

The cost of PFAS pollution for our society

Final report

Prepared by WSP, Ricardo and Trinomics
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Contents

1. Introduction	1
1.1. This report	1
1.2. Project context	2
1.2.1. What are PFAS	2
1.2.2. Policy context	5
1.2.3. State of the science on impacts and societal costs of PFAS pollution	6
2. Method	14
2.1. Overview	14
2.2. Literature review	15
2.3. Interviews	15
2.4. Exposure scenarios	16
2.4.1. Overall Approach	16
2.4.2. Development of Baseline Year (2024)	17
2.5. Cost assessment	24
2.5.1. Overview	24
2.5.2. Human health costs	24
2.5.3. Remediation and treatment costs	39
2.5.4. Ecosystem service costs	43
2.6. Methodological limitations	43
2.6.1. Concerning the human health cost assessment	43
2.6.2. Concerning the remediation/treatment cost assessment	46
2.6.3. Concerning the ecosystem service cost assessment	48
3. Results	50
3.1. Exposure scenarios	50
3.2. Human health costs	53
3.2.1. Current costs of PFAS pollution	53
3.2.2. Future costs Scenario 1: Business as usual for emissions	60
3.2.3. Future costs Scenario 2: Drinking Water Directive (DWD)	63
3.2.4. Future costs Scenario 3: Environmental Quality Standards (EQS)	65
3.2.5. Future costs Scenario 4: Total stop of production and use of PFAS	69
3.2.6. Comparison of scenarios	73
3.3. Soil remediation / water treatment costs	77
3.3.1. Current costs of PFAS pollution	77
3.3.2. Future costs Scenario 1: Business as usual for emissions	77

3.3.3. Future costs Scenario 2: Drinking Water Directive (DWD)	80
3.3.4. Future costs Scenario 3: Environmental Quality Standards (EQS).....	83
3.3.5. Future costs Scenario 4: Total stop of production and use of PFAS.....	84
3.3.6. Comparison of scenarios	86
3.4. Ecosystem service costs	87
3.4.1. Potential pathways from PFAS exposure to ecosystem service impacts ..	87
3.4.2. Case study 1: Effects on algae and climate regulation	91
3.4.3. Case study 2: Effects on pollinators and food provisioning	92
3.4.4. Case study 3: Effects on poultry, livestock, and food provisioning.....	93
3.4.5. Case study 4: Effects on aquaculture and food provisioning	94
3.4.6. Considerations of future costs.....	95
4. Conclusions	97
4.1. Scenario 1 (Business as usual)	97
4.2. Scenario 2 (Drinking Water Directive).....	98
4.3. Scenario 3 (Environmental Quality Standards).....	99
4.4. Scenario 4 (Total stop of production and uses of PFAS)	101
4.5. Scenario comparison	102
4.6. Gaps/limitations and areas for further work	105
Annex A – Task 1 report (initial data gathering)	
Annex B – Task 2 report (method development)	
Annex C – Task 3 (exposure scenario modelling)	
Annex C1 - Task 3 report	
Annex C2 - Blood serum concentrations for specific PFAS species by cohort and year	
Annex D – Task 4 report (cost assessment)	

Abstract

Per- and polyfluoroalkyl substances (PFAS) are persistent, bioaccumulative chemicals widely used in industry and consumer products, and now detected across environmental media and human populations. This study assesses the societal costs of PFAS pollution in the European Economic Area (EEA) under four hypothetical exposure scenarios: 1) business as usual (BAU) for emissions; 2) full compliance with the Drinking Water Directive (DWD); 3) full compliance with Environmental Quality Standards (EQS); and 4) a total ban on PFAS production and use. Scenario modelling was conducted for the period 2024–2050, projecting PFAS emissions, environmental concentrations, and human exposure across different population cohorts. Based on this, human health impacts were quantified and monetised, soil remediation and water treatment costs were estimated, and the potential costs of ecosystem service losses were assessed qualitatively. In 2024, quantifiable annual health costs from human exposure to PFOA, PFOS, PFHxS and PFNA (for which sufficient literature evidence was available) were estimated at EUR 39.5 [0.005-600.5] billion/year, while annual treatment/remediation costs are estimated at EUR 3.8 [0.002-24.2] billion/year. The total quantifiable costs are predicted to decrease slowly over the assessment period in scenarios 1 (BAU) and 2 (DWD) due to decreasing health costs from legacy PFAS, while treatment/remediation costs and ecosystem service losses would increase. Scenario 3 (EQS) would lead to the elimination of health costs by 2040, but is associated with tens of billions of EUR of wastewater treatment costs annually. Scenario 4 would eliminate the health costs from legacy PFAS in the 2040s, and lead to a reduction in remediation costs. Ecosystem service losses would also decrease in scenarios 3 and 4.

Executive summary

Introduction

Per- and polyfluoroalkyl substances (PFAS) are a large group of synthetic chemicals (potentially over 10,000 substances) used in a wide range of industrial and consumer applications due to their water, oil, and dirt-repellent properties and high chemical stability. Their persistence, mobility, and bioaccumulative potential mean they are now ubiquitous in the environment and human populations. PFAS exposure is linked to a range of adverse health outcomes and environmental impacts. These can be associated with costs to society, such as healthcare costs, costs for cleaning up pollution, and the loss of ecosystem services.

This study, commissioned by the European Commission's DG Environment and delivered by WSP, Ricardo and Trinomics, assesses the societal costs of PFAS pollution in the European Economic Area (EEA). It updates and expands on previous work (notably Goldenman et al., 2019¹), quantifying both current and future costs under four hypothetical scenarios.

Methodology

This study was divided into four tasks. In **Task 1**, a **literature review and targeted expert consultation** was undertaken to gather data on the state of knowledge regarding human and environmental exposure to PFAS pollution in the EEA, its human health and environmental impacts, as well as previous estimates and available methods for assessing the societal costs of PFAS pollution.

In **Task 2**, a **human health and environmental cost valuation methodology** was developed to update and expand the existing literature investigating the societal costs of current and future PFAS pollution in the EEA. Three main types of societal costs were identified and assessed in this study: costs associated with the human health impacts of PFAS pollution, costs associated with the remediation and treatment of soil and water to remove PFAS pollution, and potential costs associated with the ecosystem service impacts of PFAS pollution.

Task 3 involved the modelling of prospective **exposure scenarios** based on hypothetical PFAS future pollution levels in EEA. The following four hypothetical 'what if' scenarios were assessed:

¹ Goldenman et al. (2019). The cost of inaction: A socioeconomic analysis of environmental and health impacts linked to exposure to PFAS. Available at: [THE COST OF INACTION](#)

- **Scenario 1** – A business-as-usual (BAU) situation for PFAS emissions, reflecting the regulatory status as of June 2024 (hence not reflecting the later implementation of the REACH restrictions on PFHxA, on PFAS in firefighting foams, nor the proposed universal PFAS restriction).
- **Scenario 2** – Full compliance with the recast Drinking Water Directive (DWD) thresholds of 100 ng/l for the sum of 20 PFAS and 500ng/l for “Total PFAS”.
- **Scenario 3** – Full compliance with the Commission proposed quality standard of 4.4 ng/l PFOA-equivalent for the sum of 24 PFAS under the Environmental Quality Standards and Groundwater Directives (EQSD and GWD) for surface water and groundwater, respectively.
- **Scenario 4** – A total stop of production and uses of PFAS. It is assumed however that some articles already in use would continue to be used until their end of life as it will not be possible to recall those (consumers articles).

The model estimated numbers of sites that are potentially contaminated from PFAS production and use, as well as concentrations in different environmental compartments and in human blood serum in different exposure cohorts:

- **Background cohort:** General population not living near PFAS sources.
- **Elevated cohort:** People living near PFAS production or use sites. The elevated cohort was further divided into “**elevated-high**” (closest to sites) and “**elevated-low**” (further away, above background but below hotspot levels).
- **Occupational cohort:** Workers at PFAS manufacturing or use facilities.

Lastly, **Task 4 quantified human health and environmental costs** of current and future PFAS pollution up to 2050 by applying the methodology developed in Task 2, using data gathered in Task 1 and the results of the modelling of exposure scenarios from Task 3. Human health costs are estimated based on the estimated size of the affected populations and levels of exposure (blood serum concentrations), which were combined with the latest exposure response functions (ERFs) for thirteen health risks or endpoints to quantify and value the health impacts of PFOA, PFOS, PFHxS and PFNA exposure, for which evidence is available. The health impacts assessed in this study thus focus on the effects of exposure to these four substances, which are already regulated. Remediation and treatment costs are estimated based on the predicted numbers of contaminated sites requiring remediation and volumes of water requiring treatment, combined with the best available unit costs per site or per volume of water. Ecosystem service costs were assessed qualitatively by demonstrating the potential pathways from environmental exposure to ecosystem service impacts, including case studies on ecosystem services related to climate regulation and food provisioning.

Exposure scenarios

The universal PFAS restriction dossier² provides data for a business-as-usual scenario where total PFAS emissions will multiply by 2.5 to 2.75 times between 2020 and 2050. This large increase in emissions means there could be a two and a half times increase of PFAS concentrations in the environmental media and human blood serum (except for certain PFAS substances, such as legacy PFAS whose concentrations are already declining due to existing legislation and which are also the ones for which health effects can be computed due to available evidence³). According to our calculations, there could be an increase in the area exposed to elevated concentrations of PFAS from 8% of the area of the EEA in 2020 to 10.5% by 2050, and subsequent increase in the exposed cohorts equivalent to an additional 10 million EEA citizens moving from a background cohort level of exposure to an elevated cohort (both high and low) level of exposure. Note that the increase in contaminated area is smaller than the increase in emissions, because the model assumes (based on literature references, including Eurostat) that increase in use and emission partly occurs at pre-existing sites where it increases the concentration but not the area of contamination.

