 30% of respondents.

The stakeholder consultation and literature research identified potential alternatives to sealing and sealing devices, coatings for wires, and piping systems, which are listed below and discussed further in Appendix 4. No technically viable alternatives have been identified for capacitors. Examples of these alternatives include:

- Sealing applications:
    - ACM (ethylene acrylate copolymer)
    - EPDM (ethylene propylene diene monomer)
    - Metallic seals, nickel alloy 625
- Coatings for wires:
    - Ceramics
    - Polyetherketone (PEEK)
    - Polypropylene (PP)
- Piping:
    - C-PVC
    - FRP (Fiber Reinforced Plastic) FRP (Fiber Reinforced Plastic)
    - Polypropylene (PP)

Despite the identification of potential substitute materials, stakeholders indicated that many **alternatives are not commercially available yet for sealants and sealing devices, coatings for wires, and piping which meet the combination of demanding properties required for safe operations and these only cover limited applications; and no alternatives have yet to be identified for capacitors**. The feasibility of alternatives is further discussed in Appendix 4.

Within the proposed derogation period (12 years plus 18 months following entry into force of the restriction), the availability of alternatives may evolve. Ongoing research and development activity, including EU-funded[60] projects, is targeting PFAS substitution. In parallel, patent activity related to PFAS-free materials is increasing, with significant growth observed internationally (especially China[61]). These developments may support broader commercialisation of PFAS-free solutions during the derogation period.

However, stakeholder evidence suggests that alternatives may not be available for all uses within the derogation timeframes. Once suitable alternatives are identified, these will require testing in relevant environments, which could take years. Alternatives would need to comply with recognised technical standards (such as ISO and API standards), demonstrate performance under demanding operating environments and secure approvals for use. This would then be followed by standards development and management of change to implement alternatives in operations. For example, sealants require to be temperature resistant, suitable in high stress environments and to be durable with a long lifespan.

Stakeholders further emphasised that the economic viability of PFAS-free alternatives will be a critical determinant of adoption, particularly for assets nearing the end of their operational lifetime. High production or certification costs associated with emerging materials could limit uptake, even where technically suitable options exist. Consequently, the commercial success of PFAS-free alternatives will depend not only on meeting performance and safety requirements but also on achieving cost-competitive and scalable production.

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[60] European Commission. (n.d.) CORDIS – EU research results. Available from: https://cordis.europa.eu/search?q=%27PFAS%27%20AND%20%27alternatives%27&p=1&num=10&srt=Relevance:decreasing

[61] Essenscia. (2023). PFAS substitutes – A patent literature based analysis. Available from:https://www.essenscia.be/wp-content/uploads/2023/10/patent-cell-tw_pfas-substitutes_oct2023.pdf

Thus, while regulatory action might stimulate expenditure in R&D, this might yield a re-allocation of resources toward compliance-driven substitution rather than broader productivity- or decarbonisation-related innovation. This diversion can crowd out research that would otherwise enhance efficiency, competitiveness or decarbonisation in ways not directly related to PFAS replacement. Smaller firms may be disproportionately affected, as limited budgets constrain their ability to balance compliance-oriented R&D with broader strategic innovation. Consequently, even as regulation stimulates new activity, it may simultaneously reduce the overall productivity and effectiveness of the innovation portfolio at the sector level.

Whilst additional investment in R&D could generate positive economic and environmental outcomes within the EEA, the regulatory drivers might also redirect resources towards compliance-driven substitution activities. This could, in some cases, reduce more productive investments or breakthrough innovation compared to the baseline, potentially affecting negatively the overall efficiency of innovation outcomes.

4.1.7 Sectoral competitiveness, trade and investment flows

Overall, the restriction (RO2) could weaken the EEA's global competitiveness across the O&G value chain, with both direct and indirect effects limiting the Union's ability to compete internationally, especially in upstream O&G production, CCS, oil refining, and renewable fuels production.

Direct impacts on global competitiveness are likely to arise from reduced production capacity, higher operating costs and lower utilisation rates across the value chain under the restriction scenarios. In the high impact scenario, upstream extraction, refining activity and large parts of the renewable fuels and fuel distribution sectors may cease entirely once PFAS dependent equipment reaches end of life, removing the EEA from international export markets for crude oil, refined products and renewable fuels. Even in the medium impact scenario, operators are likely to face persistent cost pressures, shorter maintenance cycles and earlier than expected asset closures, placing the EEA at a disadvantage relative to competitors in regions where PFAS containing equipment can still be used. The CCS sector may experience similar effects, as investment is likely to shift toward jurisdictions with lower HSSE risks and fewer technological constraints, reducing the EEA's ability to compete globally in emerging carbon management industries.

Indirect impacts may also affect trade patterns, investment flows and supply chain dynamics. As domestic production capacity declines, the EEA could become increasingly dependent on imported crude oil, refined fuels and renewable fuels, exposing it to greater price volatility, reduced security of supply, geopolitical risk and deterioration in its trade balance. Reduced throughput and higher logistics costs in the distribution network may make the region a less attractive location for fuel reliant industries, thereby further weakening its competitive position. At the same time, innovation pathways may shift outside the EEA, as firms in less constrained regions are able to expand production with proven PFAS based technologies at lower cost, capturing global market share vacated by EEA operators. Together, these indirect effects are likely to reinforce the direct economic impacts, amplifying pressures on the EEA's global competitiveness across the oil and gas value chain.

4.1.8 Overall economic impacts

The EEA's economy overall could be negatively affected by the restriction scenario, with a reduction in the O&G value chain's activity and, thus, contribution to the EEA's Gross Domestic Product (GDP) against the baseline.

The contribution of the EEA's upstream O&G operations to GVA could be reduced by an estimated PV of €18 billion/year in the high-impact scenario and €3 billion/year in the low-impact scenario. The contribution of the EEA's downstream value chain to GVA could be reduced by an estimated PV of €15 billion/year in the high-impact scenario and €3 billion/year in the low-impact scenario. Table 4-7 overleaf presents the estimated effects on GVA contributions of the sector from 2041-2055, against the baseline.

Table 4-7: Overview of the economic impact assessment for the restriction scenario against the baseline

Total impacts on the GVA contributions of the following industry in scope, against the baseline (PV/year for 2041-2055 in billion euros, € 2025)	High-impact scenario	Medium-impact scenario	Low-impact scenario
Upstream O&G	**18**	**8**	**3**
Downstream value chain			
Crude oil refining	7	3	1
Renewable fuels	4	2	1
Fuel distribution	4	2	1
Total downstream value chain	**15**	**7**	**3**

Source: Ricardo analysis based on evidence collected from stakeholders and publicly available, Eurostat, and other sources.

A qualitative assessment aggregating all impact analysis was also conducted. For the purposes of this assessment, it is assumed that the net effect on innovation could be slightly positive, albeit limited in scale. Overall, it is considered that the effects on the EEA economy would be detrimental when compared to the baseline 2041-2055, even after accounting for the mitigating effects achieved through research and development efforts to replace baseline products and manufacturing processes with alternatives that comply with the restriction scenarios. The increased costs of doing business in the EU could further deter the EU industry's global competitiveness position.

The economic impact conclusions are summarised qualitatively in the Table below, using the scoring framework described in Section 2 and, in more detail, in Appendix 1

Table 4-8 Overview of the relative economic impact for the restriction scenario against the baseline

Economic impacts	RO2 (against baseline)
Conduct of business, sustainable production, admin burden	-5.0
Sectoral competitiveness, trade and investment flows	-4.0
Innovation and research	+1.0
Overall economic impact	**-3.0**

Source: Ricardo analysis based on the evidence presented in this Study.

4.2 HEALTH IMPACTS

This section presents the assessment of the shortlisted health impacts of the PFAS restriction scenario (RO2), against the baseline. These impacts have been assessed qualitatively. This section is structured into Section 4.2.1, a brief recap of the baseline; and Section 4.2.2, covering the qualitative assessment of public health & safety and health system impacts.

4.2.1 Recap of the baseline

The baseline evidence indicates that there is limited data for the sectors in scope and no studies quantifying PFAS blood concentrations in workers in the upstream O&G, refining, or fuel distribution sectors (see Section 3.1.4).

The main theoretical PFAS exposure routes associated with these sectors include potential inhalation and dermal contact during handling and maintenance activities, although there is currently no sector-specific evidence available for this exposure. Indirect exposure via environmental releases from waste treatment processes where the PFAS is not mineralised back to elemental constituents also remains a potential pathway, however there is a lack of data on this potential pathway in the literature. For these routes there is a lack of sector-specific monitoring data, a substantial evidence gap that introduces significant uncertainty and necessitates a precautionary approach when considering their potential relevance.

Key uncertainties relate to the lack of sector-specific and fluoropolymer exposure measurements, limited toxicological data for most PFAS of interest, and insufficient evidence on fluoropolymer degradation or leaching from the equipment in scope. While empirical data on health impacts within these sectors is limited, fluoropolymers are selected because of their mechanical resistance and chemical stability[20]. These material properties suggest that degradation under normal operating conditions is likely to be minimal. However, the absence of sector-specific measurements introduces uncertainty regarding their potential contribution to PFAS exposure.

As a result, the baseline assessment relies on qualitative evidence to characterise potential health risks, recognising both the widespread health burden associated with monomer PFAS and the limited ability to attribute any portion of this burden to the sectors assessed. Whilst monomeric PFAS are out of scope of this study, available studies highlight that exposure to these PFAS may be associated with adverse health effects, which is relevant, there are traces of monomeric PFAS in the components in scope[40,18], and, such evidence offers a reference point for consideration as part of a qualitative assessment.

4.2.2 Public health & safety and health systems

PFAS-containing equipment used in the upstream O&G, oil refining and fuel distribution sectors (e.g., sealants, sealing devices, coatings and gaskets) is typically enclosed within industrial systems and designed to withstand extreme temperatures, pressures, and corrosive environments[49]. These characteristics mean that, under normal operating conditions, direct exposure to fluoropolymers and fluoroelastomers or other PFAS from equipment in use is expected to be limited. However, without sector-specific monitoring data, uncertainty persists regarding actual exposure potential.

However, as with other PFAS applications, the potential for exposure cannot be fully excluded, particularly where equipment is handled, maintained, dismantled, or treated to waste. The available evidence indicates that the in-scope fluoropolymers and fluoroelastomers themselves have low bioavailability due to their large molecular size, but emissions of more bioavailable PFAS during waste treatment may still contribute to human exposure[18] (with PFAS uses in manufacturing and processing being out of scope). As discussed previously, there is limited data for the sectors in scope, and no studies quantifying PFAS blood concentrations or health impacts among workers in these activities.

During the use phase, potential exposure may occur primarily during maintenance, repair, or inspection of PFAS-containing components. These activities may involve direct handling of sealing devices, coatings for wires, or gaskets, although the magnitude of exposure is expected to be very low due to the enclosed nature of the equipment and the use of personal protective equipment[11]. Inhalation of dust or fumes represent the most plausible theoretical exposure routes in occupational settings. While thermal decomposition of fluoropolymers and fluoroelastomers can generate hazardous fumes at very high temperatures, such conditions are not expected to occur during intended use in the sectors in scope. Nevertheless, the absence of sector-specific exposure measurements means that potential risks during maintenance cannot be fully characterised.

At end of life, PFAS-containing equipment is typically incinerated, co-recycled with metallic material or landfilled, and these processes may release PFAS into the environment[51]. Incineration of fluoropolymers and fluoroelastomers requires high temperatures to achieve effective destruction, and incomplete combustion may generate degradation products that are more bioavailable than the parent polymer. Landfilling may also contribute to long-term PFAS releases through leachate, although the extent of this contribution for the equipment in scope remains uncertain. Workers involved in waste handling, dismantling, or incineration may therefore experience indirect exposure[18] but no data are available to quantify exposure levels or associated health impacts for these activities in the sectors assessed.

Fluoropolymers and fluoroelastomers also contribute to worker safety by providing exceptional resistance to chemical corrosion, high temperatures, and aggressive process fluids[62]. In upstream O&G and refining operations, these properties help maintain equipment integrity and prevent leaks of hydrocarbons, acids, bases, and solvents. By reducing the likelihood of corrosion-related failures or degradation,

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[62] ECHA. (2023). Annex E to the Annex XV restriction report. Proposal for a restriction. Available from: https://echa.europa.eu/documents/10162/8de11d7c-c56f-e204-5072-e89f11071219

fluoropolymer-based components support safe handling of hazardous substances and minimise the risk of chemical exposure or other incidents.

Under RO2, a reduction in the use of PFAS-containing equipment is expected to decrease the potential for PFAS-related exposure over time. As PFAS-containing components are phased out, the number of PFAS-bearing items handled during maintenance and routine operations will decline, lowering the likelihood of direct occupational contact with PFAS. However, during the transition period, exposure potential may temporarily increase as operators remove legacy PFAS-containing components and replace them with compliant alternatives. This may lead to a short-term rise in handling, dismantling, and waste-management activities involving PFAS-containing materials, although exposure levels are still expected to remain low due to the enclosed nature of the equipment and the use of protective measures.

In the longer term, the substitution of fluoropolymers and fluoroelastomers with PFAS-free alternatives is expected to reduce indirect exposure arising from end-of-life treatment. As fewer PFAS-containing components enter incineration or landfill streams, the potential for PFAS releases to air, soil, or leachate will diminish, lowering environmental contributions to human exposure. However, the extent of this benefit will depend on the performance of PFAS-free alternatives. If substitutes have reduced durability or chemical resistance, there is a possibility of increased equipment failures or leaks, which could elevate worker exposure to hazardous process chemicals. These risks are not PFAS-specific but represent an important safety consideration associated with material substitution.

Overall, RO2 is anticipated to have a slight positive impact on public health and safety by reducing the use of PFAS-containing equipment and lowering the potential for PFAS-related exposure in both occupational and environmental contexts. Short-term increases in PFAS-containing waste during the transition period may moderate these benefits, and uncertainties remain regarding the performance of PFAS-free alternatives and the potential for increased exposure to other hazardous substances if equipment integrity is compromised. Given the limited sector-specific and exposure data which contributes to the uncertainty, the net health effects cannot be quantified, and the direction of any effect remains uncertain. Qualitatively, available evidence suggests that the net effect could be positive, by potentially reducing PFAS exposure.

The health impact conclusions are summarised qualitatively in the Table below, using the scoring framework described in Section 2 and, in more detail, in the Appendices.

Table 4-9 Overview of the health impact assessment for the restriction scenario against the baseline

Health impacts	RO2 (against baseline)
Public health & safety and health systems	+2.0

Source: Ricardo analysis based on the evidence presented in this Study.

4.3 SOCIAL IMPACTS

This section presents the assessment of the shortlisted social impacts (in addition to health above) of the restriction scenario (RO2) in scope of this SEA against the baseline. These impacts have been assessed qualitatively and where possible quantitatively. This section consists of the following:

- Section 4.3.1: Impact on employment of upstream O&G operations in the EEA
- Section 4.3.2: Impact on employment of downstream conventional fuel refining, renewable fuels and fuel distribution in the EEA.
- Section 4.3.3: Wider impacts on consumers and the society (e.g., price impacts, supply disruptions, wider macroeconomic impacts on downstream industries).

The analysis and results presented in this section are based on publicly available evidence and literature, including Eurostat datasets such as PRODCOM and SBS and the online survey and follow-up interviews of upstream O&G companies and ‘downstream user’ businesses across the sectors in scope. These sources are used to estimate potential social impact for the period 2026 to 2055.

4.3.1 Employment impacts on the upstream O&G and CCS sector

The adoption of the restriction scenario could lead to a direct net reduction in the number of jobs supported by upstream O&G operations in the EEA. This decline arises from the projected contraction of the upstream O&G sector under the restriction, which accelerates and deepens the structural downward trend already expected in the baseline.

Employment in the sector is projected to fall steadily for more than a decade as hydrocarbon production declines, assets mature and investment shifts toward low carbon technologies. The sector is estimated to employ around 106,000 people in 2025, falling to around 33,500 by 2040 in the baseline and continuing on a declining trend to 2055. The introduction of the proposed PFAS restriction could, therefore, exacerbate the ongoing long-term contraction by reducing viable operating life, accelerating facility closures and limiting opportunities for workforce redeployment within the sector.

Across the three scenarios, the reduction in employment is broadly proportional to the reduction in turnover and economic activity in the period 2041-2055. In the **high-impact** scenario, all remaining upstream jobs would be lost, averaging around 21,000 jobs in any given year. In the **medium-impact** scenario, jobs supported by the industry would decline partially, around 10,000 jobs in any given year. In the **low-impact** scenario, where operational disruption is limited, 3,000 jobs could be lost in any given year, relative to the baseline[63]. The estimated, potential job losses under the restriction scenarios are presented in the Table below.

Table 4-10 Direct employment supported by the upstream O&G industry in FTE from 2041-2055, in any given year over the period when compared to the baseline

Average annual direct employment supported by the following sector against the baseline (FTE) in 2041-2055	**High-impact scenario**	**Medium-impact scenario**	**Low-impact scenario**
Upstream O&G sector	- 21,000 FTE	-10,000 FTE	-3,000 FTE

Source: Ricardo analysis based on evidence collected from stakeholders and publicly available, Eurostat datasets.

An additional source of social impact arises from the fact that the long-term decline in upstream O&G employment was expected to be partially offset by a transition into CCS-related roles[64]. CCS activities draw on many of the same transferable skills found in the offshore O&G workforce, such as subsurface geology, drilling and well integrity expertise, pipeline and compression engineering, and marine operations, offering a viable pathway to maintain employment and sustain industrial activity during the energy transition. However, the negative implications of the restriction for the CCS sector, as discussed in Section 4.1.2, introduce additional uncertainty regarding this transition pathway. If CCS investment is delayed or displaced outside the EEA, opportunities for redeployment may diminish, increasing the risk of deeper and more sustained employment losses than anticipated under the baseline trajectory.

4.3.2 Employment impacts in the 'downstream user' industry segment (crude oil refining, renewable fuels and fuel distribution)

Across the 'downstream user' industry segment, including crude oil refining, renewable fuels and fuel distribution, the restriction RO2 is also projected to lead to reductions in jobs supported from 2041-2055, driven by reduced operating capacity, early facility closures and rising operating costs under the medium and high-impact scenarios.

Under the **high-impact** scenario, jobs supported by downstream user industry segments could decline by approximately 250,000 jobs in any given year in the period 2041-2055. In the **medium-impact** scenario, employment losses are estimated at around 113,000 jobs, while the **low-impact** scenario could lead to 38,000 job losses relative to the baseline.

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[63] Please note that it is acknowledged that other macroeconomic dynamics could accommodate the employees losing their jobs. However, a dynamic macroeconomic analysis is out of scope of this assessment.

[64] European Commission. (2020). The role of CCUS in a just transition. Available at: https://ccuszen.eu/sites/default/files/TG1_Briefing-Role-of-CCUS-in-Just-Transition_0.pdf

The magnitude of job losses in the renewable fuels sector could be largest, because jobs supported by this sector are increasing in magnitude in the baseline, spurred by the growth of biofuel manufacturing in the EEA supported by decarbonisation policies. The restriction would therefore not only reduce existing employment but also impede job creation that would otherwise have accompanied the scaleup of renewable fuels production.

By contrast, job losses in conventional refining and fuel distribution are driven by a combination of accelerated decline and increased operational challenges. Employment in refinery operations had already been expected to fall over time as fossil fuel use diminishes, but the restriction may bring forward closures and heighten layoff risks. Fuel distribution networks would also face structural impacts, with reduced throughput and the need for more intensive maintenance or early retirement of PFAS-dependent infrastructure leading to lower labour demand.

Estimated, potential job losses under the restriction scenario RO2 are presented in the following Table.

Table 4-11: Direct employment supported by the ‘downstream user’ industry in FTE from 2041-2055, in any given year over the period when compared to the baseline

Average annual direct employment supported by the following sector against the baseline (FTE) in 2041-2055	**High impact scenario**	**Medium impact scenario**	**Low impact scenario**
Crude oil refining	- 32,000 FTE	-15,000 FTE	-5,000 FTE
Renewable fuels	-171,000 FTE	-77,000 FTE	-26,000 FTE
Fuel distribution	-47,000 FTE	-21,000 FTE	-7,000 FTE
Total ‘downstream user’ industry segments	**-250,000 FTE**	**-113,000 FTE**	**-38,000 FTE**

Source: Ricardo analysis based on evidence collected from stakeholders and publicly available, Eurostat datasets.

4.3.3 Other social impacts

Beyond the direct employment losses within the downstream user industry segments, the restriction may give rise to wider social impacts through disruptions in fuel supply, increases in fuel prices and ripple effects on sectors that rely heavily on refined fuels, distributed products and renewable fuels.

Supply disruptions could affect the availability of conventional fuels such as diesel, petrol and kerosene, as well as renewable fuels used for blending into transport fuels or supplied directly to aviation and maritime operators. In the high-impact scenario, where refining and distribution activities may cease entirely from 2041 onwards, downstream industries could face severe shortages, and some may be forced to curtail production or rely on imported fuels at materially higher cost. The medium-impact scenario also presents challenges including intermittent supply constraints, lower throughput across pipelines and terminals, and reduced production from renewable fuel facilities may lead to delays, bottlenecks and reduced reliability for downstream users. In the high-impact scenario, where refining and distribution activities may cease entirely from 2041 onwards, downstream industries could face severe shortages, and some may be forced to curtail production or rely on imported fuels at materially higher cost.

Higher fuel prices, driven by reduced domestic production, increased import dependency and the operational inefficiencies associated with transitional equipment, would generate significant knock-on effects for consumers and the wider economy. Households could face rising transport and heating costs, particularly in rural or peripheral regions where mobility alternatives are limited. Logistics-intensive sectors would likely experience compressed margins as transport costs rise, while firms in competitive global markets may face difficulty passing these additional costs onto customers. Price increases in fuels may also contribute indirectly to inflationary pressures by raising the cost of goods and services across supply chains.

A **wide range of sectors** that rely on products from conventional refining, fuel distribution and renewable fuels may experience knock-on effects, including aviation, which depends on jet fuel and is expected to increasingly rely on Sustainable Aviation Fuels; maritime transport, where higher marine fuel costs could raise freight rates;

agriculture, which may face higher diesel or renewable diesel prices with implications for food costs; and construction, heavy manufacturing and chemicals, where fuel-based industrial heat and refinery feedstocks are essential inputs.

These sector-specific impacts may translate into **broader macroeconomic effects**, the scale of which is difficult to map due to complex, interdependent supply chains and evolving energy market conditions. Although fossil fuel use is expected to decline by 2041, oil and gas derived fuels will still play an important role, and renewable fuels will remain critical for hard to abate sectors. As a result, higher fuel costs, supply constraints or reduced refining and distribution capacity may propagate through the economy, particularly affecting regions with limited access to alternatives.

Taken together, these spillovers mean that, in the high-impact scenario where activities may cease entirely in the sectors under scope of this study, the wider social and macroeconomic effects are likely to be significant, with extensive disruption spreading across multiple layers of the EEA economy.

4.3.4 Overall social impacts

In summary, the most significant impacts on the EEA society would be negative, including a potential loss of thousands of job opportunities when compared to the baseline; negative impacts on the availability, and cost of final products for downstream industrial users, consumers and households, affecting their daily lives in ways that could be impactful; and steps against the EEA's climate targets through potentially negative impacts on the EEA's renewable fuels and CCS sectors.

The social impact conclusions are summarised qualitatively in the Table below, using the scoring framework described in Section 2 and, in more detail, in the Appendix 1.

Table 4-12 Overview of the social impact assessment for the restriction scenario against the baseline

Social impacts	RO2 (against baseline)
Employment	-2.0
Consumer and households	-2.0
Overall social impact (excl. health)	**-2.0**

Source: Ricardo analysis based on the evidence presented in this Study.

4.4 ENVIRONMENTAL IMPACTS

This section presents the assessment of the shortlisted environmental impacts of the restriction scenarios in scope of this SEA against the baseline. Due to the lack of robust quantitative information, particularly the absence of reliable emissions data, these impacts have been assessed qualitatively. This section consists of the following:

- Section 4.4.1– A brief recap of the baseline
- Section 4.4.2– Waste production, generation, and recycling
- Section 4.4.3– Quality of natural resources
- Section 4.4.4 – Efficient use of resources
- Section 4.4.5 – The likelihood or scale of environmental risk
- Section 4.4.6 – Overall environmental impacts

4.4.1 Recap of the baseline

PFAS emissions occur across the entire life cycle of PFAS-containing equipment. Emissions of fluoropolymers and fluoroelastomers might be limited during their use and end-of-life phases; however, there is a lack of quantitative data for these aspects.

Fluoropolymers and fluoroelastomers are specifically selected for their mechanical resistance, chemical stability, and very low propensity to degrade or leach under normal operational conditions. As a result, any releases are expected to be minimal. However, even though fluoropolymers and fluoroelastomers used in sealings and sealing devices, coatings for wires, and piping systems are generally considered highly stable, small PFAS releases may still occur through abrasion, wear, or degradation during use and disposal. Baseline emission estimates for upstream O&G, oil refining and fuel distribution sectors remain uncertain due to limited monitoring data, reliance on default release factors, and a lack of sector-specific information as described in Section 3.1.5. For these reasons, emissions from in-scope equipment and sectors cannot be quantified for this SEA.

Inappropriate end-of-Life management of PFAS-containing equipment may contribute to emissions of PFAS to the environment. Although most PFAS-containing equipment is incinerated or landfilled (see Table 4-13), these processes may always ensure complete destruction of PFAS if lower temperature incineration is used, and inappropriate management can lead to releases through leachate, air emissions, or incomplete thermal breakdown[11]. Recycling remains minimal due to the technical challenges in separating fluoropolymers and fluoroelastomers from other materials.

Table 4-13: Percentage of waste that is either incinerated, landfilled, or recycled

Equipment waste	Desk-based proposal	Survey-based assumptions	% of "Don't Know" and/or "N/A" answers from Survey
% waste that is incinerated	80-85%	50% (40-85%)	70% (N=8)
% waste that is landfilled	10-15%	15% (5-30%)	70% (N=8)
% recycled	5-10%	15% (0-20%)	70% (N=8)

The equipment in scope has long service lives but requires periodic replacement, significant volumes of equipment can reach end of life each year, contributing to potential ongoing emissions. Overall, annual end-of-life volumes range from 500-17,000 units for sealants and sealing devices, from 1-40 km for wire coatings, 90-1,800 capacitors, and 3-40 km of piping systems and hoses (see Section 3.1.5).

4.4.2 Waste production, generation, and recycling

PFAS-containing equipment in scope of this SEA (sealants and sealing devices, coatings for wires, capacitors, and pipes) at end of life are treated primarily through incineration (80–85%), with smaller proportions landfilled (10-15%) or recycled (5-10%), as shown in the previous section. These disposal routes reflect the technical challenges associated with fluoropolymers and fluoroelastomers, which are highly persistent, chemically stable, and often embedded within composite materials[51]. As a result, recycling options for PFAS-containing equipment remain limited, with 80-85% of waste being incinerated (with the destruction of polymeric PFAS as described in Section 3.1.5); 10-15% of waste being recycled and 5-10% of waste being recycled based on desk research and stakeholder engagement. Composites (which would include PFAS and non PFAS composites) are difficult to recycle as they are durable, strong and non-homogeneous[65]. The presence of fluoropolymers and fluoroelastomers in waste can also present issues for recycling[66].

Landfills can also act as long-term sources of PFAS leachate, while lower temperature incineration may only partially break down fluoropolymers and fluoroelastomers, potentially generating additional PFAS degradation products such as TFA and HCF[51].

Under the RO2 restriction, a reduction in PFAS use could be associated with a decrease of PFAS-containing equipment at end of life over time. During the transition period, waste quantities may temporarily increase as operators replace legacy PFAS-containing components with compliant alternatives. This could lead to a short-term rise in disposal activities, particularly incineration, as operators remove older equipment from service. However, the proposed derogation for spare parts may moderate this effect. Consequently, the anticipated short-term increase in waste quantities during the transition period may be less pronounced.

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[65] Composites UK (2021) Composites Recycling: Where are we now? Available from: https://compositesuk.co.uk/wp-content/uploads/2021/10/Recycling-Report-2016-Light-Background.pdf

[66] Torkelis A et al (2024) The Factors Influencing the Recycling of Plastic and Composite Packaging Waste. Sustainability, 16(21), 9515.

Increased incineration may also have implications for energy use, as high-temperature treatment of fluoropolymers and fluoroelastomers is energy-intensive and may reduce the overall environmental and energy efficiency of waste management systems.

In the longer term, the restriction is expected to have positive outcomes related to waste generation, as PFAS-free alternatives could be recycled more easily. Reduced volumes of PFAS-containing equipment at end of life will lower the volumes of PFAS being treated at end of the life and reduce the risk of long-term environmental releases from landfills and incinerators. However, although not yet available, there is also a possibility that some PFAS-free alternatives may have shorter operational lifetimes or reduced performance under extreme conditions (e.g., high temperatures, corrosive environments)[62]. If this occurs, equipment may require more frequent replacement, leading to higher overall waste generation, even though this waste would no longer contain PFAS. This could result in increased disposal volumes and more frequent incineration or landfill use over the long term. Specific to incineration, the additional treatment demand is energy intensive, which in combination with higher waste volumes would reduce the overall positive impact.