For the **baseline year (2024)**, 86% of the EEA population is estimated to be in the background cohort, and 14% in the elevated cohort (comprising 3% in the elevated-high, and 11% in the elevated-low sub-cohorts), and <1% in the occupational cohort. In **scenarios 1 and 2** (business as usual for emissions and DWD compliance, respectively), the increase in emissions by two and a half times the baseline year (2020 in the universal REACH restriction dossier) could mean that, by 2050, 17% of the EEA population is in the elevated cohort. Since the increase in emissions is driven by increased production and use of PFAS, it would also likely lead to a significant increase in the number of sites requiring remediation. Our calculations estimate an increase from around 11,500 sites in 2024 to around 14,200 sites in 2050 (most increased emissions are assumed to come from increased production in existing sites).

² 2023 version of the Background Document. An update of the Background Document for the universal PFAS restriction proposal was published in late August 2025. The methodology, calculations and text in the present report were largely prepared before that date, so the present report is based on the March 2023 version of the universal PFAS restriction dossier.

³ Time series data for blood serum concentrations of four named PFAS (PFOA, PFOS, PFNA, and PFHxS) spanning 2001 to 2024 shows a declining trend over time as regulatory enforcement takes effect. The trends over the time-series are assumed to continue to apply to these four named PFAS from the baseline year 2024 until the end of the assessment period. This decrease is assumed to be compensated by increasing concentrations of other, unnamed PFAS to lead to the projected increase in overall PFAS concentrations. See also Annex C1 (Section 2.2.3) for further details on this assumption and Annex C2 for a breakdown of the projected blood serum concentrations by PFAS species.

Assuming the drinking water threshold of 100 ng/l for the sum of 20 PFAS is respected everywhere in the EEA, **scenario 2** is estimated to lead to a minor reduction in blood serum concentrations (<2µg/l). The majority of drinking water supplies are calculated as being well below the 100 ng/l in scenario 1, even by 2050. In cases where water was predicted to exceed the limit in scenario 1 (such as the elevated-high sub-cohort from 2020, and elevated-low sub-cohort by 2040), limiting the intake of PFAS via drinking water under scenario 2 resulted in limited reductions in blood serum concentrations, due to more significant intake of PFAS via food. Note that other pathways such as air and indoor dust would also contribute to exposure and blood serum concentrations and are not considered in this study.

The proposed water quality standard (4.4 ng/l PFOA-equivalent) considered in **scenario 3** is very low compared to surface water and groundwater concentrations (in the tens to low hundreds of ng/l). This could result in a reduction in blood serum concentration of a similar order (95-99%) by 2050. For the background cohort, adult blood serum concentrations could decline from 14 µg/l in 2020 to 0.7 µg/l in 2050. For the elevated-high cohort, blood serum concentrations could fall drastically from 51 µg/l in 2020 to 0.7 µg/l in 2050. The number of PFAS producing/using sites potentially requiring remediation is assumed to be unchanged in this scenario compared to scenarios 1 and 2, as this scenario focuses on EQS compliance only, with no assumption taken on emissions. However, if this step was considered, compliance with the proposed threshold in surface water and groundwater would be equivalent to a reduction of emissions by 99% compared to the year 2024.

Scenario 4 (the stop of PFAS use and production) models a significant reduction in emissions from 2030 (64% reduction compared to 2024), with continued decline reaching zero by 2040. Biomonitoring data suggests half-lives of between 2 and 10 years, depending on the specific PFAS. Given the heavy reduction in emissions and new exposure, the results of scenario 4 show that blood serum concentrations could fall by as much as 100% by 2050 (i.e., for both background and elevated cohorts (high and low), PFAS in blood could be eliminated by 2050, assuming a complete stop of PFAS use and emissions from 2030). The rate of decline of PFAS in blood serum after limiting exposure could take between 15 and 20 years, depending on the initial concentration level (i.e. it takes longer for elevated concentrations to reach zero). In parallel, due to the persistence of PFAS in soil, it is assumed that the extent of the contaminated area is fixed at the peak year of emissions (expected to be reached in 2026), with no decline in the area of the elevated cohort or the number of contaminated sites following declining emissions (i.e., the emissions cease but the sites remain contaminated). This could lead to continued human exposure, which has not been considered in the model, because the model assumes a direct relationship between emissions (which fall to zero by 2040 in this scenario) and exposure.

Cost results and conclusions

Three main types of societal costs have been identified and assessed in this study: (i) costs associated with the human health impacts of pollution from 4 already regulated PFAS among thousands of existing PFAS (namely PFOA, PFOS, PFHxS and PFNA) for which scientific literature on health impacts is sufficiently developed, (ii) costs associated with the remediation and treatment of soil and water to remove PFAS pollution, and (iii) potential pathways for costs associated with the losses of ecosystem services due to PFAS pollution (simply referred to as ‘ecosystem service costs’ in the following). An overview of the estimated costs for each scenario is presented below, and shown in [Table 1](#), which presents undiscounted annual costs in 2024, 2030, 2040 and 2050, as well as the present value over the whole assessment period. The ecosystem service costs could not be quantified nor monetised, but the case studies in this report have shown that PFAS may affect ecosystem services that contribute billions of euros to the EEA economy, which is also summarised in [Table 1](#).

Under scenario 1 (Business as usual), the estimated health costs (although limited to 4 PFAS only) dominate the quantified costs. Scenario modelling predicted an increase in emissions of PFAS overall, while PFOA, PFOS and PFHxS emissions and thus blood serum levels were estimated to decline over the period⁴. This results in an estimated 169,600 [20-1,731,000]⁵ DALYs and 1,050 [0-26,030] statistical deaths attributable to PFOA, PFOS, PFHxS and PFNA exposure in 2024, decreasing to 125,400 [10-1,264,100] DALYs and 400 [0-18,640] statistical deaths in 2050. As a result, human health costs from PFOA, PFOS, PFHxS and PFNA pollution are estimated at €39.5 [0.005-600.5] billion/year in 2024, reaching €29.5 [0.004-426.0] billion in 2050. The increasing blood serum levels of ‘other PFAS’ types that are not yet sufficiently studied in the scientific literature and could not be quantified, are likely to result in an increase in the combined disease burden from all PFAS pollution between 2025-2050. This is, however, not captured here. Remediation costs and miscellaneous costs of PFAS pollution (all PFAS) add another €3.8 [0.002-24.2] billion/year in 2024. The exposure modelling in Task 3 predicted an increase in the number of contaminated sites that require remediation, leading to an increase in the estimated remediation costs to €4.7 [0.003-29.9] billion/year in 2050. It is assumed that no significant drinking water or wastewater treatment is occurring specifically to remove PFAS in scenario 1.

⁴ As discussed in Section 2.4.2.3, concentrations for PFOA, PFOS, PFHxS and PFNA are projected based on past time-series data. Despite a 2023 REACH restriction, PFNA blood serum levels continue to rise through 2024, likely due to ongoing exposure from existing stockpiles and PFNA’s slow elimination rate.

⁵ As a reminder: Square brackets indicate the potential range of values, taking into account the estimates from the sensitivity analysis. For example, “€39.5 [0.005-600.5] billion” indicates a medium estimate of €39.5 billion, a low sensitivity estimate of €0.005 billion, and a high sensitivity estimate of €600.5 billion.

Ecosystem service costs could not be quantified, but they could be significant and would be expected to increase in this scenario, at least partially offsetting the decrease in health costs. The total present value of quantifiable costs over the assessment period is estimated at around €440 billion in scenario 1 (with human health costs limited to PFOA, PFOS, PFHxS and PFNA only).

Under scenario 2 (Drinking Water Directive), the estimated health costs are comparable to scenario 1, despite the reduction in PFAS concentrations in drinking water. This is because drinking water only accounts for a small fraction of human exposure and, therefore, exposure modelling predicts virtually identical concentrations of PFAS in blood serum under scenarios 1 and 2. Human health costs from PFOA, PFOS, PFHxS and PFNA pollution are thus estimated to decline from €39.5 [0.005-600.5] billion/year in 2024 to €29.5 [0.004-426.0] billion in 2050, due to the estimated decline in blood serum concentrations of PFOA, PFOS, PFHxS. Similar to scenario 1, the increasing blood serum levels of 'other PFAS' types that are not yet sufficiently studied in the scientific literature and could not be quantified, are likely to result in an increase in the combined disease burden from all PFAS pollution between 2025-2050. Costs for soil remediation and removal of PFAAs from drinking water are expected to be relatively small compared to the health costs, contributing €3.8 [0.002-24.2] billion/year in 2024, increasing to €6.2 [0.3-153.4] billion/year in 2050. This increase is based on the predictions from the Task 3 exposure modelling that the number of contaminated sites requiring soil remediation increase (equivalent to scenario 1), and that the volumes of drinking water requiring additional treatment due to DWD threshold exceedances increase. Costs to remove TFA from drinking water have been calculated separately (due to more severe uncertainties associated with TFA). The inclusion of TFA would increase the drinking water treatment costs dramatically. Assuming that Member States apply the Total PFAS threshold of 500 ng/l, additional drinking water treatment costs of around €14-15 billion would be estimated to be incurred in the EEA per year. Ecosystem service costs would be expected to be comparable to scenario 1, since drinking water treatment does not significantly affect PFAS pollution in the environment. **The present value of quantifiable costs over the assessment period is estimated at around €450 billion in scenario 2 (with human health costs limited to PFOA, PFOS, PFHxS and PFNA only), which is slightly higher than in scenario 1.** When considering drinking water treatment to remove TFA, the present value of scenario 2 could even be over €200 billion higher than in scenario 1.