In sum, the net impact on waste could be beneficial, by reducing hazardous-waste, although this could be potentially offset over the long-term by increased replacement rates and higher volumes of waste if substitute materials prove less durable. The presence of PFAS in waste, however, could introduce recyclability challenges for composite materials.

4.4.3 Quality of natural resources

Fluoropolymers and fluoroelastomers are not soluble in water and are bioinert[67]. Due to their carbon-fluorine bond, they have resistance to natural degradation in the environment, and they can persist for long periods of times without breaking down[68]. This persistence means that even low annual emissions can lead to steadily increasing environmental stocks over time. As discussed in Section 3.1.5, risks to soil quality are also related to site-specific hydrogeology (i.e. soil and the release scenario for the contaminants to enter the environment.

Under the RO2 restriction, reductions in fluoropolymers and fluoroelastomers use and potential emissions from the upstream O&G, oil refining and fuel distribution sectors are expected to have a small positive impact on the quality of natural resources, primarily by slowing the accumulation of persistent PFAS in environmental compartments. Lower emissions during the end-of-life phases of equipment will reduce the emissions of PFAS to soils, air, and water bodies, thereby decreasing long-term exposure for ecosystems. Over time, this can help stabilise or reduce PFAS concentrations in natural resources, particularly in localised areas where equipment-related emissions occur.

However, the benefits may be moderated by several factors. Firstly, fluoropolymers and fluoroelastomers already present in the environment will persist for many decades, meaning improvements in environmental quality will occur slowly. Secondly, if PFAS-free substitutes have shorter operational lifetimes, increased equipment turnover could lead to higher volumes of waste entering landfills or incineration. While this waste would not contain PFAS, increased disposal volumes could place additional pressure on waste infrastructure and, depending on the materials used, may introduce other pollutants or resource-quality considerations. Nonetheless, these trade-offs do not offset the primary benefit of reducing releases of substances that are extremely persistent and mobile.

Overall, the net impact of RO2 on the quality of natural resources could be positive, driven by potential reduced fluoropolymers and fluoroelastomers emissions, although improvements will materialise gradually due to the long environmental half-lives of PFAS.

4.4.4 Efficient use of resources

PFAS-containing equipment supports relatively efficient resource use during the operational phase due to its long service life, high durability, and resistance to extreme temperatures, corrosion, and chemical exposure. These characteristics reduce the frequency of equipment replacement and limit the need for additional raw materials, manufacturing inputs, and transport activities over time[62]. PFAS-containing components can be considered resource-efficient in use, as they minimise the consumption of materials.

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[67] Améduri B (2023) Fluoropolymers as Unique and Irreplaceable Materials: Challenges and Future Trends in These Specific Per or Poly-Fluoroalkyl Substances. Molecules,28(22): 7564.

[68] Dolatabad AA et al (2025) Thermal decomposition of fluoropolymers: Stability, decomposition products, and possible PFAS release. Journal of Hazardous Materials, 496, 139322.

Under RO2, a shift away from PFAS-containing equipment may introduce new inefficiencies if alternative materials have shorter operational lifetimes. Many PFAS-free alternatives do not match the extreme durability or chemical resistance of fluoropolymers and fluoroelastomers, meaning that equipment may require more frequent replacement which would also result in an increase of waste generation. This would increase the demand for raw materials, manufacturing energy, and transport, potentially leading to higher cumulative resource consumption over the equipment's lifecycle. In sectors such as upstream O&G and refining, where equipment is exposed to harsh operating conditions, reduced durability could translate into significantly higher turnover rates, amplifying resource use even if the materials themselves are less environmentally persistent.

However, end-of-life treatment is also an important part of overall resource efficiency. At present, an estimated 80–85% of PFAS-containing equipment is incinerated, and the high-temperature conditions required to destroy fluoropolymers and fluoroelastomers make this process particularly energy-intensive. This means that, despite their long service life, PFAS-containing components currently contribute to substantial energy use at disposal.

If PFAS-free alternatives can be recycled or treated using lower-temperature processes, RO2 could reduce the energy burden associated with disposal[69]. In this respect, even materials with shorter service lives may offer advantages if their end-of-life treatment requires substantially less energy than the high-temperature destruction needed for PFAS-containing equipment. However, any reduction in disposal-related energy use may be offset by increased material throughput if PFAS-free alternatives require more frequent replacement. As a result, the overall effect on resource efficiency will depend on the balance between lower-energy end-of-life treatment and potentially higher consumption of materials over the equipment lifecycle[70].

The overall impact of RO2 on resource efficiency is therefore mixed. While the restriction reduces reliance on highly persistent substances and may encourage the development of more circular material systems in the long term, it may also lead to increased material throughput if substitutes do not achieve comparable performance. This trade-off is particularly relevant for components with long service lives under the baseline, where the replacement of PFAS-containing equipment could shift resource use patterns from long-cycle, low-frequency replacement to shorter-cycle, higher-frequency turnover.

The net effect is uncertain and entirely depends on the durability and recyclability of the alternatives adopted, which is not known at this stage.

4.4.5 The likelihood or scale of environmental risk

Fluoropolymers and fluoroelastomers are environmentally persistent. Highly-resistant fluoropolymers can be fragmented into smaller molecules by weathering and physical stress over time, which may increase PFAS uptake into living organisms[71]. These risks are compounded by the potential for long-range transport, meaning that emissions from localised industrial activities can contribute to contamination far beyond the immediate area of release. As a result, the baseline scenario reflects a steadily increasing environmental risk profile.

Under RO2, potential reductions in polymeric PFAS use and emissions from the upstream O&G, oil refining and fuel distribution sectors are expected to lower the likelihood and scale of PFAS-related environmental risks by reducing the incremental loading of persistent PFAS into environmental compartments. By limiting releases during the use and end-of-life phases, the restriction reduces the potential emissions of PFAS to the environment, thereby slowing the growth of environmental stocks and reducing long-term exposure.

However, the extent of environmental risk reduction will depend on the performance characteristics of PFAS-free alternatives. Many PFAS-containing components currently in use provide exceptional chemical resistance, thermal stability, and durability, which help prevent leaks, equipment failures, and accidental releases of process fluids and are required for safe operations. If substitute materials do not achieve comparable performance, particularly in high-temperature, high-pressure, or corrosive environments, there is a potential for increased operational and environmental risks[62]. These could include more frequent leaks, fugitive emissions, or accidental discharges of hydrocarbons, chemicals, or other hazardous substances. While these risks are not directly related to PFAS, they represent an important environmental consideration.

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[69] Xian, H., Li, X. & Zhang, C. Rethinking sustainable pathways for PFAS. Nat. Chem. 18, 213 (2026). https://doi.org/10.1038/s41557-025-02044-y

[70] European Commission (EC) Joint Research Centre (JRC) (2012). Product Environmental Footprint (PEF) Guide. Deliverable 2 and 4A of the Administrative Arrangement between DG Environment and the Joint Research Centre No N 070307/2009/552517, including Amendment No 1 from December 2010.

[71] European Environment Agency (2025) PFAS polymers in focus: supporting Europe's zero pollution, low-carbon and circular economy ambitions. Available from: https://www.eea.europa.eu/en/analysis/publications/pfas-polymers-in-focus

Items of PFAS-containing equipment often have long service lifetimes and high reliability, whereas some alternatives may require more frequent replacement or may not perform as robustly under extreme conditions. Increased failure rates or shorter operational lifetimes could elevate the likelihood of environmental incidents, increase maintenance-related disturbances, and place additional pressure on waste-management systems. Nonetheless, these risks based on a qualitative review of the available evidence are generally expected to be lower in magnitude than continued PFAS use and emission.

Overall, RO2 could reduce the likelihood and scale of PFAS-specific environmental risks, although the net benefit will depend on the performance of substitute materials and the extent to which industry can mitigate any new operational risks that arise.

4.4.6 Overall environmental impacts

In summary, the assessment suggests there could be net positive impacts on the environment from adopting RO2; however, this remains uncertain. The most substantial **positive impact of the restriction is the reduction in PFAS emissions** mostly during the end-of-life phases of equipment. As fluoropolymers and fluoroelastomers are environmentally persistent, even modest reductions in annual releases (e.g., from fluoropolymer production sites) contribute meaningfully to slowing the accumulation of PFAS in the environment. This leads to long-term improvements in the quality of natural resources and reduces chronic exposure risks for ecosystems. Additional benefits arise from reduced reliance on energy-intensive PFAS production and specialised waste-treatment processes, as PFAS-free alternatives are generally more compatible with conventional disposal and recycling pathways. Together, these effects support a gradual but meaningful reduction in long-term environmental burdens.

Potential **negative impacts relate primarily to the performance and durability of PFAS-free alternatives**. PFAS-containing equipment currently provides exceptional resistance to heat, chemicals, and mechanical stress, resulting in long service lifetimes and low failure rates. If substitutes do not match this performance, more frequent replacement cycles may be required, increasing resource consumption, waste generation, and transport-related energy use. Reduced durability may also elevate operational risks, including a higher likelihood of leaks or accidental releases of process fluids, particularly in demanding operating environments. While these impacts are generally less severe and more manageable than PFAS-related risks, they represent important trade-offs that may moderate the overall environmental benefits of the restriction.

The environmental impact conclusions are summarised qualitatively in the Table below, using the scoring framework described in Section 2 and, in more detail, in the Appendices.

Table 4-14 Overview of the environmental impact assessment for the restriction scenario against the baseline

Environmental impacts	RO2 (against baseline)
Waste production, generation, and recycling	+2.0
Quality of natural resources	+2.0
Efficient use of resources	-1.0
The likelihood or scale of environmental risk	+0.5
Overall environmental impact	**+2.0**

Source: Ricardo analysis based on the evidence presented in this Study.

4.5 OTHER IMPACTS

4.5.1 Impacts on the UK

The EU PFAS restriction is likely to have indirect but material implications for the UK's upstream and downstream petroleum and renewable fuels products sectors, primarily through equipment supply chain pressures. The UK Continental Shelf is a significant energy source, with 31 Mtoe produced in 2024, despite a structural long-term decline in output[72]. Procurement costs or delivery times for PFAS-containing

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[72] GOV.UK (2025). Oil and Oil Products. Available from: https://assets.publishing.service.gov.uk/media/68dbe4c7c487360cc70c9f5f/DUKES_2025_Chapter_3.pdf

equipment used in high-pressure and high-temperature applications, such as seals, gaskets and flexible risers, may rise where supply chains rely exclusively on EEA manufacturing. As the UK already faces maturing basins and declining output, these constraints could reinforce investment uncertainty and lead to premature closure of operations.

For the crude oil refining sector, the UK produced 51 Mt of refined products in 2024[72] slightly more than half of the top EEA producer Germany, or just under the fourth largest EEA producer, the Netherlands. The UK was a net importer of petroleum products by 13 million tonnes. EU PFAS restrictions affecting refinery equipment or imported components could exacerbate supply chain vulnerabilities, particularly as the UK already depends heavily on imported fuels and intermediate feedstocks. Refinery operations, which rely on PFAS-containing seals, coatings and heat- resistant components, may face higher maintenance costs or be forced to source alternative materials compliant with EU thresholds to maintain access to the European market.

Renewable fuels production in the UK may be affected through similar equipment related channels. Since a substantial share of biofuel feedstocks and additives are traded with the EU, compliance with PFAS related material specifications for storage, pumps and blending systems may become necessary for export-oriented operators, increasing operational expenditure.

Fuel distribution systems, which depend on PFAS containing coatings, linings and gaskets for safe handling of petrol, diesel, kerosene and renewable fuels, could encounter increased replacement costs if EU suppliers shift to PFAS-free alternatives.

Moreover, if the UK also chooses to adopt a similar PFAS restriction (RO2) in the near future, socioeconomic impacts might be similar to those presented in this study for the EEA, given close economic ties and socioeconomic similarities.

4.5.2 Impacts on Switzerland

Switzerland does not undertake crude oil extraction, and domestic refinery output is very limited, totalling 2.9 Mtoe in 2024[73]. As a result, the country relies entirely on imported crude oil and imports 88% of the oil products it consumes. This structural dependence means **Switzerland's exposure to the EU PFAS restriction (RO2) arises almost entirely through its reliance on imported fuels, refined products, and equipment manufactured in the EU, rather than through impacts on domestic production**. Any PFAS-related disruption to EU refining capacity, pipeline systems, or distribution infrastructure could therefore affect Swiss energy supply, increasing the risk of higher prices, tighter availability of key products, or volatility in trade flows. Because of its import dependence, the proposed restriction could translate directly into higher import prices or supply constraints for Swiss consumers and industries. Renewable fuels supply chains, which are closely integrated with European refining and blending operations, may also be affected if PFAS dependent components used in EU storage, blending, or certification processes are phased out or replaced. Switzerland's fuel distribution system, which relies on imported equipment and PFAS-containing components such as hoses, seals, and storage materials, could face higher replacement and maintenance costs as EEA manufacturers transition to PFAS-free specifications.

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[73] IEA. (2026). Country Overview – Switzerland. Available at: https://www.iea.org/countries/switzerland/oil

5. CONCLUSIONS

This section outlines the overall conclusions that are supported by the Study, building on the latest guidelines and available evidence, including a summary of cost-effectiveness and the qualitative balance of impacts, costs and benefits for the restriction scenario, and an overview of the key limitations.

5.1 STUDY LIMITATIONS

The main limitations affecting this study are the availability of quality data, the uncertainty of the proposed REACH restriction[74], the relatively high level of complexity for how these restriction scenarios may affect the value chain in the EEA and the environment, and the application of expert-judgement in a qualitative assessment.

Firstly, there is limited available data and data available has limited quality. There is limited historical evidence of relevance, given that the restriction scenario goes over and above any policies implemented in the EEA and internationally related to PFAS. There is also limited evidence on the size of typical operations, the quantities of the equipment in scope used in typical operations, the prevalence of PFAS in the equipment, the end-of-life management of PFAS-containing equipment and emissions of PFAS. Stakeholder surveys and validation workshops were therefore used to triangulate available information and characterise the potential implications of the policy scenario under consideration. Remaining uncertainty is topic-specific and has been captured by the use of impact scenarios and conservative assumptions, with qualitative methods applied to address gaps in the available evidence necessary for quantification.

Moreover, the sample also comprises a disproportionate number of large firms. This is not deemed a significant issue since the majority of the manufacturing output is generated by large firms, and a comparative analysis between SME versus large enterprise impacts was not possible due to sample limitations.

Secondly, the final REACH PFAS restriction proposal remains uncertain. This means that the restriction details are not yet clear, and assumptions have been required. Assumptions have been quality assured and verified by Concawe and IOGP so that they reflect the current debate as much as possible. As discussions are ongoing, the assumptions made in this assessment may not accurately reflect the regulatory changes that enter into force. However, the assessment carried out and its outputs are highly dependent on these assumptions and, therefore, reflect the same level of uncertainty.