Under scenario 3 (Environmental Quality Standards), estimated remediation/treatment costs dominate the total quantifiable costs of PFAS pollution. This is largely because of the assumption that additional treatment to remove PFAS will be required for all wastewater in the EEA to achieve compliance with the EQS. Costs for soil remediation and wastewater treatment are estimated to decrease slowly from around €80.2 [21.6-712.9] billion/year in

2024 to €75.4 [19.9-666.9] billion/year in 2050. The decrease reflects a decline in the EEA population, which is assumed to lead to an equivalent decline in the amount of wastewater generated. The resulting reductions in PFAS concentrations in the environment (and therefore also food and drinking water) has been estimated to result in a sharp reduction in blood serum concentrations of PFAS over time (overall, and specifically for PFOA, PFOS, PFHxS and PFNA which are considered for the quantifiable health costs as discussed above). As a result, quantifiable human health costs from PFOA, PFOS, PFHxS and PFNA pollution are estimated to decline from €39.5 [0.005-600.5] billion/year in 2024 to €12.0 [0.001-373.5] billion in 2030. Subsequently, zero health costs are estimated in the medium and low-sensitivity scenarios for 2040 and 2050 given the negligible levels of PFAS in human blood serum, although some health impacts are estimated in the high-sensitivity scenario with equivalent monetary costs of €3.5 billion in 2040 and €3 billion in 2050. In addition, the blood serum levels of 'other PFAS' types that are not yet sufficiently studied in the scientific literature and could not be quantified could result in additional disease burden between 2025-2050. **The present value of quantifiable costs over the assessment period is estimated at around €1.7 trillion (with human health costs limited to PFOA, PFOS, PFHxS and PFNA only), which is about €1.3 trillion higher than estimates under scenarios 1 and 2, due to the dominant wastewater treatment costs.** However, ecosystem service costs, which could not be quantified, would be expected to gradually decrease in this scenario and to be lower than in scenarios 1 and 2, at least partly offsetting the wastewater treatment costs.

Under scenario 4 (Total stop of production and uses of PFAS), estimated health costs dominate the quantified costs of PFAS pollution. Costs from human exposure to PFOA, PFOS, PFHxS and PFNA are estimated to fall sharply from €39.5 [0.005-600.5] billion/year in 2024 to €0.5 [0-21.5] billion/year in 2040. This is a less steep decline than costs estimated under scenario 3 due to the assumption that stockpiles of articles that cannot be repealed (consumer articles) would continue to be used until they reach their end of life, leading to a slightly slower decline in predicted blood serum concentrations. In 2050, the steep decline in exposure towards zero levels of PFAS in human blood translates to no monetary costs. However, the blood serum levels of 'other PFAS' types that are not yet sufficiently studied in the scientific literature (and thus not quantified) could result in additional disease burden between 2025-2040. Similarly to scenario 1, the remediation costs would still be relatively small compared to the health costs (around €3.8 [0.002-24.2] billion/year throughout the assessment period) and no significant drinking water or wastewater treatment specifically to remove PFAS has been assumed. Similarly to scenario 3, ecosystem service costs would be expected to gradually decrease in this scenario and to be lower than in scenarios 1 and 2. In conclusion, out of the four assessed scenarios, scenario 4 would be expected to be the scenario associated with the lowest societal costs of PFAS pollution by far. **The present value of quantifiable costs over the assessment period is**

estimated at around €330 billion in scenario 4 (with human health costs limited to PFOA, PFOS, PFHxS and PFNA only), which is about €110 billion lower than the present value for scenario 1.

In summary, scenario 4 is expected to have the lowest societal costs of PFAS pollution, out of the four assessed scenarios. This is primarily because the stop of production and use of PFAS would reduce emissions, leading to a gradual decline in health costs (with a lag due to the persistence of PFAS in human blood serum), even when assessing the health costs of only 4 PFAS. Under this scenario, soil remediation costs would no longer increase either (assumed to remain constant over the assessment period due to the persistence of PFAS in soil) and no additional water treatment costs are expected. Ecosystem service costs (not quantified) would also fall gradually in scenario 4.

In the medium-sensitivity scenario, the highest quantifiable costs are estimated for scenario 3 due very high wastewater treatment costs that are expected to be required to comply with EQS thresholds. However, the scenario does lead to gradually declining human health costs (with a lag due to the persistence of PFAS in human blood serum), and gradually declining ecosystem service costs (not quantified).

Scenarios 1 and 2 are expected to lead to relatively similar societal costs, in between scenarios 4 and 3. In both scenarios 1 and 2, costs for remediation/treatment and ecosystem service losses are expected to increase over the assessment period due to increasing PFAS emissions, while human health costs are estimated to fall slightly between 2024 and 2050 due to the estimated decline in blood serum concentrations of legacy PFAS (PFOA, PFOS, PFHxS).

The present study's estimates of the societal costs of PFAS pollution in the EEA are broadly consistent in scale (multiple billions of euros per year) with previous landmark analyses, such as Goldenman et al. (2019) and Forever Pollution Project (2025), despite methodological updates, expanded scope (e.g. health end-points), and new exposure modelling.

These conclusions should be interpreted carefully, considering the uncertainties and limitations noted in this report. In particular, study authors believe that the estimates of human health costs, based on only 4 regulated PFAS, represent a lower bound to the total potential health damage that PFAS exposure may cause in the EEA, even though the study is more comprehensive than previous ones. Similarly, despite expanding on previous studies in terms of assessing ecosystem service impacts, the associated costs could still not be quantified, and could be significant.

Table 1 – Comparison of estimated health costs, remediation/treatment costs and ecosystem service costs of PFAS pollution in the EEA by scenario, undiscounted costs per year and present values over the whole assessment period (medium estimate and [low-high] sensitivities, in 2024 euros)

Scenario	Health costs from human exposure to PFOA, PFOS, PFHxS and PFNA	Soil remediation / water treatment costs	Potential costs associated with the losses of ecosystem services
Scenario 1: Business as usual	Undiscounted annual values: 2024: €39.5 [0.005-600.5] bn 2030: €29.5 [0.005-529.5] bn 2040: €27.0 [0.004-456.5] bn 2050: €29.5 [0.004-426.0] bn Present value over assessment period: €360 [0.052-5,750] bn	Undiscounted annual values: 2024: €3.8 [0.002-24.2] bn 2030: €3.9 [0.002-25.1] bn 2040: €4.3 [0.003-27.0] bn 2050: €4.7 [0.003-29.9] bn Present value over assessment period: €78.3 bn	 Potentially significant and increasing impact (not quantifiable) on ecosystem services that contribute € billions to the EEA economy.
Scenario 2: Drinking Water Directive (DWD)	Undiscounted annual values: 2024: €39.5 [0.005-600.5] bn 2030: €29.5 [0.005-529.5] bn 2040: €27.0 [0.004-456.5] bn 2050: €29.5 [0.004-426.0] bn Present value over assessment period: €360 [0.051-5,750] bn (Comparable to scenario 1, since drinking water only accounts for a small fraction of human exposure)	Undiscounted annual values: 2024: €3.8 [0.002-24.2] bn (€20.0 [2.2-817.3] bn with TFA) 2030: €4.2 [0.07-47.6] bn (€19.8 [2.2-804.1] bn with TFA) 2040: €4.5 [0.07-50.6] bn (€19.7 [2.1-782.9] bn with TFA) 2050: €6.2 [0.3-153.4] bn (€19.7 [2.1-763.5] bn with TFA) Present value over assessment period: €85.8 bn (€297.5 bn with TFA)	 Comparable to scenario 1.

Scenario	Health costs from human exposure to PFOA, PFOS, PFHxS and PFNA	Soil remediation / water treatment costs	Potential costs associated with the losses of ecosystem services
Scenario 3: Environmental Quality Standards (EQS)	Undiscounted annual values: 2024: €39.5 [0.005-600.5] bn 2030: €12.0 [0.001-373.5] bn 2040: €0.0 [0.0-3.5] bn 2050: €0.0 [0.0-3.2] bn Present value over assessment period: €240 [0.03-4,350] bn	Undiscounted annual values: 2024: €80.2 [21.6-712.9] bn 2030: €79.0 [21.2-701.5] bn 2040: €77.1 [20.5-683.4] bn 2050: €75.4 [19.9-666.9] bn Present value over assessment period: €1,480 bn	 Potentially significant impact (not quantifiable) on ecosystem services will continue for some time due to persistence, bioaccumulation and biomagnification of PFAS. Gradual decrease of impacts (not quantifiable) in the long term due to eventual degradation, dispersion to lower concentrations, and remediation/treatment.
Scenario 4: Total stop of production and uses of PFAS	Undiscounted annual values: 2024: €39.5 [0.005-600.5] bn 2030: €17.0 [0.002-412.5] bn 2040: €0.5 [0.0-21.5] bn 2050: €0.0 bn Present value over assessment period: €260 [0.033-4,500] bn	Undiscounted annual values: 2024: €3.8 [0.002-24.2] bn 2030: €3.8 [0.002-24.4] bn 2040: €3.8 [0.002-24.4] bn 2050: €3.8 [0.002-24.4] bn Present value over assessment period: €72.8 bn	 Comparable to scenario 3.

1. Introduction

1.1. This report

WSP and Ricardo have prepared for DG ENV a **study on the cost of PFAS pollution for our society**⁶ under framework contract ENV.01/FRA/2023/0006 *Economic analysis of environmental policies and analytical support in the context of Better Regulation* led by Trinomics B.V.

The objective of this study is to complement and update the existing sources of information (such as the Goldenman et al. (2019) study for the Nordic Council of Ministers⁷) on the overall costs of PFAS pollution in the EU and in the EEA. More specifically, the objective of this study is to present information on all components of the societal costs of PFAS pollution, expressed in monetary terms and based on an up-to-date list of impacts of PFAS on the environment and human health.