Thirdly, the policies under consideration will affect the O&G value chain and the environment in multiple and complex ways. The proposed policies are expected to reduce the use of PFAS-containing equipment, which may in turn threaten the economic viability of certain operations within the EU-27. The scale of these impacts will vary across sub-sectors and individual businesses, as firms may respond in different ways. They may succeed in adopting substitutes, but also must adjust the scale of operations, discontinue activities, or relocate outside the EU-27. Each of these responses would generate transitional and/or recurring costs relative to the baseline. Because this impact pathway has been simplified for analytical purposes, these represent inherent limitations of the assessment.

To be specific, given that businesses may respond in different ways, the magnitude of economic impacts such as turnover, employment, and GVA is likely to be sensitive to the underlying assumptions. These assumptions include the market share of PFAS-free alternatives, the criticality of non-substitutable components, and the in-scope sector impact. To reflect this, sensitivity analyses were undertaken to examine how these assumptions influence the key estimates. Under each assumption, the potential impact along with the extent of product withdrawal or operational scale reduction was estimated. The resulting ranges from different impact scenarios are presented in the main report (see Section 4.1).

For environmental impacts, there are considerable data limitations surrounding the levels of PFAS associated with the equipment in scope and thus the resulting emissions of PFAS to the environment. Within the ECHA restriction documents, emissions are provided, i.e. for the petroleum and mining sector and for sealing applications. However, granular estimates of emissions i.e. at a sector level for sealing applications is not available and there is a lack of quantitative data for PFAS emissions from fluoropolymers and fluoroelastomers during use and end of life. This has also been verified by our stakeholder consultation activities.

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[74] Draft SEAC Opinion issued on 26 March 2026, referencing the updated Background Document issued autumn 2025.

There are also considerable data limitations surrounding the health impacts. The available evidence points to a health burden attributable to some PFAS. However, within the O&G value chain the attribution of the health burden from PFAS is not possible to be quantified. There is also a lack of exposure data for the oil and gas sector to PFAS and also for fluoropolymers and fluoroelastomers in general.

Fourthly, the application of expert judgement in a qualitative appraisal, especially when the evidence, has limitations. There are uncertainties associated with the results of expert judgement in qualitative assessments. This includes selection bias in the selection of experts, potential biases of experts and also in the collection of the evidence. Within this SEA, expert judgement has been used to validate assumptions where there is limited underlying data. Finally, there are also several known unknowns, such as how technological progress, especially concerning PFAS alternatives in this case, may affect the O&G value chain and the wider society and whether and how this would interact with the impacts of a REACH restriction.

There are a range of uncertainties and limitations associated with the evidence and assumptions developed for this Study, which require further research. However, the conclusions have been tested for sensitivity in the assumptions, and the main findings and conclusions are considered the most probable position, given what is known to date about the effects of a restriction through this sector.

5.2 MAIN FINDINGS

The outputs of this assessment and the comparison of the impacts between the Net-Zero baseline pathway (‘do nothing’) scenario and the restriction scenario suggest that:

- The restriction scenario will have a large negative economic impact on the sectors. This includes relative losses in turnover and GVA for both the upstream and downstream O&G sectors. There would likely also be negative impacts on the sectoral competitiveness, trade and investment flows, and a potential, slightly positive impact for innovation and research.
- Slight positive impacts on human health are likely, especially through reduced potential occupational exposure to PFAS; gradual lowering of exposure to PFAS via the environment and PFAS-related long-term health risks; mitigated slightly by short-term transitional exposure during removal and disposal of legacy equipment, and potential substitution-related risks if reduced equipment durability increases exposure to other hazardous substances.
- Additional social impacts of the restriction would likely be negative, including job losses in upstream and downstream sectors. There could also be negative impacts of the restriction for consumers and households.
- The main environmental impacts are a slight reduction in PFAS emissions; slower accumulation of PFAS in the environment; reduced likelihood of ecosystem contamination; potential decreases in energy-intensive activities, possible increased material throughput, waste generation, energy use, and operational risks.

These impacts are further described in the following sections.

5.2.1 Economic Analysis

The economic analysis indicates that the proposed restriction is likely to have substantial negative impacts on both the EEA upstream oil and gas sector and the ‘downstream user’ industry segments (crude oil refining, renewable fuels and fuel distribution). For upstream operators, the restriction is expected to lead to pronounced losses in economic activity as facilities become unable to safely or legally replace PFAS-containing critical components at end-of-life. In the high-impact scenario, this results in a full cessation of upstream production by 2041, while the medium- and low-impact scenarios yield progressively smaller but still material reductions in operational capacity. On an annualised discounted basis, upstream operators are projected to lose the equivalent of €26 billion in turnover and €18 billion in GVA per year under the high-impact scenario, with lower levels of economic loss in the medium and low cases.

For downstream sectors (crude oil refining, renewable fuels and fuel distribution), similar negative impacts are expected from the restriction. The restriction is expected to lead to pronounced losses in economic activity as facilities become unable to safely or legally replace PFAS-containing critical components at end-of-life. In the high impact scenario, widespread facility shutdowns could occur, whilst the medium and low scenarios yield progressively smaller but still material reductions in operational capacity. On an annualised discounted basis, the conventional fuel refinery sector is projected to lose the equivalent of €74 billion in turnover and €7 billion GVA per year under the high-impact scenario, with lower levels of economic loss in the medium and low cases. On an annualised discounted basis, the renewable fuels sector is projected to lose the equivalent of €53 billion in turnover and €4 billion GVA per year under the high-impact scenario, with lower levels of economic loss in the medium and low cases. For fuel distribution operations, on an annualised discount basis, the sector is projected to lose the equivalent of €12 billion in turnover and €4 billion GVA per year under the high-impact scenario.

5.2.2 Health and wider Social Impact Analysis

The analysis indicates that the proposed restriction could have a modest but overall positive health effects. However, there are limited sector-specific evidence, no biomonitoring data for workers in the activities assessed, and insufficient information on emissions from fluoropolymers and fluoroelastomers during use and end-of-life treatment, meaning the assessment remains largely qualitative. Although PFAS-containing components are typically enclosed and direct exposure during normal operations is expected to be very low, potential exposure may occur during maintenance, dismantling, and waste treatment. By progressively reducing the use of PFAS-containing equipment, RO2 is expected to lower the likelihood of occupational and indirect environmental exposure to PFAS over time, thereby reducing PFAS-related health risks. These benefits may be moderated in the short-term by transitional waste-handling activities and, in the longer term, by uncertainties regarding the durability and performance of PFAS-free alternatives, particularly if reduced material integrity were to increase exposure to other hazardous substances. Nonetheless, the net effect is anticipated to be beneficial from a PFAS-exposure perspective.

The wider social impact analysis indicates that the adoption of the restriction scenario could lead to a direct net reduction in the number of jobs supported by upstream O&G operations in the EEA, with projected loss of 21,000 jobs annually in the more likely high-impact scenario, and a loss of 3,000 jobs annually in the less likely low-impact scenario from 2041 to 2055, against the baseline scenario. Moreover, negative impacts on the CCS sector may diminish redeployment opportunities, which increases the risk of deeper and more sustained employment losses than anticipated under the baseline trajectory. Across the ‘downstream user’ industry segment, including crude oil refining, renewable fuels and fuel distribution, the restriction could also lead to large reductions in jobs. Estimated job losses are projected at 250,000 FTE annually in more likely high-impact scenario, and range 38,000 FTE annually in the less likely low-impact scenario against the baseline scenario, from 2041 to 2055. Negative impacts for consumer, households and other downstream sector may result from the restriction resulting from potential supply disruptions, and higher refinery product prices. Overall, however, social impacts are likely to be neutral, with any positive health effects being potentially mitigated by negative employment and consumer impacts in the period of appraisal.

5.2.3 Environmental Impact Analysis

The environmental analysis indicates that the proposed restriction is likely to generate slight overall net positive impacts on both the EEA upstream oil and gas sector and the ‘downstream user’ industry segments (crude oil refining, renewable fuels and fuel distribution), primarily through reducing PFAS emissions to the environment during the end-of-life phases of equipment. Additional benefits may arise from a gradual shift away from energy-intensive end-of-life treatment of fluoropolymer-based materials and improved compatibility of alternative materials with conventional recycling and waste-management systems.

However, these benefits are moderated by uncertainties and trade-offs. The environmental impacts of fluoropolymer and fluoroelastomers use in in-scope equipment remain uncertain due to limited available data, particularly regarding sector-specific emission estimates, end-of-life releases, and the performance of substitute materials. If PFAS-free alternatives have shorter service lives or reduced durability, increased equipment turnover could lead to higher material throughput, greater waste generation, and additional energy use, potentially offsetting part of the environmental gains. There is also a risk that reduced performance could elevate operational failures, with associated environmental consequences unrelated to PFAS. Overall, while RO2 is expected to reduce PFAS-related environmental pressures, the magnitude of the net benefit will depend on the durability, recyclability, and operational reliability of alternatives, as well as improvements in monitoring and data availability over time.

5.2.4 Balance of economic, social impacts and environmental impacts

The outputs of the SEA have resulted in a set of comparable ratings for the restriction scenario against the baseline, across the broad economic, social (including health) and environmental impact categories and overall costs and benefits. Table 5-1 below reiterates, for ease of reference, the colour-coding used to summarise the qualitative assessment of impacts referring to the direction (positive or negative) and magnitude (weak or strong) of any expected impacts. A more detailed description of the qualitative assessment methodology and other analytical methods employed in this report can be found in the Appendices.

Table 5-1 Scoring and colour coding used to present the assessment conclusions.

Strongly negative	Negative	Weakly negative	No or limited impact	Weakly positive	Positive	Strongly positive	Unclear
-5	-3	-1	0	+1	+3	+5	N/A

Table 5-2 below summarises the aggregated economic, social and environmental impacts by restriction scenario from a societal perspective, covering all pertinent stakeholders: industry (large and smaller businesses), citizens and workers, third countries. These ratings have been aggregated from an analysis across ten economic, social and environmental impact categories which were shortlisted for in-depth assessment as a result of a screening exercise summarised in Appendix 1. Please note that the net social effects capture impacts on employment (negative), impacts on consumers and households (negative) and impacts on human health (positive).

Table 5-2 Overview of the economic and environmental impacts for the restriction scenario*

Restriction Scenario	Economic impacts	Social impacts	Environmental impacts
Restriction Scenario 1 (against baseline)	-3.0	0	+2.0

*Source: Ricardo analysis based on the evidence presented in this Study. *Rounded figures*

In addition, the balance of costs and benefits to EU society in scope of this SEA provides additional insights into the merits of each restriction scenario. The impacts across the broad categories have, therefore, been grouped into economic, health and social impacts and environmental costs and benefits for a relatively more straightforward comparison of the options. Table 5-3 brings together the aggregated economic and environmental impacts by restriction scenario from a societal perspective, covering all pertinent stakeholders: manufacturers and importers of surfactants, downstream user sectors in scope, EU-27 citizens and the EU-27 environment. Similar colour-coding is used, again, to refer to the direction (positive or negative) and size (small or large) of any expected impacts.

Table 5-3 Economic, social and environmental costs and benefits of the restriction scenarios against the baseline*

Restriction Scenario	Costs	Benefits	Benefit: Cost Ratio
Restriction Scenario 1 (against baseline)	-5.0	+3.0	<1

*Source: Ricardo analysis based on the evidence presented in this Study..*Rounded figures*

In summary, the estimated benefits under the restriction scenario RO2 are likely lower, in scale, than the costs. The assessments presented in the preceding sections of this report have highlighted a range of costs that could be incurred across the economic and social dimensions. In addition, some potential benefits have been identified, associated with innovation and research although these are very uncertain (economic); public health and safety and health systems (social); and waste production and treatment and quality of natural resources (environmental). These benefits are likely of lower scale, when compared to the costs, which is represented by a benefit-to-cost ratio (BCR) lower than 1. This presents evidence against the adoption of the RO2 considered in this Study.

Appendices

Appendix 1: Methodology

This Appendix provides additional information on the methodology employed in this Study for assessing the impacts from the implementation of the restriction scenario. The following aspects are elaborated further on:

- Mapping of impacts
- Screening of impacts
- Baseline estimation
- Assessment of the impacts

A1.1 Mapping of Impacts

The potential impacts of each restriction measure or groups of similar measures have been mapped employing impact pathway and theory of change approaches. These potential impacts have been being categorised in line with the Better Regulation Guidelines Tools #18 (identification of impacts) and #56 (typology of costs and benefits)[75]. This mapping exercise produced a longlist of 17 potential impacts from the adoption of the restriction scenario.

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[75] European Commission (2021) Better Regulation Toolbox. Available from: https://commission.europa.eu/law/law-making-process/planning-and-proposing-law/better-regulation/better-regulation-guidelines-and-toolbox/better-regulation-toolbox_en#relatedlinks

Table _ A 1 Mapping of impacts

#	Specific impact category	Primary broad nature of impact	Affected parties	**Relation with underlying initiative (Direct or Indirect)**	Frequency	Likelihood
1	Conduct of business (e.g. withdrawal of substances, developing substitutes, adjustments, adapting production processes, cost avoidance through reduction in sick leave, etc.)	Economic	Enterprises	Both	One-off and recurring	High
2	Administrative burdens on businesses (e.g., training staff, administrative adjustments to new provisions, etc.)	Economic	Enterprises	Direct	One-off	Medium
3	Innovation and research (e.g. effects on research and development, new production methods, alternatives, etc.)	Economic	Enterprises	Indirect	One-off	High
4	Sectoral competitiveness and trade (e.g. costs of doing business,	Economic	Enterprises	Direct	One-off and recurring	High

#	Specific impact category	Primary broad nature of impact	Affected parties	**Relation with underlying initiative (Direct or Indirect)**	Frequency	Likelihood
	capacity to innovate, market share impacts, etc.)					
5	Functioning of the internal market and competition (e.g. free movement of goods and services, reduction in consumer choice, etc.)	Economic	All parties	Indirect	One-off and recurring	Medium
6	Sustainable consumption and production (e.g. effects on the relative prices of environmentally friendly versus unfriendly products and the transition to safe and sustainable chemicals)	Economic	All stakeholders	Indirect	One-off and recurring	Medium
7	Third countries, developing countries, and international relations (e.g. effects on adjustment costs in developing countries or goods and services	Economic	Global citizens	Both	One-off and recurring	Medium

#	Specific impact category	Primary broad nature of impact	Affected parties	**Relation with underlying initiative (Direct or Indirect)**	Frequency	Likelihood
	produced or consumed, etc.					
8	Employment (e.g. new jobs created or lost, etc.)	Social	EU residents	Both	Recurring	High
9	Consumers and households (e.g. effects on consumers' ability to access goods and services, their prices, quality, etc.)	Social	EU residents	Both	Recurring	High
10	Public health & safety and health systems	Social (health)	EU residents	Both	Recurring	High
11	Climate	Environmental	All stakeholders	Indirect	Recurring	Medium
12	Quality of natural resources	Environmental	All stakeholders	Direct	Recurring	High
13	Biodiversity, including flora, fauna, ecosystems and landscapes	Environmental	All stakeholders	Direct	Recurring	Medium
14	Waste production, generation, and recycling	Environmental	All stakeholders	Direct	Recurring	High

#	Specific impact category	Primary broad nature of impact	Affected parties	**Relation with underlying initiative (Direct or Indirect)**	Frequency	Likelihood
15	Efficient use of resources (renewable and non-renewable)	Environmental	All stakeholders	Indirect	Recurring	High
16	The likelihood or scale of environmental risk	Environmental	All stakeholders	Indirect	Recurring	High
17	Transport and the use of energy	Environmental	All stakeholders	Indirect	Recurring	Medium

A1.2 Screening of Impacts

The affected stakeholders for each of these specific impact categories, the underlying relationships with the initiative and the frequency and certainty of impact were also identified. Based on this, the available evidence and expert opinion, a screening exercise was performed to identify the most significant impacts for in-depth assessment across all restriction scenarios, to enable a proportionate approach for the assessment of impacts.

The screening exercise has been primarily qualitative, based on the evidence available at early stages of the project and reviewed periodically, and following the Better Regulation Guidelines[76]. Each specific impact category has been scored across the following dimensions using different qualitative scales: the expected magnitude of potential impact (-5 to +5 score, where the sign reflects the direction of impact, whilst the number reflects the scale of impact); the likelihood of impact (0 to +3 score, where a higher number reflects a higher likelihood); and the importance of impact against EC's objectives (0 to +3 score, where a higher number reflects a higher importance). The Table below provides more details.

Table _A 2 Impact screening approach

Criteria	Guidance
1 – Affected stakeholders	Select primary stakeholders affected by the impact of the/group of measure/s. • All stakeholders • Public authorities • All businesses • Businesses: Manufacturers and importers • Businesses: Downstream user sectors • EU citizens • (Global citizens)
2.1 – Absolute impact: magnitude	• Select qualitatively per type of impact: • None (0) • Low (1) • Low/Medium (2) • Medium (3) • Medium/high (4) • High (5) These are considered as follows: • High: Widespread and deep effects on the EU's economic wellbeing, whether affecting the majority of EU residents, businesses and other actors or some of these actors in a very significant way • Medium: Substantial/ transformational impact on a small group of stakeholders or marginal/ small impact on a wide range of stakeholders across the EU. • Low: Marginal or small impact on a small group of stakeholders or limited impact on a wide range of stakeholders. • None: No impact expected with a high level of certainty.
2.2 – Absolute impact: likelihood	Select qualitatively per type of impact: • None (0) • Low likelihood (1)

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[76] European Commission (2021) Better Regulation Toolbox. Available from: https://commission.europa.eu/law/law-making-process/planning-and-proposing-law/better-regulation/better-regulation-guidelines-and-toolbox/better-regulation-toolbox_en#relatedlinks

Criteria	Guidance
	• Medium likelihood (2) • High likelihood (3) These are considered as follows: • High: Evidence points to the impact materialising in the scale identified with a high level of certainty (e.g., >75% chance) • Medium: Evidence is unclear that the impact would materialise in the scale identified although it is likely (e.g., ~ 50% chance) • Low: Evidence is limited, and the impact may not materialise at all or is unlikely to materialise in the scale identified (e.g., <25% chance). • Note: Certain (or almost certain) that the impact identified will not materialise.
2.3 – Absolute impact: direction	Select qualitatively per type of impact: • Positive • Negative • None • Unclear Note: Positive should contribute towards EU objectives, efficiency, productivity, etc. Whereas negatives do not contribute to EU objectives, increase costs or negatively affect business opportunities.
3.1 – Relative impact: Disproportionately affected stakeholder group	Select the stakeholder that may be affected disproportionately if any: [From list of stakeholders] Note: These should highlight the group of stakeholders that will be significantly affected even if the overall impact is low.
3.2 – Relative impact: likelihood	Select qualitatively per type of impact: • Low likelihood (1) • Medium likelihood (2) • High likelihood (3)
3.3 – Relative impact: direction	Select qualitatively per type of impact: • Positive • Negative • None • Unclear
4 – Relationship	Select qualitatively per type of impact: • Direct • Indirect • Both
5 – Relevance	Select qualitatively per type of impact: • None • Low • Medium • High These are considered as follows: • High: all of the impact identified is intended and aligned with the objectives.

Criteria	Guidance
	• Medium: a major part of the impact identified is intended and somewhat aligned with the objectives. • Low: a small part of the impact identified against a given category is intended and somewhat aligned with the objectives. • None: the impact identified against a given category is not intended.

In general, an impact category with medium level of negative or positive impact (-2/+2 score or a higher scale negative or positive), with a medium or higher level of likelihood would be selected for more in-depth assessment (e.g., the conduct of business is very likely to be affected significantly)). Secondly, expert judgement was used to develop a shortlist for in-depth assessment. The shortlist comprises of the following ten impact categories. A more detailed assessment underpinning this list is presented in the following Table.

- Conduct of business, sustainable production, SMEs, admin burden
- Innovation and research
- Sectoral competitiveness, trade and investment flows
- Employment
- Consumers and households
- Public health & safety and health systems
- Quality of natural resources in the environment
- Waste production, generation, and recycling
- Efficient use of resources
- The likelihood or scale of environmental risk

Table _A 3 Screening of impacts

#	Specific impact category	Primary broad nature of impact	Affected parties	Relevance for specific parties	Magnitude of potential impact [-5,5]	Likelihood [0,3]	**Importance against EU objectives [0,3]**	Most significant (Yes/No)
1	Conduct of business (e.g. withdrawal of substances, developing substitutes, adjustments, adapting production processes, cost avoidance through reduction in sick leave, etc.)	Economic	Enterprises	n/a	-4	3	2	Yes
2	Administrative burdens on businesses (e.g., training staff, administrative adjustments to new provisions, etc.)	Economic	Enterprises	n/a	-2	1	2	No
3	Innovation and research (e.g. effects on research and development, new production methods, alternatives, etc.)	Economic	Enterprises	n/a	-2	3	2	Yes
4	Sectoral competitiveness	Economic	Enterprises	n/a	-2	3	2	Yes

#	Specific impact category	Primary broad nature of impact	Affected parties	Relevance for specific parties	Magnitude of potential impact [-5,5]	Likelihood [0,3]	**Importance against EU objectives [0,3]**	Most significant (Yes/No)
	and trade (e.g. costs of doing business, capacity to innovate, market share impacts, etc.)							
5	Functioning of the internal market and competition (e.g. free movement of goods and services, reduction in consumer choice, etc.)	Economic	All parties	n/a	-2	2	1	No
6	Sustainable consumption and production (e.g. effects on the relative prices of environmentally friendly versus unfriendly products and the transition to safe and sustainable chemicals)	Economic	All stakeholders	n/a	-1	3	0	No
7	Third countries, developing countries, and international relations (e.g. effects on adjustment costs in	Economic	Global citizens	n/a	0	1	1	No

#	Specific impact category	Primary broad nature of impact	Affected parties	Relevance for specific parties	Magnitude of potential impact [-5,5]	Likelihood [0,3]	**Importance against EU objectives [0,3]**	Most significant (Yes/No)
	developing countries or goods and services produced or consumed, etc.							
8	Employment (e.g. new jobs created or lost, etc.)	Social	EU residents	n/a	-2	3	2	Yes
9	Consumers and households (e.g. effects on consumers' ability to access goods and services, their prices, quality, etc.)	Social	EU residents	n/a	-2	2	2	Yes
10	Public health & safety and health systems	Social (health)	EU residents	n/a	2	3	3	Yes
11	Climate	Environmental	All stakeholders	n/a	1	1	3	No
12	Quality of natural resources	Environmental	All stakeholders	n/a	0	0	3	Yes
13	Biodiversity, including flora, fauna, ecosystems and landscapes	Environmental	All stakeholders	n/a	2	2	1	No
14	Waste production, generation, and recycling	Environmental	All stakeholders	n/a	2	3	3	Yes

#	Specific impact category	Primary broad nature of impact	Affected parties	Relevance for specific parties	Magnitude of potential impact [-5,5]	Likelihood [0,3]	**Importance against EU objectives [0,3]**	Most significant (Yes/No)
15	Efficient use of resources (renewable and non-renewable)	Environmental	All stakeholders	n/a	-2	3	2	Yes
16	The likelihood or scale of environmental risk	Environmental	All stakeholders	n/a	2	3	2	Yes
17	Transport and the use of energy	Environmental	All stakeholders	n/a	2	2	2	No

A1.3 Baseline estimation

This study defined and characterised how different business figures of the EEA Oil & Gas, petroleum refining, renewable fuels and distribution sector, would likely evolve in the absence of the proposed restriction, drawing from Tool #57, Tool #58, Tool #59, and Tool #60 of EC's Better Regulation Toolbox. This includes:

- Defining the **'Do nothing'** or **baseline scenario**, that is, what the EEA Oil & Gas, petroleum refining, renewable fuels and distribution sector outcomes may look like in the absence of the proposed restriction;
- Identifying key economic and sectoral indicators that can be used to characterise the potential evolution of the EEA Oil & Gas, petroleum refining, renewable fuels and distribution sector; and
- Quantifying how these indicators would likely evolve over a period of 30 years (2026-2055).

First, policy experts from the study team defined what the 'Do nothing' would look like in terms of EEA legislation. The study team experts confirmed the existing legislation and the legislative changes that are already expected for implementation over the period which are going to affect these sectors. In particular, the evolution of these sectors is intrinsically tied to the EU's long-term strategy[77] to achieve net-zero GHG emissions by 2050.

Long-term projections on petroleum products supply in the EU under the Net Zero 2050 scenario from Network for Greening the Financial System's (NGFS)[78] REMIND-MAgPIE were used to derive plausible sectoral growth trends till 2055. These trends were also supported by the 'More Molecules' and 'Max Electron' projections for the sector made in the S&P (2025)[79] study, which also assumes achievement of net-zero emissions by 2050. Baseline scenario for the renewable fuels sector is based on 2030 and 2050 projection trends provided in European Commission's 2024 study[30] on drop-in renewable fuels outlook.

Secondly, the team established a set of indicators of focus to characterise the baseline of the EEA Oil & Gas, petroleum refining, renewable fuels and distribution sector, and the EEA economy, which would become the quantitative baseline against which the policy options would be assessed. The following table outlines the selected indicators, based on their relevance and the evidence available from Eurostat, the EEA and OECD Statistics.

Table _A 4: List of economic indicators and statistics used in the definition of a baseline and analysis of impacts (excluding renewable fuels)

Indicator	Source(s)
Turnover	Enterprise statistics by size class and NACE Rev. 2 activity[80]
Gross Value added (GVA)	
Employment	
Crude oil prices	Europe Brent Spot Price FOB from EIA[81], supported by FuelsEurope 2025 Statistical Report[82]
Refined petroleum product prices in EU	EU Weekly Oil Bulletin[83]

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[77] European Commission. (n.d.). 2050 long-term strategy. Available at: https://climate.ec.europa.eu/eu-action/climate-strategies-targets/2050-long-term-strategy_en

[78] NGFS. (2026). Scenarios Portal. The Network for Greening the Financial System (NGFS). Available at: https://www.ngfs.net/ngfs-scenarios-portal/

[79] S&P Global and Concawe. (2025). Study on the potential evolution of Refining and Liquid Fuels production in Europe. Available at: https://www.concawe.eu/publication/study-on-the-potential-evolution-of-refining-and-liquid-fuels-production-in-europe/

[80] Eurostat. (2025). Dataset - Enterprise statistics by size class and NACE Rev. 2 activity - sbs_sc_ovw. Available at: https://ec.europa.eu/eurostat/databrowser/view/sbs_sc_ovw__custom_19876047/default/table

[81] EIA. (2026). Dataset - Europe Brent Spot Price. Available at: https://www.eia.gov/dnav/pet/hist/LeafHandler.ashx?n=PET&s=RBRTE&f=M

[82] FuelsEurope. (2025). Statistical Report – 2025. Available at: https://www.fuelseurope.eu/publications/publications/statistical-report-2025

[83] European Commission. (2026). Weekly Oil Bulletin. Available at: https://energy.ec.europa.eu/data-and-analysis/weekly-oil-bulletin_en

For identification of sectoral activities, the mapping across sectors and NACE codes was applied as shown in the table below.

Table _A 5: Sectors and NACE codes mapping

Sector	Relevant NACE codes
Upstream Oil & Gas	B6 - Extraction of crude petroleum and natural gas B9.10 - Support activities for petroleum and natural gas extraction
Petroleum Refining	C19.2 - Manufacture of refined petroleum products
Fuel Distribution sector	H49.20 - Freight rail transport H49.40 - Freight transport by road and removal services H49.50 - Transport via pipeline H50.20 - Sea and coastal freight water transport H52.10 - Warehousing and storage H52.20 - Support activities for transportation
Renewable fuels sector	Relevant NACE codes not available at required resolution. Turnover and employment baseline projections taken from European Commission's 2024 study on drop-in advanced renewable fuels outlook. 2031 to 2050 turnover is assumed to grow at the rate of sector's overall energy contribution adjusted for medium- and long-term expected decline in cost of production from IEA (2020)[84]. GVA projections based on GVA-to-turnover ratio for petroleum refining sector.

For upstream oil & gas, and petroleum refining, 100 percent of the economic indicator values reported under the NACE codes were attributed to the sector. For the fuel distribution sector, the identified NACE codes are wider in their scope and cover other sectors as well. The following table shows the ranges assumed in apportioning the share of each NACE code's economic indicator value to the fuel distribution sector. In addition, an adjustment to the baseline projections of the fuel distribution sector was undertaken to account for projected increase in renewable fuels supply.

Table _A 6: Assumed shares of fuel distribution sector in NACE sectors

Sector	Fuel distribution share (%)		
	Low	High	Notes
Transport via pipeline (NACE 49.50)	80%	90%	In Europe, the dominant long-distance pipeline flows move fuels, and only a little pipeline revenue is earned from non-fuel liquids or industrial product pipelines.[85]
Freight transport by road (NACE 49.41)	2%	4%	In 2024, 3% of the total EU road transport tonnage was for Coke and refined petroleum products.[86] The low and high share interval are assumed at +/- 1% to take into account variations due to distance travelled, specialized nature of freight and regional wage differences.