This assessment describes not only the cost of current pollution but also estimated future costs under four prospective scenarios representing hypothetical future developments, hence showing the current and future costs of inaction compared across alternative levels of action.

This report is the final deliverable of the project and presents the results of all tasks (see Section 2). It is structured as follows:

- The remainder of Section 1 provides additional context for this study, including a summary of the initial data gathering (Task 1) regarding the state of the science on societal costs of PFAS.
- Section 2 summarises the methodology for the study.
- Section 3 summarises the results with a focus on the cost assessment. The results of the exposure scenarios, on which the cost assessment is based are provided in Annex C. Further details of the cost assessment results are provided in Annex D.
- Section 4 discusses the conclusions that can be drawn from the results.

Throughout the project, reports were issued upon completion of each task. These Task reports are provided in Annexes A-D for additional context and detail.

⁶ Specific Contract No 090202/2024/924706/ENV.B2

⁷ Goldenman et al. (2019). The cost of inaction: A socioeconomic analysis of environmental and health impacts linked to exposure to PFAS. Available at: [THE COST OF INACTION](#)

1.2. Project context

1.2.1. What are PFAS

Per- and poly-fluoroalkyl substances (PFAS) are a large class of synthetic chemicals with diverse structures and properties, broadly defined as substances that contain a carbon-fluorine bond, usually -CF₂- or -CF₃- constituents⁸. The number of substances within this group remains unknown but estimates have increased over the years. In 2015, a KEMI study⁹ reported more than 3,000 PFAS were on the global market for commercial use. An OECD Study¹⁰ searched for perfluorinated compounds and found 4,730 PFAS in 2018. These earlier estimations were based on the previous OECD definition, which was narrower (excluding fluoropolymers, F-gases and many other structures). Most recently, the 2023 REACH restriction proposal of PFAS suggests there might be as many as 10,000 chemicals in this group¹¹ (which includes fluoropolymers and fluorinated gases).

These substances can be categorised in several ways, including by chemical structure and functional groups, carbon chain length, regulatory status, and others. In the present study, we have structured our review of the available evidence into three major groups of substances^{12,13}:

- **Per- or Poly- fluoroalkyl Acids (PFAAs)** and precursors to PFAAs are a main subgroup of PFAS, known for their persistence, bioaccumulation, and potential toxicity. PFAAs are typically classified into per- or poly-

⁸ [Per- and polyfluoroalkyl substances \(PFAS\) - ECHA](#)

⁹ Swedish Chemicals Agency (2015). Occurrence and use of highly fluorinated substances and alternatives: Report from a government assignment. <https://www.kemi.se/en/publications/reports/2015/report-7-15-occurrence-and-use-of-highly-fluorinated-substances-and-alternatives>

¹⁰ OECD (2018). Toward a new comprehensive global database of per and polyfluoroalkyl substances (PFASs): summary report on updating the OECD 2007 list of per and polyfluoroalkyl substances (PFASs). [https://one.oecd.org/document/ENV/JM/MONO\(2018\)7/en/pdf](https://one.oecd.org/document/ENV/JM/MONO(2018)7/en/pdf)

¹¹ ECHA (2023). ECHA publishes PFAS restriction proposal. <https://echa.europa.eu/-/echa-publishes-pfas-restriction-proposal>

¹² OECD (2021), Reconciling Terminology of the Universe of Per- and Polyfluoroalkyl Substances: Recommendations and Practical Guidance, OECD Series on Risk Management of Chemicals, OECD Publishing, Paris, <https://doi.org/10.1787/e458e796-en>.

¹³ Environment Agency (2021). Poly- and perfluoroalkyl substances (PFAS): sources, pathways and environmental data. Available at: https://assets.publishing.service.gov.uk/media/611e31fbd3bf7f63b19cea2d/Poly-and_perfluoroalkyl_substances_sources_pathways_and_environmental_data_report.pdf

fluorocarboxylic acids (PFCAs) and per- or poly- fluorosulfonic acids (PFSAAs). Examples of substances in this group include PFOA, PFOS, PFNA, PFHxS and TFA.

- **Polymeric PFAS** are polymers with fluorinated compounds and include fluoropolymers, side-chain fluorinated polymers and polymeric perfluoropolyethers. Fluoropolymers are polymers containing repeated fluorinated monomer units. Fluoropolymers have fluorine atoms directly attached to their carbon-only backbone. They can be also fully or partially fluorinated, linear or branched. There are two distinct sub-types of fluoropolymers: fluoroplastics and fluoroelastomers, which differ according to their elasticity properties. Fluoropolymers are the most widely used polymeric PFAS. Side-chain fluorinated polymers have a non-fluorinated polymer backbone with fluorinated side chains, and can degrade into PFAAs.
- **Fluorinated gases**, or F-gases.

In some instances, the present study also refers to PFAS groups according to length of their carbon chain (ranging from “long chain” to “ultra-short chain”) or regulatory status (“legacy” PFAS that have been regulated and/or phased out such as PFOA and PFOS, as opposed to “non-legacy” or “emerging” PFAS). Further detail is provided in Section 2.3 of the Task 1 report (Annex A).

The scope of substances covered by the cost estimates is based on the available evidence and methods to quantify the associated health and environmental costs. This is discussed in the methodology section below (Section 2).

The special physical properties of PFAS (strong water, oil, dirt repellence, along with high chemical stability¹⁴) mean that since their commercialisation in the 1950s, use has grown almost exponentially across a particularly wide range and diverse set of applications. This means that these substances have become ubiquitous in industry and consumer products and mixtures.¹⁵ They are used in many sectors including pharmaceuticals and medical devices, food contact materials, electronics, textiles and clothing, firefighting, transport (aviation, automotive), cosmetics, and biocides (list not exhaustive), specifically owing to their favourable chemical properties.¹⁶

In addition to these physical properties, the majority of PFAS meet the criteria for classification as persistent (P) or very persistent (vP) in the environment as defined previously by Regulation (EC) No 1907/2006 concerning the Registration,

¹⁴ <https://echa.europa.eu/-/echa-publishes-pfas-restriction-proposal> / [2.5 PFAS Uses and Products – PFAS — Per- and Polyfluoroalkyl Substances \(itrcweb.org\)](#)

¹⁵ European Chemicals Agency (no date) Per-and poly-fluoroalkyl substances (PFAS). Available at: [Per- and polyfluoroalkyl substances \(PFAS\) - ECHA \(europa.eu\)](#)

¹⁶ Interstate Technology Regulatory Council (no date) PFAS Uses and Products. [2.5 PFAS Uses and Products – PFAS — Per- and Polyfluoroalkyl Substances \(itrcweb.org\)](#)

Evaluation, Authorisation and Restriction of Chemicals (REACH)¹⁷ and more recently Regulation (EC) No 1272/2008 on the classification, labelling and packaging of substances and mixtures (CLP Regulation).^{18,19,20} In the proposed universal REACH restriction, PFAS are considered as a group because all members of the group share the very persistent property of the perfluorinated part(s) of PFAS molecules.²¹ Additionally, some of these substances can be toxic, mobile, bioaccumulative and/or carcinogenic, mutagenic or reprotoxic (CMR) and, therefore, present risks to human health and the environment through exposure.²²

Environmental releases of PFAS occur directly or indirectly at all stages of the product life-cycle (production, use, disposal), and groundwater and drinking water contamination is particularly prevalent.²³

Humans can be exposed to PFAS in several ways and at different stages of their life.^{24,25,26} This is because of the widespread use, which, combined with their persistence and mobility, leads to the presence of PFAS in drinking water, soil and biosolids, and water, especially near waste and manufacturing sites that produce or use PFAS. Human exposure to PFAS can occur from:

- Drinking water contaminated with PFAS.
- Eating certain foods that may be contaminated with PFAS, including fish.
- Breathing air containing PFAS.

¹⁷ Regulation (EC) No 1907/2006 of the European Parliament and of the Council of 18 December 2006 concerning the Registration, Evaluation, Authorisation and Restriction of Chemicals (REACH), establishing a European Chemicals Agency, amending Directive 1999/45/EC and repealing Council Regulation (EEC) No 793/93 and Commission Regulation (EC) No 1488/94 as well as Council Directive 76/769/EEC and Commission Directives 91/155/EEC, 93/67/EEC, 93/105/EC and 2000/21/EC. <https://www.echa.europa.eu/web/guest/regulations/reach/legislation>

¹⁸ Regulation (EC) No. 1272/2008 of the European Parliament and of the Council of 16 December 2008 on classification, labelling and packaging of substances and mixtures, amending and repealing Directives 67/548/EEC and 1999/45/EC, and amending Regulation (EC) No. 1907/2008. <https://www.echa.europa.eu/web/guest/regulations/clp/legislation>

¹⁹ European Chemicals Agency (2023) Guidance on the Application of the CLP Criteria. [179850f6-0221-583e-144c-48d7e72e7b3a](https://echa.europa.eu/179850f6-0221-583e-144c-48d7e72e7b3a) (europa.eu)

²⁰ <https://echa.europa.eu/hot-topics/perfluoroalkyl-chemicals-pfas>

²¹ BAuA, RIVM, KEMI, Norwegian Environment Agency, Danish Environmental Protection Agency (2023). Annex XV Restriction Report – Proposal for a Restriction - Per- and polyfluoroalkyl substances (PFASs). <https://echa.europa.eu/documents/10162/1c480180-ece9-1bdd-1eb8-0f3f8e7c0c49>

²² European Chemicals Agency (no date) PFAS – what are the concerns? [Per- and polyfluoroalkyl substances \(PFAS\) - ECHA \(europa.eu\)](https://echa.europa.eu/hot-topics/perfluoroalkyl-chemicals-pfas)

²³ <https://echa.europa.eu/hot-topics/perfluoroalkyl-chemicals-pfas>

²⁴ EEA (2019). Emerging chemical risks in Europe – PFAS. <https://www.eea.europa.eu/publications/emerging-chemical-risks-in-europe>

²⁵ U.S. EPA (2024). Our Current Understanding of the Human Health and Environmental Risks of PFAS. <https://www.epa.gov/pfas/our-current-understanding-human-health-and-environmental-risks-pfas> (accessed on 24 July 2024).

- Swallowing contaminated dust.
- Using products made with PFAS or that are packaged in materials containing PFAS.
- Working in occupations such as firefighting or chemicals manufacturing and processing.

Overall, people can be exposed to PFAS through all environmental compartments and diverse exposure media, such as water, dust, soil, etc., and via all exposure pathways (ingestion, inhalation and/or dermal exposure).

1.2.2. Policy context

In the European Union to date, PFAS have typically been regulated using a substance-by-substance (or groups of substances) approach. Under the REACH Regulation, for example, substances (or groups of substances) are regulated either through identification as a Substance of Very High Concern (SVHC) or through the restriction process, whilst under the CLP Regulation, PFAS are regulated based on their harmonised classifications.²⁷ At the international level (and transposed into European legislation), four PFAS are listed under the Stockholm Convention of Persistent Organic Pollutants.²⁸ A non-exhaustive list of regulated PFAS is shown in Table 2.

Table 2 – Examples of PFAS substances regulated in the European Union

Policy mechanism	Substances regulated
EU Persistent Organic Pollutants (POPs) Regulation	Perfluorooctane sulfonic acid (PFOS), its salts, and perfluorooctane sulfonyl fluoride (PFOS-F) Perfluorooctanoic acid (PFOA) Perfluorohexane-1-sulphonic acid (PFHxS)
REACH Regulation (SVHC, SVHC candidates and Restricted Substances)	2,3,3,3-Tetrafluoro-2-(heptafluoropropoxy)propionic acid, its salts, and its acyl halides (HFPO-DA) Perfluorobutane sulfonic acid (PFBS) Perfluoroheptanoic acid (PFHpA) and its salts (SVHC Candidate) C9-C14 perfluorocarboxylic acids
Classification, Labelling and Packaging (CLP) Regulation	Perfluorooctanoic acid (PFOA) Ammonium pentadecafluorooctanoate (APFO) Perfluorononan-1-oic acid (PFNA) and its sodium and ammonium salts Nonad2.6.1ecafluorodecanoic acid (PFDA) and its sodium and ammonium salts Perfluoroheptanoic acid (PFHpA)
Drinking Water Directive	Concentration limits for all PFAS in water set as 0.5 µg/l

²⁷ Ibid footnote 22 [Per- and polyfluoroalkyl substances \(PFAS\) - ECHA \(europa.eu\)](https://echa.europa.eu/en/per-and-polyfluoroalkyl-substances-pfas)

²⁸ Stockholm Convention (no date) Overview – PFAS. [Overview \(pops.int\)](https://pops.int/)

Policy mechanism	Substances regulated
Prior Informed Consent Regulations	Perfluorooctanoic acid (PFOA) Perfluorooctane sulfonic acid (PFOS)

Source: Thomas et al., (2023) Global regulations around PFAS: The past, the present and the future, International Chemical Regulatory and Law Review, 6, 3. [ICRL – International Chemical Regulatory and Law Review: Global Regulations Around PFAS: The Past, the Present and the Future \(lexxion.eu\)](#).

The substance-by-substance approach has continued to be applied to PFAS in recent years, for example, as Member States voted to restrict perfluorohexanoic acid (PFHxA) in February 2024, which was recommended for classification as Repro. 1B (H360d) the following month by the Committee for Risk Assessment (RAC).^{29,30} However, in 2025, following the grouping approach recommended in the Chemicals Strategy for Sustainability³¹, all PFAS used in fire-fighting foams were restricted.³² The grouping approach intends to speed up regulatory action for substances considered potentially harmful to human health and the environment and to prevent regrettable substitution. In March 2023, Germany, the Netherlands, Sweden, Norway and Denmark submitted a joint proposal for an Annex XV restriction on all PFAS, proposing to move away from the substance-by-substance approach and adopt a grouping approach using a broad definition.^{33,34}

1.2.3. State of the science on impacts and societal costs of PFAS pollution

1.2.3.1. Human health impacts

An in-depth literature review and expert interviews were conducted to develop an evidence base of human exposure to PFAS, the associated health risks, observed and/or studied exposure-risk relationships, available assessments of human health impacts and monetary costs associated with PFAS exposure and health risks, and

²⁹European Commission (2024) Commission Regulation (EU) amending Annex XVII to Regulation (EC) No 1907/2006 as regards undecafluorohexanoic acid (PFHxA), its salts and PFHxA-related substances. <https://ec.europa.eu/transparency/comitology-register/screen/documents/090483/6>

³⁰ European Chemicals Agency (2024) Registry of CLH intentions until outcomes – undecafluorohexanoic acid. <https://echa.europa.eu/registry-of-clh-intentions-until-outcome/-/dislist/details/0b0236e1877da3b1> [date accessed 23.07.2024]

³¹ European Commission (2020) The Chemicals Strategy for Sustainability. <https://www.echa.europa.eu/hot-topics/chemicals-strategy-for-sustainability>

³² https://ec.europa.eu/commission/presscorner/detail/en/ip_25_2286

³³ <https://echa.europa.eu/documents/10162/f605d4b5-7c17-7414-8823-b49b9fd43aea>

³⁴ An update of the Background Document for the universal PFAS restriction proposal was published in late August 2025. The methodology, calculations and text in the present report were largely prepared before that date, so the present report is based on the March 2023 version of the universal PFAS restriction dossier.

geographical and historical trends. These findings are presented in Section 3.1 of Annex A and summarised in the table below.

Table 3 – Summary of findings from the literature review and expert interviews

Research questions	Findings
To what extent are humans exposed to PFAS in the EU?	Recent (2019-2024) human biomonitoring studies have found levels of PFAS in the blood serum of different EU population groups. There is more evidence of legacy PFAAs (PFOA, PFOS, PFNA, PFHxS), when compared to other, less regulated substances (e.g., PFPeA, PFHxA, etc). ³⁵
What human health risks PFAS exposure is associated with?	Studies suggest that the following human health endpoints are associated with PFAS exposure confidently: respiratory infections, autoimmune thyroid disease, liver diseases, reproductive disorders (low sperm count/mobility), maternal/neonatal risks (gestational hypertension, decreased foetal growth, low birth weight). ³⁶ There are other human health outcomes that are associated with PFAS exposure less confidently, such as diabetes.
What are the observed risk relationships and/or predicted human health impacts from those risks?	There is literature evidence quantifying risk-relationships for infections, autoimmune disorders, musculoskeletal disorders, cardiovascular disease risk factors, chronic kidney disease, non-alcoholic fatty liver disease, cancers, reproductive disorders and maternal/neonatal risks. Confidence in these risk-relationships varies. ³⁷ Other links to health risks remain more suggestive or speculative and lack quantified risk-relationships. Only a few studies identified have quantified the human health impacts that could be attributable to PFAS exposure, and this is primarily in terms of events or days of ill health, attributable incident or prevalent cases, Disability-Adjusted Life Years (DALYs), and preventable deaths.

³⁵ Sources are detailed on the Task 1 Report (see Section 3.1.1 of Annex A), including HBM4EU and related studies such as Richteroova et al (2023), Uhl et al (2023), Fabelova et al (2023); and other studies such as Andersen et al (2024), Goen et al (2023), Palesova et al (2023), Plass et al. (2023), Rihackova et al (2023), DeLuca et al (2022), Papadopoulou et al (2021), Gebbink et al (2020), Pitter et al (2020), Poonthong et al (2020), Balk et al (2019), etc.

³⁶ Sources are detailed on the Task 1 Report (see Section 3.1.2 of Annex A), including Mahdavi et al. (2024), Pan et al. (2023), Pinney et al. (2023), Plass et al. (2023), Xu et al., (2023), Birru et al. (2021), Fenton et al. (2021), Steenland et al. (2021), Banjabi et al. (2020), European Food Safety Authority (2020), Goldenman et al (2019), Kim et al. (2016).

³⁷ Sources are detailed on the Task 1 Report (see Section 3.1.3 of Annex A), including Ebel et al. (2023), Hu et al. (2023), Pan et al. (2023), Plass et al. (2023), Obsekov, Kahn & Trasande (2023), Zhang et al. (2023), Costello et al. (2022), Bartell and Vieira (2021), Dalsager et al. (2021), Shearer et al. (2021), Eves et al. (2020), Goldenman et al (2019), Impinen et al. (2019), Govarts et al. (2018), Lauritzen et al. (2018), Liu et al. (2018), Steenland et al. (2018), Sun et al. (2018), Wielsøe et al. (2017), Dalsager et al (2016), Khalil et al. (2016), Zhang et al. (2015), Johnson et al. (2014), Vagi et al. (2014), Eriksen et al. (2013), Wen et al. (2013), Buck Louis et al. (2012), Min et al. (2012), Steenland & Woskie (2012), Whitworth et al. (2012), Shankar et al. (2011), Stein et al. (2009).