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[84] IEA. (2020). *Advanced Biofuels – Potential for Cost Reduction*. Available at: https://www.ieabioenergy.com/blog/publications/new-publication-advanced-biofuels-potential-for-cost-reduction/

[85] ReportLinker. (2026). European Turnover of Pipeline Transportation by Country. Available at: https://www.reportlinker.com/dataset/c5a3235034682da1b3b96aa27820782ac82e03d2

[86] Eurostat. (2025). Road freight transport statistics. Available at: https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Road_freight_transport_statistics

Sector	Fuel distribution share (%)		
	Low	High	Notes
Freight rail transport (NACE 49.20)	1%	3%	Coke and refined products account for around 10% of total rail freight share, both by tonnes and tonne/km. Shares assigned here include a +/- 2% uncertainty range in how freight share translates to KPIs.[87]
Sea and coastal freight water transport (NACE 50.20)	10%	15%	In 2024, coke and refined petroleum products accounted for 16.5% of gross weight of seaborne goods handled in main EU ports. A slightly lower share range is assumed to account for variations in cost per tonne-km.[88]
Warehousing and storage (NACE 52.10)	2%	4%	These shares are based on the assumption that refined petroleum products account for only a small portion of total warehousing and storage sector.
Support activities for transportation (NACE 52.2)	0%	1%	These shares are based on the assumption that refined petroleum products account for only a small portion of total support activities for transportation, which serves the entire freight system and all commodity types.

For economic indicators, data from 2024 was utilized. Where 2024 data was not available, data from latest year was used, adjusted for inflation using Eurostat HICP index. All monetary values were converted to constant 2025 prices. For NGFS scenario and renewable fuels baseline scenarios, annual values for intervening years were calculated using linear interpolation over available years.

A1.4 Consult Stakeholders and Gather Evidence of the Baseline and Potential Impacts

A consultation strategy was developed, including Concawe and IOGP members. A five-part, 46 question validation survey of desk-based findings was designed and shared with Concawe and IOGP members. This consisted of the following:

- Participant information, gathering data about the respondents such as size and primary activities.
- Part 1, seeking to form the baseline, including the size of typical operations.
- Part 2, seeking to form the baseline, including the volume of equipment in scope and the presence of PFAS in this equipment.
- Part 3, investigating the criticality of the PFAS-containing equipment.
- Part 4, gathering information on business responses and potential alternatives.
- Part 5, gathering information on the end-of-life management for the in-scope equipment.

Following the analysis of the survey, three validation workshops were performed with Concawe and IOGP members. One workshop focussed on the validation of the survey results and two workshops focussed on validation of the baseline and the impact pathway.

A1.5 Assessment of the Economic, Social and Environmental Impacts of the Restriction Scenario

This section details the approach and methodology (quantitative and qualitative) employed for assessing the economic and environmental impacts, costs and benefits for the restriction scenario under consideration (see Section 3.2) for the proposed REACH restriction of PFAS.

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[87] Eurostat. (2025). Railway freight transport statistics. Available at: https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Railway_freight_transport_statistics

[88] Eurostat. (2025). Maritime transport of goods - annual data. Available at: https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Maritime_transport_of_goods_-_annual_data

Quantitative approach

This section outlines the methods used to estimate the economic and environmental impacts. Quantitative analysis, inspired by the Standard Cost and Economic Modelling approaches, was carried out to estimate impacts and costs on businesses, also relevant for the 'One In, One Out' considerations. Insufficient evidence was identified to isolate administrative burden. Adjustment (or compliance) costs were primarily the focus of the analysis.

A three-step methodology was implemented to thoroughly analyse the desk based and survey data and extract actionable insights.

- The first step involved a comprehensive distributional analysis that was performed for each question in the survey. This involved an examination of the distribution of responses to identify any notable patterns, trends, or outliers. Medians, modes, 25th and 75th percentile estimates, minima and maxima were also considered
- The second step involved comparing the survey with the results of the desk-based research. Dependent on the outcome, the desk-based results were either taking forward to the SEA or adjusted; otherwise, the survey-based results were taken forward to the SEA.
- The internal analysis was supplemented with external evidence obtained from industry reports and follow-up interviews with selected respondents. These external sources served to contextualise our findings within broader industry trends and validate our assumptions. Furthermore, engaging in dialogue with survey participants allowed us to delve deeper into specific responses, gaining valuable qualitative insights that enriched our analysis.

Based on this methodology, key percentage impacts were estimated that were later combined with broader baseline data on the evolution of economic variables to estimate the economic and wider economic impacts of the proposed restrictions. This was done as follows:

- Potential production value losses were estimated by considering the proportion of the portfolio that would be affected, minus the proportion that would be exempted and substituted based on the 'assumptions' developed through analysing the evidence provided by businesses through the targeted consultation. That is, losses estimated are net of any substitution/ market for alternatives. These are applied to the baseline developed for this Study. Mathematically, this can be represented as follows:

  $$Turnover\ loss = Turnover * (affected\ portfolio\%) * (1 - substitution\%)$$
- The assumed trajectory of production losses was applied to sales turnover and GVA, assuming proportionate impact.
- Employment is assumed to be affected proportionately to how business operations might be affected, albeit any effects are estimated to be lower based on a relationship established between production and employment from the sample and published studies.

These core impacts were presented as annual averages (or annualised over the period of 2026-2040) for a comparison against the baseline. An annualisation exercise was done as follows: where required, Equivalent Annual Costs or Impacts were calculated for the selected indicators. The Net Present Value (NPV) of any impact or cost over the period 2026-2055 was estimated by summing the projected cost over the period and discounted at a real discount rate of 3% in line with the European Commission's Better Regulation Toolbox #64. The following equation was employed:

Equation A2.1: $NPV = \sum_{t=0}^{n} \frac{C_t}{(1+r)^t}$, where n refers to the time period from 2026-2055, C_t refers to the costs or impacts in time period t, and r refers to the real discount rate.

Secondly, the NPV of the cost or impact was multiplied by an annualization factor, pertaining to the period of policy impact, which is 2041-2055. This factor is given by the following equation:

Equation A2.2: $EF = \frac{r}{[1-(1+r)^{-t}]}$, where r refers to the real discount rate and n refers to the number of periods. Note that this formula and approach were adapted to account for the assumed timetable of policy implementation.

Qualitative approach

A qualitative thematic approach was adopted to analyse a set of questions included in the survey, covering various economic impacts such as competitiveness, reallocation of operations, among other topics. Thematic analysis entailed systematically identifying and interpreting recurring themes within the responses to discern overarching patterns. Additionally, content analysis was employed to scrutinize this set of questions, involving the systematic categorisation and interpretation of response content to identify recurring topics or ideas. This facilitated an exploration of the prevalence and distribution of specific themes or concepts across responses, illuminating the range and diversity of perspectives within the data. These qualitative methods yielded valuable insights into respondents' perspectives, facilitating a deeper understanding of the anticipated economic, social and environmental impacts following the introduction of restrictions.

A1.6 Comparison of the Restriction Scenario against the Baseline

The evidence and conclusions developed through earlier tasks, were brought together to assess how the restriction scenario compared with the baseline and with which type and level of impacts. This has been done using a Multi-Criteria Analysis (MCA) approach, based on Tool #62 of the latest Better Regulation Toolbox and ECHA’s guidelines and studies. These are described below.

MCA-based qualitative scoring approach

An overarching qualitative framework was employed to bring together all of the evidence and analysis against each of the two restriction scenarios on a scale of -5/+5, capturing both the estimated magnitude of impact as well as its likely direction when compared to the baseline. The Table below outlines how this scale would be described and presented.

Table _A 7 Scoring and colour coding used to present the assessment conclusions.

Strongly negative	Negative	Weakly negative	No or limited impact	Weakly positive	Positive	Strongly positive	Unclear
-5	-3	-1	0	+1	+3	+5	N/A

The framework facilitates an iterative process that is overseen by the economist lead to ensure that all the evidence is drawn on whilst retaining internal coherence. The following five steps have been taken to assess impacts.

- Step 1: Selected proxy indicators and construct a qualitative and, where possible, quantitative evidence base of the scale of potential impacts identified.
- Step 2: A team of experts from the consultant project team considered and assessed the impacts of policy measures (or options) across each category following some general guidance, accessing the available evidence, and using their expert judgement.
- Step 3: A re-calibration exercise was carried out every time inputs from experts are reviewed by the PM/Lead economist. This ensured that the impact ratings remained internally coherent and are challenged constructively.
- Step 4: An impact aggregation exercise was performed. This exercise was required to aggregate the qualitative rating of impacts across specific categories to the level of broad pillars: economic and environmental and social costs and benefits. To ensure comparability across pillars differing in the number of categories included, re-scaling was undertaken so that the scale of impacts presented is always from -5/+5.
- Step 5: Validation and quality assurance activities was also taken by a separate team of experts within the team.

In more detail, given the relatively limited quantitative evidence, a number of proxies and approaches were employed to establish qualitative scores and achieve internal coherence (Steps 1-3 above). The following list summarises, at a very high-level, a few references employed in the iterative process to reach a final position on the qualitative ratings for each option and category of impact.

- First, impacts on industrial activity were considered across core restriction scenarios. Evidence collected via the targeted stakeholder survey was essential to establish qualitative scores that were internally coherent (i.e., the relative position of impacts was reasonable across the restriction scenario).

- Secondly, these assessments were used as an anchor or benchmark to develop a relative position of impact across the other economic and wider economic categories such as innovation and research, global competitiveness and trade, employment and consumers and households. When impacts were identified on these categories, this was generally judged to be of smaller scale than conduct of business by 3 to 6 points.
- Thirdly, expert judgement was required to establish qualitative scores or ratings for environmental impact categories. These were triangulated with the evidence identified e.g., is there a possibility of significant positive impact on the environment from restricting the use of a particular substance and, if so, what could this look like? The qualitative score was further contrasted with the scale of costs and a judgement was made as to whether a similar scale of benefit could be accrued or not from the adoption of the restriction scenario.

This qualitative method provides a platform for experts/consultants to triangulate evidence with expert judgement, which is required especially in this context of limited evidence and complex impact pathways. The outputs of this method offer a guide or a best recommendation as to the balance of impacts, costs and benefits given the information, time and resources available, for consideration by the Commission. The conclusions are not irrefutable but present a best view. This is aligned with the principles set out in the Better Regulation Guidelines, including proportionality, and others.

Having iterated and established a rating for each impact category across each restriction scenario, these **scores were aggregated and mapped onto -5/+5 scale** (Step 4 above) at the broad impact level (economic and environmental) and the level of costs and benefits for a higher level and more effective comparison of the restriction scenarios.

- This aggregation and re-calibration can only be effective if the impacts, costs and benefits are on a comparable scale. Therefore, the following steps were undertaken:
- First, the ratings for each of the broad impact categories; the costs (negative ratings); and the benefits (positive ratings) were aggregated.

Following this, a judgment was made to map the highest score in absolute terms “-15” in costs onto the -5/+5 scale as “-5”. This was done to provide as much visibility in the differences of scale of impact across restriction scenarios. However, the mapping could be adjusted without any implications on the conclusions reached as the relative positions of the ratings will remain.

Appendix 2: Sector definition

This Appendix provides a description of the sector definition for upstream Oil & Gas, refining operations, fuel distribution operations and the renewable fuels sector. A quantitative estimation of impacts was undertaken for these sectors based on the definitions described here. Impacts the on CCS sector was assessed qualitatively.

A2.1 Overview

The collection of data for the manufacturing of surfactants and the downstream user markers has utilised Eurostat datasets which is based on the Structural Business Statistics (SBS)[53] and the Prodcom database[52]. The SBS contains data by industrial sector, following the classification by NACE Rev.2 of economic activities. The Prodcom database provides data on the production of manufactured goods, following a fine classification of products which allows the construction of production values for each of the sectors. These classifications have been defined by expert judgement.

A2.2 O&G Sector Definition

For each of the sectors in-scope, the relevant NACE classification and Prodcom classification codes are below.

Table _A 8: Sectors and NACE codes mapping

Sector	Relevant NACE codes
Upstream Oil & Gas	B6 - Extraction of crude petroleum and natural gas B9.10 - Support activities for petroleum and natural gas extraction
Petroleum Refining	C19.2 - Manufacture of refined petroleum products
Fuel Distribution Sector	H49.20 - Freight rail transport H49.40 - Freight transport by road and removal services H49.50 - Transport via pipeline H50.20 - Sea and coastal freight water transport H52.10 - Warehousing and storage H52.20 - Support activities for transportation
Renewable fuels sector	Relevant NACE codes not available at required resolution. Turnover and employment baseline projections taken from European Commission's 2024 study on drop-in advanced biofuels outlook. 2031 to 2050 turnover is assumed to grow at the rate of sector's overall energy contribution adjusted for medium- and long-term expected decline in cost of production from IEA (2020)[84]. GVA projections based on GVA-to-turnover ratio for petroleum refining sector.

Appendix 3: Monomeric PFAS

This Appendix provides an overview of the health and environmental impacts for monomeric PFAS. As discussed in the main part of this SEA, there is limited information on the health risks associated with human exposure to fluoropolymers and fluoroelastomers. Monomeric PFAS is out of scope of this SEA, however there is available information on health effects following exposure. This evidence provides a reference point for consideration as part of the qualitative assessment that has been performed for the health and environmental impacts.

A3.1 Baseline scenario

Health baseline for monomeric PFAS

Human exposure to a selection of monomeric PFAS has been documented through biomonitoring studies and intake assessments. These studies show that people worldwide are exposed to a range of PFAS, with the highest levels found among workers and residents near contaminated sites including from fluorochemical manufacturing plants[89] and from the use of PFAS containing firefighting foams at airfields[90]. Direct consumer or general public exposure to monomeric PFAS attributable to the upstream O&G, CCS, oil refinery and fuel distribution sectors is not expected.

Exposure to PFAS can occur through the direct intake of PFAS- (e.g., such as by consuming PFAS-containing food[91] and drinking water[92]) or indirectly through precursor compounds that degrade into PFAS in the body. As PFAS are ubiquitous in environmental media and used in many consumer products, the general population may be exposed through food, drinking water, indoor dust, air, and contact with treated materials[93]. Occupationally exposed individuals may experience higher exposure through inhalation, dust ingestion, and dermal contact in the workplace[94].

More broadly, human exposure to PFAS can affect people's health, by increasing the probability of infections, autoimmune disorders, reproductive disorders, liver diseases, maternal and neonatal risks[95]. Most of the available human-health data for PFAS relate to a small subset of well-studied PFAS, particularly PFOS and PFOA, while more than 99% of PFAS lack data on repeated-dose toxicity, carcinogenicity, or reproductive toxicity. In the REACH restriction proposal, the focus has been on long-term health endpoints most consistently affected in animal studies, such as effects on liver, kidney, thyroid, immune system, and lipid metabolism, while acute toxicity and sensitisation were not considered relevant. Mutagenicity appears limited to a small number of PFAS and was therefore not a central endpoint in their hazard assessment.

Across the EEA, biomonitoring data show that a number of monomeric PFAS are widely detected in human blood serum, with concentrations varying by age, sex, and geography. A recent consultancy study for the European Commission[95] presents average serum levels for several regulated PFAS (notably PFOS, PFOA, PFHxS and PFNA), which remains measurable in the general population ('background cohort'), with some groups in occupational settings and/or contaminated areas ('elevated/occupational cohort') showing higher body burdens. The following table presents an overview of PFAS levels in human blood serum in the EU.

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[89] Gebbink WA and van Leeuwen SPJ (2020) Environmental contamination and human exposure to PFASs near a fluorochemical plant: Review of historic and current PFOA and GenX contamination in the Netherlands. Environment International, 137, 105583.

[90] Hron LMC (2024) Monitoring of per-and polyfluoroalkyl substances (PFAS) in human blood samples collected in three regions with known PFAS releases in the environment and three control regions in South Germany. Analytical Toxicology, 98. 3727-3738.

[91] EFSA Panel on Contaminants in the Food Chain (2020) Risk to human health related to the presence of perfluoroalkyl substances in food. EFSA Journal. https://doi.org/10.2903/j.efsa.2020.6223

[92] Zhou Y et al (2025) Per- and Polyfluoroalkyl Substances in Potential Drinking Water Sources Globally: Distributions, Monitoring Trends, and Risk Assessment. Water, 17(22), 380.

[93] Sunderland EM et al (2019) A review of the pathways of human exposure to poly- and perfluoroalkyl substances (PFASs) and present understanding of health effects. Journal of Exposure Science & Environmental Epidemiology, 29_131-147.

[94] Christensen BT and Calkins MM (2024) Occupational Exposure to Per- and Polyfluoroalkyl Substances: A Scope Review of the Literature from 1980-2021. J Expo Sci Environ Epidemiol., 33(5), 673-686.

[95] European Commission: Directorate-General for Environment, Ricardo, Trinomics and WSP. (2026). *The cost of PFAS pollution for our society – Final report*, Publications Office of the European Union. Available from: https://data.europa.eu/doi/10.2779/9590509

Table _A 9: 2024 blood serum levels of PFAS (median values) by cohort in the EU, for four regulated PFAS and 'others'

Cohort	PFOA	PFOS	PFNA	PFHxS	Other PFAS
Background cohort	1.81 µg/L	5.04 µg/L	0.77 µg/L	0.68 µg/L	7.30 µg/L
Elevated/ occupational cohort	19.46 µg/L	5.65 µg/L	0.77 µg/L	1.91 µg/L	28.61 µg/L

Source: Ricardo presentation of analysis in recent study published by the Commission.

The recent Commission publication into the 'Cost of PFAS pollution' estimated the current health burden attributable to PFAS exposure across the EEA, focusing on four regulated PFAS (PFOA, PFOS, PFHxS and PFNA) for which exposure response- functions are available. The analysis quantified statistical cases of attributable Disability-Adjusted Life Years[96] and attributable statistical deaths across a range of endpoints, including immune effects, metabolic disorders, developmental outcomes and certain cancers (Table below).

Table _A 10: Health burden in the EEA attributable to human exposure to four regulated PFAS

Metric	Estimated disease burden and health costs per year, to four regulated PFAS in the EEA (2024)
Attributable Disability-Adjusted Life Years	169,600 [20-1,731,000]
Attributable statistical deaths	1,050 [0-26,030]
Human health costs (Billion euros, 2024€)	39.5 [0.005-600.5]

Source: Ricardo presentation of analysis in recent study published by the Commission.

These four, regulated PFAS were found to drive most of the quantifiable burden, primarily because information is limited for other PFASs. The study emphasises that these estimates represent a lower bound of the true health burden. Other studies are available in the literature assessing worker exposure to PFAS. For example, Lucas et al. reviewed the literature to identify occupations that may experience occupational exposure[97]. Identified occupationally exposed populations included ski wax technicians, firefighters and fluorochemical plant workers for monomeric PFAS, with no data provided on fluoropolymers or fluoroelastomers. Other studies have included PFAS serum levels in chemical production workers[97]. However, no studies have been identified for PFAS exposure for oil and gas sector workers.

Environmental baseline

Recent evidence from the Commission's publication into 'Cost of PFAS pollution'[95] highlights that PFAS emissions already contribute to potentially sizeable environmental and ecosystem-service impacts across the EEA. Although ecosystem-service costs cannot be quantified due to major methodological and data gaps, the study identifies plausible pathways through which certain monomeric PFAS may enter and harm aquatic and terrestrial organisms, disrupt ecological functions, and lead to societal costs. Adverse effects to a number of PFCAs and PFSAs have been observed in a wide range of species, including fish, birds, mammals, invertebrates, algae and plants, linked to PFAS persistence, bioaccumulation, biomagnification and chronic toxicity.

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[96] 'One DALY represents the loss of the equivalent of one year of full health', WHO (https://www.who.int/data/gho/data/themes/mortality-and-global-health-estimates/global-health-estimates-leading-causes-of-dalys/)

[97] Lucas et al. (2023). Occupational exposure and serum levels of per- and polyfluoroalkyl substances (PFAS): A review. Am J Ind Med, 66, 379-392.

A3.2 Analysis of Impacts

Health Impacts

The baseline evidence indicates that PFAS exposure is associated with a range of adverse health effects, but there is limited data for the sectors in scope and no studies quantifying PFAS blood concentrations in workers in the upstream O&G, refining, or fuel distribution sectors.

Environmental Impacts

The persistence of monomeric PFAS means they resist natural breakdown and accumulate in soils, water, sediments, and living organisms.

i. Quality of Natural Resources

PFAS emissions to the environment can contribute to long-term accumulation in natural resources, including soils, sediments, groundwater, and surface waters, and air. Once PFAS is released, they can migrate through environmental compartments and remain for long periods of time. This persistence means that even low annual emissions can lead to steadily increasing environmental stocks over time. PFAS contamination of natural resources is already documented across the EEA, with PFAS detected in drinking water sources, agricultural soils, sediments, and biota[45].

In addition to their persistence and mobility, several PFAS exhibit ecotoxicological properties that can adversely affect aquatic and terrestrial organisms. Evidence shows effects across a wide range of species, including fish, crustaceans, amphibians, invertebrates, birds, mammals, algae, and plants, with impacts observed on reproduction, development, behaviour, immune function, and survival[95]. If these effects materialise in the environment, they can lead to broader ecosystem damage, including reduced population viability and disruption of food webs. In some cases, PFAS contamination has also resulted in food being discarded to avoid human-health risks, leading to economic losses for agricultural producers.

ii. Likelihood or scale of environmental risk

Monomeric PFAS emissions contribute to a high likelihood of long-term environmental risks due to the persistence, mobility, and bioaccumulative properties of monomeric PFAS. These risks are compounded by the potential for long-range transport, meaning that emissions from localised industrial activities can contribute to contamination far beyond the immediate area of release.

Appendix 4: Evidence review of alternatives

The use of PFAS-containing equipment across the upstream O&G, CCS, refinery, and fuel distribution operations will be impacted by the restriction scenario. In the following section the expected response for this industry segments (downstream users) will be considered.

Under the restriction scenario, downstream users of PFAS-containing equipment will have to substitute the equipment containing PFAS, such as replacing PFAS-containing sealants with similar performance if available, upon adoption of a PFAS restriction. To evaluate, the proportion of equipment containing PFAS that could be substituted, we issued an online survey (further discussed in Appendix 4) to Concawe and IOGP members. The table below summarises these findings.

Table _A 11 Percentage of equipment that could be replaced with PFAS-free alternatives

Equipment	% that could be replaced*
Sealants and sealing devices	30% (15%-90%)
Coatings for wires	20% (10%-60%)
Capacitors	10% (0%-10%)
Piping system and hoses	10% (5%-40%)

* The numbers are presented as follows: midpoint (lower and upper bound values)

Under the restriction scenario, survey respondents were also asked on the current availability of alternatives. From the results of the survey, respondents indicated that commercially available suitable alternatives are not yet available.

The use of PFAS-containing equipment across multiple applications will be impacted by the restriction. The following subsections provide an overview of **alternative substances** that were identified as potential alternatives for the four major equipment classes as follows:

- Sealants and sealing devices
- Coatings for wires
- Capacitors
- Piping systems and hoses

A3.1 Sealants and Sealing Devices

Sealing applications require materials with high temperature resistance, broad chemical compatibility, and long-term reliability. Sealing materials must not degrade, lose elasticity, swell, crack, react, or become permeable when in contact with these substances, even over prolonged service periods. In many refinery applications, seal failure can result in loss of containment, safety hazards, environmental emissions, increased energy consumption, and unplanned shutdowns. As a result, sealing materials must also exhibit low friction, dimensional stability, resistance to creep, and consistent performance over time, while complying with established international design and safety standards. In some cases, sealing materials must additionally avoid contaminating process streams.

Desk-based research, including ECHA’s Annex XV consultation feedback, indicate that alternatives to fluoropolymers, fluoroelastomers and perfluoropolyethers in sealing applications are generally not technically feasible where a combination of demanding properties is required. While certain hydrocarbon elastomers (e.g. NBR, HNBR, ACM) may be technically feasible for less demanding applications, they typically exhibit lower chemical resistance, reduced temperature tolerance, higher permeability, or increased wear, leading to shorter service life and higher maintenance needs.

As discussed above, the survey findings also reach similar conclusions to the desk research as respondents have not identified any commercially available PFAS-free alternatives for sealants and sealing devices suitable for upstream O&G and CCS; refinery and fuel distribution operations. Identified alternatives are summarised in the following table. The highlighted substances are alternatives that have been suggested by across multiple sources.

Table _A 12 PFAS-free alternatives for sealing applications[98]

Name of alternative	Summary of technical feasibility
ACM (ethylene acrylate copolymer)	Operating temperature range between -30 °C to 150 °C (special grades up to 175 °C); limited resistance to moisture / water; limited resistance to acids; poor abrasion resistance; high coefficient of friction.
AEM (ethylene acrylic rubber)	Low resistance to the transmission fluids; higher coefficients of friction
Carbon fibre elements	Only works in dry applications; brittle at temperatures greater than 125 °C.
Chrome/Nickel alloys	High operating temperature range; not suitable for all anti-corrosion situations.
EPDM (ethylene propylene diene monomer)	Operating temperature range reported between -40 °C to 150 °C; Less resistance to degradation; lower chemical resistance and is not suitable for all applications.
Graphite glass fibre seal	Inert but not elastic; poor reset and compression behaviour.
HNBR (hydrogenated nitrile butadiene rubber)	Operating temperature range reported between -40 °C to 130 °C Good abrasion resistance; chemical resistance against oils and lubricants is limited; not resistant to acids.
Metallic seals, nickel alloy 625	High operating temperature ranges; geometry and surface finish limitations; suitable for relatively low numbers of dynamic cycles before performance deteriorates. Not flexible.
Mica (silicate)	Possible contamination issues.
NBR (nitrile butadiene rubber / acrylonitrilebutadiene-rubber)	Good abrasion resistance; low chemical resistance; resistant to aliphatic hydrocarbons and fuels; not suitable for operational temperatures above 110 °C.
Organic, mineral fibre	Shorter life span; reduced sealing levels.
PA -polyamide PA12	Operating temperature range from -20 °C to 100 °C; good abrasion strength; non-resistant to acids, concentrated alkaline solutions and phenols; not suitable for operational temperatures above 100 °C.
PE polyethylene, high density - PE-HD, PE 80/100, PE 1000	Reported operating temperature range of -20 to 80 °C; good resistance against aqueous media; good weathering resistance; non-resistant to concentrated acids, aromatic hydrocarbons, chlorinated hydrocarbons.

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[98] (a) Concawe. (2023). PFAS Study in Refinery & Fuel Distribution Equipment; (b) Arcadis. (2023). Fluoropolymers in the Oil and Gas Industry. Report for the American Petroleum Institute.

Name of alternative	Summary of technical feasibility
PEEK (aryl ketone polymer)	Operating temperature range from -50 °C to 250 °C; chemical resistance similar to PP; higher friction resulting in the requirement for higher operating forces, inferior control performance; not suitable for sealing less viscous fluids or sealing between differential pressure very low elasticity and flexibility. Not flexible.
Polybutylene Terephthalate (PBT)	Low resistance to degradation; less deformable elastic modulus; less electrolyte resistance.
Polypropylene - PP-GF30 (homopolymer reinforced with 30% glass fibres)	Reported operating temperature range of 0 to 110 °C; reduced chemical resistance.
Polypropylene - PP-H (homopolymer)	Reported operating temperature range of 5 to 100 °C; reduced chemical resistance; less sealing properties.
Polysulfone – PSU, including polyarylethersulfones (PAES)	Reported operating temperature range of -15 to 160 °C; non-resistant to ketones, esters, ethers, chlorinated and aromatic hydrocarbons.
Polyvinyl chloride - PVC-U, rigid PVC	Reported operating temperature range of 0 to 60 °C; good resistance to weathering and against aqueous media; non-resistant to aromatic hydrocarbons, chlorinated hydrocarbons, ketones, ester and ethers.
PPS (polyphenylene sulfide)	Capable of operating at temperatures up to 250 °C; resistant against strong acids and bases, organic solvents, oxidising agents, hydrocarbons, conditionally resistant to chloride based solvents; increased wear rate; higher friction coefficient.
PU (polyurethane)	Reduced lifespan; fail in heat resistance; chemical incompatibility with strong acids
Steel seals	High operating temperature range; flanges and bolts to be used in the process require stronger materials during harsh temperature conditions
TPE (Thermoplastic Rubber, class of copolymers)	Good resistance to alcohols and hydrocarbons and oil; limited temperature range; limited chemical resistance.
VMQ (vinyl methyl silicone rubber)	Not suitable for operational temperatures above 150 °C; chemical incompatibility.

A3.2 Coatings for Wires

Coatings for wires and electrical components in refinery environments must meet a broad and stringent set of performance criteria, including flexibility, mechanical robustness, high dielectric strength, thermal resistance (typically from −55 °C up to 150 °C), and resistance to fuels, hydrocarbons, acids, alkalis, solvents, and biological contaminants. Additional requirements include low moisture absorption, hydrophobicity and oleophobicity, low coefficient of friction, dimensional stability, and uniform electrical properties.

Desk based evidence from ECHA consultations and the European Parliament study “The Per- and polyfluoroalkyl substances (PFAS) and their role as enablers in the competitiveness of European industry” indicates that all non-fluoropolymer alternatives fail to meet the full performance envelope required. Commodity polymers such as polyethylene, polypropylene, EPDM, SBR, and polycarbonate are generally unable to withstand upper temperature limits or aggressive chemical exposure. Other materials, such as polyamide and UHMWPE, show insufficient resistance to strong acids or bases, while PEEK, although chemically resistant in many environments, exhibits limited flexibility and sensitivity to certain aggressive chemicals.