Research questions	Findings
What are the costs associated with the human health impacts?	A few studies, such as Goldenman et al. (2019) for the Nordic Council of Ministers and Obsekov, Kahn and Trasande (2023), have developed estimates of the potential human health costs of PFAS exposure. The EEA study by Plass et al. (2023) identifies the burden of disease for a subset of European countries; however, this burden is not monetised. These studies are focused on direct, non-market cost valuation of 'life' or 'years lived in good health' (drawing on stated preference methods), and some estimations of indirect, market health costs (cost of illness method) resulting from increases in healthcare demand. Generally, other impacts are not quantified nor monetised.
What are the geographical and temporal trends in human health costs?	Variations in PFAS blood serum concentrations were identified across geographies and time. For example: higher concentrations of four PFAS compounds were found in teenagers residing in Northern (Norway, Sweden) and Western Europe (France, Germany, Belgium) compared to lower levels in Southern (Spain, Greece, Slovenia) and Eastern Europe (Slovakia); and blood serum levels of PFAS increased significantly during peak production years (1979–2001) and decreased by 23% and 22% for PFOA and PFOS respectively between 2001 and 2007. In contrast, blood serum levels for compounds such as PFNA, PFDA, and PFUnDA continued to rise after 2001. ³⁸

In addition, the literature review and interviews highlighted the **types of human health costs** that could be attributable to PFAS pollution and a range of **methods** that have been employed in the literature to monetise these (see also Section 3.3 of Annex A).

There are a wide range of human health costs that could be associated with PFAS exposure, and these can be direct (D) or indirect (I), market (M) or non-market (NM), and one-off (OC) or recurring (RC) costs. The five most significant cost categories are presented in the table below.

Table 4 – Types of human health costs

Human health costs identified	Description of costs identified	Types*		
Health and wellbeing losses	Loss of both quality and quantity of life due to illness or disability from pollution, measured as Disability-Adjusted Life Years gained or Quality-Adjusted Life Years lost.	D	NM	RC
Demographic impacts	Adverse impacts on birth rates and birth outcomes, potentially including birth defects or low birth weights.	I	NM	RC
Increased health care demand	Increased need for medical/healthcare services due to pollution-attributable health conditions, leading to higher healthcare costs.	I	M	RC
Increased social care demand	Increased need for care services due to pollution-related health conditions, which might include services provided in the market economy or outside of it.	I	M, NM	RC

³⁸ Sources include Plass et al. (2023), Richterova et al (2023), Goldenman et al (2019), Haugdahl Nøst (2014).

Human health costs identified	Description of costs identified	Types*		
Economic productivity losses	Losses in productivity captured or resulting from sickness (absence/ absenteeism), and/or from lower concentration and/or efficiency (presenteeism)	I	M	RC

* *Typology*: direct (D) or indirect (I), market (M) or non-market (NM), and one-off (OC) or recurring (RC) costs.

Methods identified for monetising human health costs include market-based, avoided damage, revealed preferences, stated preferences and benefit transfer methods. These are outlined briefly below.

- **Cost-based methods** use market data to value health impacts. This includes methods such as the cost of illness (COI) method, human capital approach and the present value of lifetime earnings (PVLE).
- **Avoided damage methods** are cost-based approaches used to estimate the economic value of preventing negative health outcomes, that is, the market and/or non-market costs that would have been incurred if the health damage had not been prevented.
- **Revealed preferences methods** use observed behaviours and market transactions by market actors to estimate the economic value of health outcomes. This includes hedonic pricing method, travel cost method and the averting behaviour method.
- **Stated preferences methods** are used to estimate the economic value of health outcomes based on individuals' expressed preferences in hypothetical scenarios, generally summarised in terms of their willingness to pay to avoid years of life lived with disability and/or lost. These methods are particularly useful when market data is unavailable or insufficient. This group includes Contingent Valuation (CV), which appears predominant in the literature as well as employed by the European Chemicals Agency and the Organisation for Economic Cooperation and Development, and Discrete Choice Experiments (DCE).
- **Benefit transfer methods** can also be employed, which draw on valuation data gathered in one situation and applying it, with adjustments, in a similar situation to a population with similar attributes and suffering from similar burden of disease. This method is used frequently as it limits the need for primary valuation studies.

The literature precedent that is most relevant primarily relies on stated preference methods and cost-of-illness approaches to assess, respectively, non-market impacts on people's health and wellbeing, and market impacts on healthcare systems and worker productivity. For non-market health and wellbeing impacts, Contingent Valuation (CV) is employed. This involves presenting respondents with a

hypothetical scenario and asking them how much they would be willing to pay for a specific benefit or to avoid a negative outcome. For example, researchers investigate people's willingness to pay to reduce risk of premature death by a small probability and estimate the social 'Value of Statistical Life' (VSL), and/or their willingness to pay for an additional year of life and estimate the 'Value of a Life Year' (VOLY). The VOLY can also be derived from VSL estimates based on considerations of life expectancy.

Goldenman et al. (2019) use the **'value of statistical life' contingent valuation method to monetise non-market disease burden**, drawing on available evidence of the 'Value of a Statistical Life' from ECHA (2016)'s 'Valuing selected health impacts of chemicals: Summary of the results and a critical review of the ECHA study'³⁹ and OECD (2012)'s 'Mortality risk valuation in environment, health and transport policies'⁴⁰. To do this, Goldenman et al. (2019) also draw on a case study approach, for example, of populations living near contaminated areas in Minnesota, U.S.; West Virginia, U.S.; Dordrecht, Netherlands; Ronneby, Sweden; and Veneto Region, Italy; to quantify, extrapolate and monetise impacts across larger populations.

Obsekov, Kahn and Trasande (2023) draw on market-based methods, such as **the cost of illness approach, to develop estimates of medical costs and productivity losses, and non-market (CV) methods to quantify and monetise disease burden**.

The OECD has undertaken a meta-analysis of the literature on the "Value of a Statistical Life" (VSL). The findings are based on a meta-analysis of 277 studies and more than 4,000 VSL estimates covering six country groups and led to guidance on how to apply the values across countries and over time. The VSL estimates are intended to support cost-benefit analyses and other policy assessments, covering any area where monetising and comparing mortality risk effects against the costs of such initiatives could inform decision making, which would include PFAS.⁴¹

³⁹ Note that a more recent study was published by ECHA in 2023 of "Reference willingness-to-pay values for monetising chemicals health impacts". Available at: https://echa.europa.eu/documents/10162/17229/seac_reference_wtp_values_en.pdf/403429a1-b45f-4122-ba34-77b71ee9f7c9

⁴⁰ Note that we will also consider more up-to-date evidence from the OECD's work on Surveys on Willingness-to-Pay to Avoid Negative Chemicals-Related Health Effects. Available at: <https://www.oecd.org/en/topics/sub-issues/risk-management-risk-reduction-and-sustainable-chemistry/the-costs-and-benefits-of-regulating-chemicals.html>

⁴¹ OECD (2025). Mortality Risk Valuation in Policy Assessment. Available at: https://www.oecd.org/en/publications/mortality-risk-valuation-in-policy-assessment_76ca89a2-en.html

1.2.3.2. Environmental impacts

The evidence base for environmental PFAS exposure and its impacts, based on literature review and interviews undertaken as part of this study, is presented in detail in Section 3.2 of Annex A, and summarised in the following.

The scientific evidence is clear that **some PFAS have the potential to harm aquatic and terrestrial animals and plants** due to their (eco)toxicological properties, their persistence, and their ability to bioaccumulate in organisms. Possible effects have been observed in fish, crustaceans, amphibians, terrestrial invertebrates, birds, mammals, algae, and plants. These effects relate to reproduction, development, behaviour, neurology, lethality, the liver, and the immune system. If materialised, these toxic effects in organisms could lead to ecosystem damage (e.g. through reduced survival and reproductive success of organisms), which could incur ecosystem service costs (e.g. through damage to food provisioning organisms and damage to primary producers which support food webs in ecosystems providing other services).

Generally, the available evidence raises significant concerns about the effects of PFAS on the environment, however, the research landscape is patchy, meaning that the specific scale and nature of the environmental impacts of PFAS cannot be confidently concluded on (e.g. effects on ecological systems such as population decline).

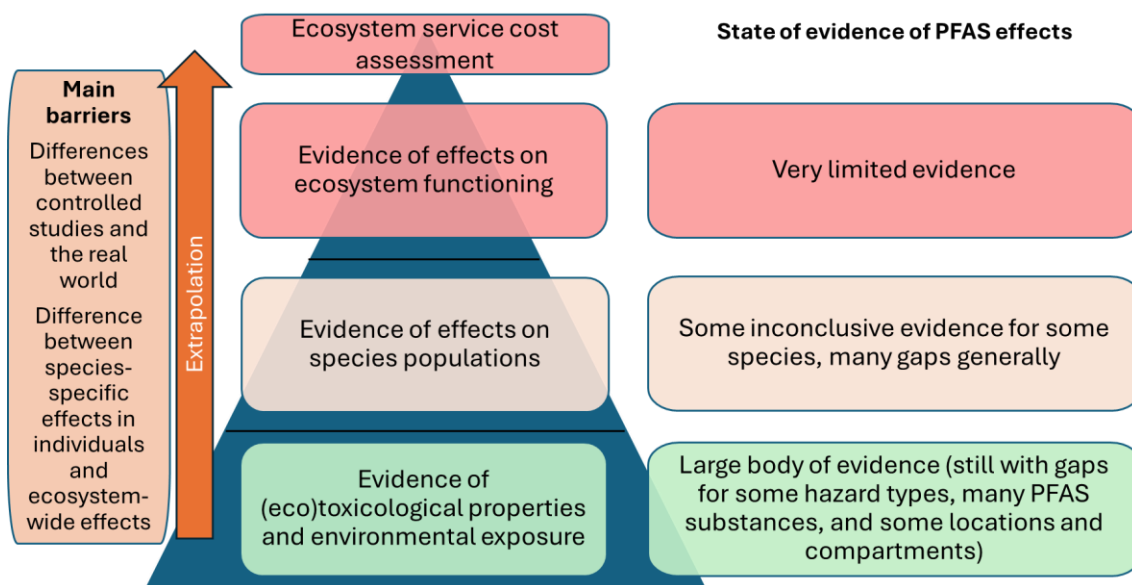
Most studies are based on traditional chemical risk assessment methods which look at the effects of substances on individual organisms under controlled conditions. These methods can be used to indicate that substances have potential effects on the environment but cannot be used to assess and quantify the impacts of substances on populations and ecological systems. Depending on the quality of data from chemical risk assessments, it may be extrapolated to estimate the potential scale of ecological impacts. However, this extrapolation is likely to be coupled with large ambiguities and uncertainties due to the differences between controlled laboratory studies and the real-world environment (which hosts complex ecological networks and is influenced by a range of biotic and abiotic factors).