The survey findings also reach similar conclusions to the desk research as respondents have not identified any commercially available PFAS-free alternatives for coatings for wires suitable for upstream O&G and CCS; refinery and fuel distribution operations. Identified alternatives are summarised in the following table.

Table _ A 13 PFAS-free alternatives for coatings for wires[99]

Name of alternative	Summary of technical feasibility
Ceramics	High operating temperature range; chemically resistant; less durable.
Epoxy	Lower UV durability; lower corrosion resistance; lower resistance regarding high temperatures.
Melamine	Lower UV durability; lower corrosion resistance; lower resistance regarding high temperatures.
Polyester	Lower UV durability; lower corrosion resistance; lower resistance regarding high temperatures.
Polyetherketone (PEEK)	Operating temperature ranges from -50 °C to 250 °C; chemical and temperature resistant; good wear resistance; not compatible with strong acids; less wear resistance.
Polyimide (PI)	Chemical and temperature resistant; incompatible with some media such as water and steam; poor release properties.
Polyoxymethylene (POM)	High strength; thermal strength; narrow operating temperatures.
Polyphenylene sulfide (PPS)	Capable of operating at temperatures up to 250 °C; some chemical resistance; higher coefficient of friction and rigidity.
Polypropylene (PP)	Reported operating temperature range of 5 to 100 °C; reduced chemical resistance against some media; lower UV resistance.
PPV	Lower UV durability; lower corrosion resistance; lower resistance regarding high temperatures.
Silicon polyester	Resistant to outdoor weathering, UV, salt spray corrosion, oxidation, detergents and thermal shock; lower performance and durability.

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[99] (a) ECHA. (2025). Annex E to the Opinion on the Annex XV dossier proposing restrictions on Per- and polyfluoroalkyl substances (PFASs). Available from: https://echa.europa.eu/documents/10162/17233/rest_pfas_bd_draft_240625_en.pdf/86488ab5-30c9-f7b9-547d-84db15535d9a?t=1755590462498 (b) Concawe. (2023). PFAS Study in Refinery & Fuel Distribution Equipment.

Name of alternative	Summary of technical feasibility
Silicone	Lower thermal stability and life expectancy; flexibility; poor strength; high water absorption.
Stainless steel	High operating temperature range; lower chemical resistance; thermal conductivity; incompatibility with some chemicals.
Ultra-high-molecular-weight polyethylene (UHMW-PE)	Low friction and wear; lower chemical resistance; flexibility and rigidity.

A3.3 Capacitors

Capacitors used in refinery and industrial applications require materials with high dielectric strength, thermal stability, chemical inertness, and long-term reliability, often under fluctuating temperature and electrical load conditions. In some cases, capacitors are used in environments exposed to aggressive chemicals or elevated temperatures, further constraining material choices.

Desk-based evidence indicates that information on alternatives to fluoropolymers and fluoroelastomers in capacitor applications is limited and insufficiently substantiated. While some stakeholders have referenced potential alternatives in the literature, detailed data on performance, costs, and long-term reliability are generally lacking. Within the ECHA Annex E PFAS restriction document, it is discussed that limited information was provided on uses and alternatives of capacitors and that based on this limited information, an assessment was not performed. Regulatory assessments note that the benefits of fluoropolymers and fluoroelastomers in capacitors are acknowledged but often not fully documented, complicating substitution assessments. Within the literature, there is a lack of information on PFAS-free alternatives for the use of PFAS in capacitors.

A3.4 Pipes

Piping systems and hoses used in refinery, petrochemical, and oil and gas applications must withstand high pressures, extreme temperatures, corrosive fluids, and dynamic mechanical stresses. In upstream and offshore environments, additional requirements include resistance to seawater corrosion, extreme temperatures, wave-induced movement, cryogenic conditions, and aggressive downhole fluids.

Desk-based research indicates that while alternative materials (e.g. metals, ceramics, PPSU, polyethylene, polypropylene, PVC, PMMA, and other polymers) may be technically feasible for certain limited uses, they generally exhibit inferior chemical and /or thermal resistance, brittleness, reduced impact strength, or shorter service life. Metals such as brass and eco-brass raise corrosion or regulatory concerns, while ceramics and silicon carbide suffer from brittleness and limited formability.

The survey findings also reach similar conclusions to the desk research as respondents have not identified any commercially available PFAS-free alternatives. Identified alternatives are summarised in the following table.

Table _A 14 PFAS-free alternatives for pipes[100]

Name of alternative	Summary of technical feasibility
C-PVC	Lower upper temperature limit; lower chemical resistance; permissible temperature of material of 0 °C to 60 °C.
Enamelled Steel	Mounting constraints; lower resistance to chemical reaction.
FRP (Fiber Reinforced Plastic	Lower upper temperature limit; lower chemical resistance.
Glass lining	Mechanical fragility

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[100] (a) Concawe. (2023). PFAS Study in Refinery & Fuel Distribution Equipment; (b) Arcadis. (2023). Fluoropolymers in the Oil and Gas Industry. Report for the American Petroleum Institute.

Name of alternative	Summary of technical feasibility
Hastelloy	Permissible temperature of material of -260 °C to 1000 °C; material heavy weight can induce changes in structural design of supports and civil construction
HDPE	Prone to failure under high pressure, lower upper temperature limit; lower chemical resistance
HD-PE	
Nickel	Mounting constraints; lower resistance to chemical reaction
PP	Lower upper temperature limit; lower chemical resistance; permissible temperature of material of 0 °C to 100 °C.
SVR	Lower upper temperature limit; lower chemical resistance
Titanium	Mounting constraints; lower resistance to chemical reaction
U-PVC	Lower upper temperature limit; lower chemical resistance; permissible temperature of material of 0 °C to 60 °C.

Appendix 5: Consultation Synopsis

This Appendix provides a more detailed presentation of the stakeholder consultation activities described in Appendix 1 that were carried out as part of this Study. It outlines the consultation strategy and analysis methodology and provides a summary of the key outcomes of the consultation activities.

The aim of the consultation was to gather evidence for the baseline and to gather evidence and opinion on the restriction scenarios under consideration and their likely impacts. The stakeholder consultation was performed by Ricardo consultants, in collaboration with Concawe and IOGP. To obtain detailed information on the baseline and the potential impacts on the proposed restriction one survey was launched and hosted on *Alchemer*. This survey sought input and/or validation of the ‘typical’ upstream O&G, fuel refinery and fuel distribution operations in the EEA, Switzerland, and the UK; the presence of PFAS in the equipment in scope; the role of this equipment; potential alternatives; end-of-life management; and PFAS emissions based on desk-based findings. Proceeding the launch of this survey, a workshop was held to explain the survey. This survey was launched on 21 October 2025 and closed on 3 November 2025.

A5.1 Stakeholder Participation

For the survey, 14 unique responses were received with most respondents being large businesses and from the refinery sector.

Five semi-structured follow-up interviews to discuss findings further and three further workshops were then held with Concawe and IOGP members. A survey validation workshop was held in November 2025. The baseline and impact scenarios were reviewed in follow-up workshops held in December 2025 and in January 2026.

A5.2 Methodology

Following the closure of the stakeholder survey, the submitted responses were analysed using Ricardo’s in-house analysis tools (Microsoft Excel). The analysis considered the overall responses of the stakeholders and also by stakeholder type, with the different options highlighted as relevant.

- Step 1: The raw data which comprised the survey responses was downloaded, cleaned and encoded to enable effective analysis, and so that meaningful outputs could be produced from the responses.
- Step 2: A comprehensive distributional analysis was performed for each question in the survey. This involved an examination of the distribution of responses to identify any notable patterns, trends, or outliers. Medians, modes, 25th and 75th percentile estimates, minima and maxima were also considered.
- Step 3: The survey responses were compared with the results of the desk-based research. Dependent on the outcome, the desk-based results were either taking forward to the SEA or adjusted; otherwise, the survey-based results were taken forward to the SEA.

Responses to open text questions or attachments provided by respondents were also reviewed and/or analysed, also split by stakeholder type and issue/interest. These questions were systematically checked for overlaps to detect any coordinated responses. Each open text reply was checked against all other open text responses for their textual similarity by considering the cosine similarity of all answers against all other answers.

A5.3 Summary of Findings

Key findings of opinions and evidence for the baseline and restriction scenario under consideration and impacts are outlined below by survey section.

Baseline

Within the survey, several questions were asked in order to develop a quantitative baseline for the size of ‘typical’ upstream O&G, fuel refinery and fuel distribution operations; the presence of PFAS in the equipment in scope; the role of this equipment; potential alternatives; end-of-life management; and PFAS emissions.

Size of a typical operation and equipment used

Within the survey, respondents were asked to verify the results from desk-based research for sizes of a typical operation for upstream O&G and CCS operations; fuel refinery and fuel distribution operations. This included on the size of operations the volume of equipment required for a typical operation. These numbers were then adjusted based on feedback from the survey and a validation workshop. These results are presented in the Tables below.

Upstream O&G and CCS

Table _A 15 Size of a typical upstream O&G operation

Indicator	/field	/offshore production platform
Production (boe/d)	300k	100k
Offshore platforms (#)	3	1
Wells (#)	50	17
Compressor stations (#)	3	1
Flexible riser pipe (m/subsea well)	250	250

Table _A 16 Size of a typical CCS operation

Indicator	/field
CO_2 captured and sequestered (million tons per year)	3
Injection wells (#)	6
CO_2 transport pipeline (km)	>60
Depth of storage (km)	2

Table _A 17 Volume of equipment required in a typical operation

Typical operation	Sealants and sealing devices (units)	Coatings for wires (km)	Capacitors (units)	Piping system and hoses (km)
Upstream O&G	26,000-52,000	40-80	1,000-3,000	400-550
CCS	3,200-4,600	5-10	570-2,200	460-620

Oil refining and distribution operations

Table _A 18 Size of a typical refining and distribution operations

Operation	#
Fuel refinery	
Capacity (million tonnes of oil equivalent per year)	10
Capacity (barrels of oil-equivalent per day)	225,000
Fuel distribution	
Pipeline network (km)	250
Road transport network (Number of truckloads per year)	72,000

Operation	#
Rail transport network (Number of wagonloads per year)	18,000
Shipping transport network (Number of trips for a medium-sized oil tanker per year)	120

Table _A 19 Volume of equipment required in a typical operation

Typical operation	Sealants and sealing devices (units)	Coatings for wires (km)	Capacitors (units)	Piping system and hoses (km)
Refinery	18,000-66,000	140-570	4,300-16,500	300-500
Distribution	1740-3450	153-256	3650-6840	186-346

Presence and criticality of PFAS-containing equipment

The survey also asked respondents to verify desk-based assumptions on the presence of PFAS in sealants and sealing devices; coatings for wires; capacitors; and piping system and hoses for a typical operation. Respondents were asked to confirm if these numbers were correct or whether these needed adjusted. These results are presented in the Tables below. From the survey and follow-up interviews, a significant share of in-scope **equipment contains PFAS**:

- Upstream O&G and CCS: **40-50%**
- Refinery sector: **50-70%**
- Distribution sector: **50-60%**

Respondents were also asked on the criticality of the equipment through multiple-choice questions, in which respondents verified that the equipment was either partly critical or mostly critical for operations.

Upstream O&G and CCS

Table _A 20 Presence of PFAS in equipment and criticality of the equipment in a typical upstream operation and CCS operation

Typical operation	Sealants and sealing devices (units)	Coatings for wires (km)	Capacitors (units)	Piping system and hoses (km)
% of equipment that might contain PFAS	45% (30-70%)	50% (20-60%)	40% (25%-70%)	40% (25%-70%)
Criticality of equipment	Mostly critical	Partly critical	Mostly critical	Mostly critical

Fuel refining and distribution operations

Table _A 21 Presence of PFAS in equipment and criticality of the equipment in refining and distribution operations

Typical operation	Sealants and sealing devices (units)	Coatings for wires (km)	Capacitors (units)	Piping system and hoses (km)
Refinery operations				
% of equipment that might contain PFAS	70% (30-90%)	50% (20-80%)	50% (20-80%)	70% (25-90%)
Criticality of equipment	Mostly critical	Partly critical	Mostly critical	Mostly critical
Distribution operations				
% of equipment that might contain PFAS	60% (30-90%)	50% (40-80%)	60% (20-80%)	60% (25-90%)
Criticality of equipment	Critical	Partly critical	Critical	Critical

End-of-life management and emissions

The survey also asked respondents to verify desk-based assumptions on the volume of equipment reaching end-of-life each year for the equipment in-scope and the proportion of this equipment that is typically incinerated, landfilled or recycled in each year. The results following the survey and the validation workshop are presented in the following tables for the volume of equipment reaching end of life. Respondents were also asked for data for PFAS emissions from the equipment, with respondents responding that is insufficient evidence or no data is available.

Upstream O&G and CCS

Table _A 22 Volume of equipment reaching end-of-life per year for upstream O&G and CCS operations

Typical operation	Sealants and sealing devices (units)	Coatings for wires (km)	Capacitors (units)	Piping system and hoses (km)
Upstream O&G	8,500-17,500	4-9	150-500	25-40
CCS	1050-1550	0.5-1.5	90-370	3-5

Fuel refinery and distribution operations

Table _A 23 Volume of equipment reaching end of life per year for refinery and distribution operations

Typical operation	Sealants and sealing devices (units)	Coatings for wires (km)	Capacitors (units)	Piping system and hoses (km)
Upstream O&G	8,500-17,500	4-9	150-500	25-40
CCS	1050-1550	0.5-1.5	90-370	3-5
Refinery operations	3000-15000	10-40	450-1800	5-25

Typical operation	Sealants and sealing devices (units)	Coatings for wires (km)	Capacitors (units)	Piping system and hoses (km)
Fuel distribution	530-1200	15-30	575-895	11-27

Business Impacts

Within the survey, respondents were asked I questions regarding the potential business impacts of the restriction scenario under consideration for their portfolio. This included on their potential business response to a PFAS restriction questions and the proportion of equipment that could be replaced with PFAS-free alternatives.

70% of respondents (N=7) reported that upon the introduction of a PFAS restriction, they would seek to substitute the PFAS-containing equipment if possible. However, 30% of respondents responded they would likely close their operations in the EU upon the introduction of a PFAS restriction.

Across the sectors, PFAS-free **alternatives are available for 10-30% (with caveats)** of the PFAS-containing equipment across sectors and this breakdown is presented in the following table for the equipment in scope.

Table _A 24 % of equipment that could be replaced with PFAS-free alternatives

Equipment	% that could be replaced
Sealants and sealing devices	30% (15%-90%)
Coatings for wires	20% (10%-60%)
Capacitors	10% (0%-10%)
Piping system and hoses	10% (5%-40%)

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