In particular, there are challenges in understanding the impacts of PFAS compared to some other chemicals because of the wide range of PFAS substances, the bioaccumulation potential and persistence of some PFAS, the potential mixtures effects of some PFAS, the potential lag time between exposure and effects from PFAS, and the complex hazard endpoints that may be relevant for some PFAS.

Some field studies looking at real life environmental effects in uncontrolled conditions have been undertaken, but often have limitations such as small sample sizes, inconclusive results (e.g. with statistically insignificant correlations), or contradictions with other studies.

The figure below summarises the **challenges in undertaking an ecosystem services cost assessment** for PFAS pollution. At the same time, it highlights that while the evidence of effects on ecosystem functioning is thin, it may be possible to extrapolate the evidence of (eco)toxicological properties and environmental exposure to PFAS to estimate ecosystem service impacts.

Figure 1 – Challenges in assessing the impacts of PFAS pollution on ecosystem services



In addition to ecosystem service costs from the (eco)toxic effects of PFAS, ecosystem service costs can arise due to human interventions to avoid human health or environmental harm from PFAS. For example:

- Food (potentially) contaminated with PFAS may be disposed of to avoid risks to human health. This can incur costs from losses in food production (as an ecosystem service), quantifiable in terms of lost profits to farms. The literature review identified some case studies where these costs have been predicted.
- PFAS concentration limits in waste can lead to the need for diversion of waste from recycling or landfill to incineration to protect the environment and human health, which can result in losses in material value and costs of incineration. This is related to ecosystem services in terms of material provisioning.
- Where land has been designated as a contaminated site due to unacceptable risks to human health or the environment, there may be losses in ecosystem services provided and opportunity costs of not being able to use the land for economic activities.

Given the challenges related to direct ecosystem service cost assessments for chemical pollution, alternative cost assessment methods have been developed to determine the value of a non-polluted environment. This is reflected by society's

willingness-to-pay to clean up the environment (e.g. through soil remediation and water treatment).

Remediation and water treatment costs indirectly represent the cost *to recover* ecosystem services (see also sections 3.2 and 3.3 of Annex A). Even without characterising the direct impacts of PFAS on ecosystem services, these costs demonstrate the price of a clean environment, capturing the essence of the ecosystem services framework (in terms of nature's contribution to people). In reality, PFAS pollution is causing both losses in ecosystem service delivery and costs to recover ecosystem services. As clean-up costs increase, ecosystem service losses should decrease, although this relationship may not be linear. Nevertheless, remediation and water treatment costs are a tangible way to estimate the monetary value of ecosystem service impacts of PFAS.

Previous assessments of the non-health costs of PFAS pollution have largely focused on soil remediation and water treatment costs (see also Section 3.3 of Annex A). A 2020 report by Wood et al.⁴² reports the costs of remediation by compartment within the EU. The report estimates that soil remediation costs are around €0.5-4.5 million per site, while ground water and drinking water remediation could cost over €30 million per site if remediation is undertaken over the course of 30 years. The Forever Pollution Project estimates costs of €95 billion over the next 20 years for remediation of legacy PFAS.⁴³ The project estimates that cleaning up the most concentrated sources of long-chain PFAS in Europe alone will be €4.8 billion per year. To remediate all PFAS over the next 20 years, the cost is estimated to be close to €2 trillion.

⁴² Wood et al. (2020). The use of PFAS and fluorine-free alternatives in fire-fighting foams. Report produced for European Commission DG Environment / European Chemicals Agency (ECHA). https://echa.europa.eu/documents/10162/6755610/pfas_flourine-free_alternatives_fire_fighting_en.pdf/d5b24e2a-d027-0168-cdd8-f723c675fa98

⁴³ Forever Pollution Project (2025). [Unaffordable - The absurd cost of 'PFAS as usual'](#)

2. Method

2.1. Overview

The overall approach to conducting this study consisted of the following four tasks:

- **Task 1: Initial data gathering** based on literature review (methodology described in Section 2.2) and targeted expert consultation (methodology described in Section 2.3). The results were submitted to the European Commission in a “Task 1 report”, which is provided in Annex A. A summary of key results is also provided in Section 1.2.3.
- **Task 2: Development of a methodology to update and expand the existing knowledge on societal costs of current and future PFAS pollution in the EEA.** The resulting cost assessment methodology is described in Section 2.4. The methodology was submitted to and agreed with the European Commission in a “Task 2 report”, which is provided in Annex B.⁴⁴
- **Task 3: Development of prospective scenarios representing hypothetical PFAS future pollution levels in EEA.** The methodology is summarised in Section 2.4. The methodology and results were submitted to the European Commission in a “Task 3 report”, which has undergone multiple iterations to refine the approach. This report is provided in Annex C1.
- **Task 4: Assessment of the societal costs of current and future PFAS pollution (up to 2050, under hypothetical future scenarios).** This involved applying the methodology developed in Task 2 (with certain updates, as mentioned above), using data gathered in Task 1 and the results of Task 3. The results and methodological updates were submitted to the European Commission in a “Task 4 report”. Extracts of this report are provided in Sections 2.4 (methodology), 3 (results), and 4 (conclusions). The full report is also provided in Annex D for additional context and details.

⁴⁴ Note that while the overall approach has not changed, some details of the methodology shown in Annex B have evolved as Task 3 and Task 4 progressed and demonstrated the need to adjust the methodology. The methodology as described in Section 2.4 of this report is up to date while Annex B is not and should only be considered as additional context for the methodological choices made in this study.

2.2. Literature review

A targeted literature review has been conducted against three high-level research questions on 1) the human health costs of PFAS, 2) the environmental costs of PFAS, and 3) the overall societal cost of PFAS, comprising 14 sub-questions (shown as sub-headings under Sections 3.1, 3.2 and 3.3 of Annex A). The following steps were followed:

- Step 1 – A list of 82 relevant literature sources were reviewed in-depth, with a focus on recent publications after 2019, including meta-analyses, secondary sources provided by the European Commission during project inception and/or the outputs of an initial review of the literature.
- Step 2 – These literature sources were prioritised for information extraction based on an evaluation of geographic and thematic relevance, robustness and limitations, and gaps were identified to help further targeting any additional searches.
- Step 3 – Additional targeted searches were undertaken to identify relevant literature that could address the gaps identified in the evidence base answering each research question. Searches used specific terms and strings (combinations of key words) applied to common search engines (Google, Google Scholar). Sources deemed potentially relevant based on their titles and abstracts were prioritised and reviewed in-depth for information extraction based a similar evaluation conducted for the 82 'known' sources in Step 1.
- Step 4 – All the information extracted was triangulated against each research question and sub-question and findings were developed.

The findings and information extracted from this literature review are summarised in Annex A (Section 3).

2.3. Interviews

Eight semi-structured interviews were conducted to validate the findings from the literature review and address any gaps. These stakeholders comprised experts and authors of key literature sources, and representatives of relevant research and Non-Governmental Organisations. Experts from the following organisations and projects have been interviewed individually or in groups as part of this Task 1:

- Dutch National Institute for Public Health and the Environment (RIVM)
- The European Environmental Bureau (EEB)
- The International Chemical Secretariat (ChemSec)
- Germany's Environmental Authority UBA

- VITO (Vlaamse Instelling voor Technologisch Onderzoek)
- The Organisation for Economic Co-operation and Development
- US Environmental Protection Agency
- Global PFAS Science Panel
- Forever Pollution Project
- ETH Zurich

The team drafted questions, structured by the main research questions posed in this study, to elicit the necessary inputs from stakeholders, and identify any new information sources and/or address gaps. Each stakeholder was provided with a tailored interview guide before the interview, targeted to the areas of research most relevant to their expertise⁴⁵.

The outputs of these interviews are documented in Annex A (Section 3).

Additional experts were consulted on an ad-hoc basis to discuss and validate approaches and assumptions during the development of the methodology in Task 2 and the modelling of exposure scenarios in Task 3. This included experts from the following organisations / projects:

- Forever Pollution Project
- Norwegian University of Science and Technology

2.4. Exposure scenarios

2.4.1. Overall Approach

The methodology for Task 3 is designed to estimate both current and future levels of PFAS pollution in the EEA under four prospective ‘what if’ scenarios, from a baseline year (2024) to 2050. The approach integrates emissions, environmental concentrations, and human exposure (via blood serum concentrations).

The study builds on and uses the same terminology as defined in the approach of Goldenman et al. (2019), which grouped the population into three exposure cohorts:

⁴⁵ An overview of all research questions was provided to all stakeholders, so that every stakeholder would have the opportunity to provide input to every research question, if they felt they had relevant input to provide.

- **Background cohort**⁴⁶: General population not living near PFAS sources.
- **Elevated cohort**: People living near PFAS production or use sites.
- **Occupational cohort**: Workers at PFAS manufacturing or use facilities.

This structure was retained, but updated using new datasets, notably the Forever Pollution Project (FPP) list of known and potential PFAS manufacturing/using sites and the universal PFAS restriction dossier under REACH⁴⁷, which provides detailed emission estimates and projections.

Note that during the development of the methodology multiple approaches were explored, including the use of the fugacity model EUSES⁴⁸. The preliminary attempts to explore the use of EUSES proved unsuccessful due to a combination of the complexity of the issue presented by PFAS and the lack of granular data to fully drive the fugacity model to achieve outputs consistent with real world monitoring.

The main steps of the methodology are summarised below. Further detail is provided in Annex C1 (Section 2).

2.4.2. Development of Baseline Year (2024)

2.4.2.1. Developing cohort groups

To determine the elevated exposure cohort, data from the FPP identifying PFAS production sites, known PFAS users, and presumptive PFAS users was used to determine the numbers of likely PFAS-emitting sites per country for the European Economic Area. Based on studies from the US and Europe, Goldenman et al (2019), estimated that 3% of the population of Sweden were exposed to concentrations of PFAS at elevated levels. Based on national average population density, the number of sites in Sweden, and assuming 3% of the population within the elevated cohort, it was possible to determine a radius per site as a zone of contamination (31 km² for

⁴⁶ Clarifying note: Under the Water Framework Directive, “background concentrations” are a defined term relating to natural background concentrations, i.e., concentrations in water of named substances that occur naturally due to e.g., geological conditions, such as metals. In this report, ‘background concentrations’ and ‘background cohort’ have been used to align with the terminology presented in Goldenman et al. (2019) as the key reference used to help guide the methodology. PFAS are man-made chemicals and do not naturally occur. Therefore, some care is needed not to misinterpret or conflate ‘background concentrations’ with the WFD use of terminology.

⁴⁷ An update of the Background Document for the universal PFAS restriction proposal was published in late August 2025. The methodology, calculations and text in the present report were largely prepared before that date, so the present report is based on the March 2023 version of the universal PFAS restriction dossier.

⁴⁸ European Union System for the Evaluation of Substances tool.

Sweden), and multiply this radius with the number of sites per country to determine the extent of the contamination per country. As a comment it should be recognised that population density can vary significantly between urban and rural areas, with the national average a blend of both. This variation is greater for some countries than others, with Sweden being an example of a wider range. National average population density was chosen as it is possible for sites to be both in urban and rural areas depending on the specific facility type.

Goldenman et al. (2019) assumed that in every country in Europe, 3% of the population are exposed to elevated concentrations of PFAS, like in Sweden. In the present study we have retained the 3% by population of Sweden as the starting point for three main reasons. Firstly, the data developed by Goldenman et al. was based on empirical data from a range of studies, along with expert judgment. Since the publication of this study in 2019, no new substantial re-assessment of exposure was identified to change this position. Secondly, by retaining this value as the starting point for the current study it provides a good level of comparability to the only other major European assessment of PFAS exposure and health costs. Thirdly, while additional regulatory actions have been taken on named PFAS, the extent of the PFAS contamination and exposure is unlikely to have diminished significantly since 2019. On the contrary, new evidence, in particular from the FPP, has shown a substantial number of potentially contaminated locations, while the REACH restriction dossier predicts under a business as usual case that emissions would continue to rise in future years.

Based on the 3% of population in Sweden and number of sites from the FPP, the derived radius of 31 km² was applied to the FPP data for all EEA countries, and the national average population density used to derive the population in the elevated cohort.

The FPP data identifies a total of around 11,500 known and presumptive sites. Additionally, the FPP (2023)⁴⁹ comment that 2,300 of these sites are ‘hotspots’ where concentrations exceed 100 ng/l. Since concentrations are likely to vary from site to site, the quoted value for ‘hotspot’ sites is assumed to cover the most contaminated locations. To provide nuance we therefore have used the total number of sites and number of hotspots to create two categories of contamination: The **elevated cohort** was divided into “**elevated-high**” – 3% of EEA population in 2024 – (closest to contaminated sites, ≥100 ng/l PFAS in water⁵⁰) and “**elevated-low**” – 11% of EEA population in 2024 – (further away, above background but below hotspot levels), using FPP data based on monitoring. The “elevated-high” group was developed based on the number of FPP-identified hotspots, distributed proportionally

⁴⁹ Forever Pollution Project (2023): Forever pollution: explore the map of Europe's PFAS contamination. Available at: https://www.lemonde.fr/en/les-decodeurs/article/2023/02/23/forever-pollution-explore-the-map-of-europe-s-pfas-contamination_6016905_8.html

⁵⁰ This corresponds to the definition of the ‘elevated’ exposure by Goldenman et al. (2019), defined as being exposed to levels of PFAS above the action value of 90 ng/l, via drinking water.

across countries based on each country's total number of PFAS manufacturing/using sites. The elevated-low group was developed based on the difference between the total FPP sites minus the hotspots.

For the **occupational cohort** (less than 1% of EEA population in 2024), the number of workers was estimated using FPP data on PFAS producers and users sites, combined with average workers per facility from Goldenman et al. (2019)⁵¹. 17 PFAS producers, 23 large PFAS-using plants, and 11,431 smaller PFAS-using plants were identified, employing a total of 358,000 workers. Retired workers were also included, with retirement rates and life expectancy data from Eurostat. The model assumes a 1.25% annual retirement rate and tracks the pool of retired workers over time.

The remainder of the population, after accounting for elevated and occupational cohorts, was assigned to the **background cohort**. In 2024, this made up approximately 86% of the EEA population.

Population changes from 2020 to 2050 were projected using compound annual growth rates (CAGR) for adults and children, with the baseline year anchored to Eurostat data. Adults population was projected to decline at -0.3% per year, and children population at -0.58% per year. The size of each cohort was adjusted over time according to these trends, ensuring that future projections reflect anticipated demographic downward changes.

2.4.2.2. Developing environmental concentrations

Monitoring data was compiled from the FPP, Joint Research Centre (JRC), Aqua Publica Europea, the NORMAN network, EFSA, and other studies (see also Annex C1, section 2.2.2). Data covered surface water, groundwater, drinking water, soil, and food. Where data was incomplete, extrapolation was used. For instance, if only 12 of the 20 PFAAs identified under the DWD were measured in a dataset, the average concentration per substance was calculated and applied to the missing substances. For food, EFSA data on four PFAS was extrapolated to estimate the sum of 20 PFAAs. In this case the authors needed to consider a trade-off between the high level of uncertainty of such an extrapolation⁵² against the need to test how policy measures under the Drinking Water Directive (scenario 2) may affect overall

⁵¹ Goldenman et al. based their estimates for number of workers per facility on data from Eurostat. While employment rates will vary over time, given that the data used by Goldenman is less than 10 years old, the decision was made that any changes would be more limited and there was greater importance to maintain continuity with the Goldenman study.

⁵² In terms of extrapolation different PFAS can vary significantly in concentration and how they behave within different conditions (e.g., water, soil, food, blood etc). The more substances present when extrapolating (i.e., smaller gap) reduces the uncertainty. In this case using only 4 substances to extrapolate to 20 PFAAs is a significant increase in uncertainty when compared e.g., to 12 of 20 substances.

exposure. To test the difference in exposure based on drinking water and food separately, a decision was made to extrapolate to 20 PFAAs for comparability, acknowledging significant uncertainty.

Due to the persistence of PFAS, environmental concentrations were assumed not to decline within the time frame of the study (i.e., before 2050). The model does not account for remediation or anthropogenic intervention under the Business as Usual scenario.

2.4.2.3. Developing blood serum concentrations

Blood serum data was collated for adults and children in each cohort as far as possible. This spanned around a total of 12 PFAS substances, with the most well covered being primarily four PFAS (PFOS, PFOA, PFNA, PFHxS) for which health impacts data is available. As with the environmental compartment, the concentrations of the missing substances was extrapolated (to reach a total of 20 PFAAs), based on the average concentrations from known substances multiplied by the number of substances to cover the missing substances. It should be recognised that different PFAS will be processed, distributed and/or eliminated differently by the human body. Therefore, there is some uncertainty in extrapolating data in this fashion. However, to provide an indicative approach of how blood serum concentrations may fluctuate and the trends under different scenarios this was deemed reasonable by the project team. For one cohort, children in the elevated high group, there was only blood serum data for PFOS, PFOA, PFNA and PFHxS. For this group specifically the ratio between adults and children in the elevated-low cohort was used to help calculate concentrations for children in the elevated-high cohort based on adults in the elevated-high cohort.

For the four main PFAS where the most data exists (PFOS, PFOA, PFNA, and PFHxS), sufficient data existed before the baseline year (i.e., 2001 – 2024) to map trends in blood serum up to and including 2024. For three substances (PFOS, PFOA, and PFHxS) there is a declining trend in blood serum concentrations. For PFNA, despite the fact that there was a REACH restriction implemented in 2023 (EC 2021/1297), there is an increasing trend in blood serum concentration up to and including 2024. It should be recognised that REACH restrictions affect the ‘new’ use of a substance, and that use of pre-existing in-use stockpiles is allowed to continue, leading to some continuing exposure. Given the slow elimination rates for PFNA, it is concluded that that these two factors are at least in part an explanation to the increasing trend.

The trends over the time-series are assumed to continue to apply from the baseline year 2024 until the end of the assessment period for the four PFAS for which health impact data is available (namely, PFOA, PFOS, PFHxS and PFNA), while the concentrations of PFAAs as a group are projected based on emissions (see next step). This position is based on the assumption that where use and exposure to a

specific PFAS (e.g., PFOS) ends, it is replaced by another PFAS which increases in use and exposure to close the gap. Precedent is set for this already in cases where e.g., PFOS was replaced (in part) by PFHxS. It is also recognised that other PFAS (such as telomer alcohols) can degrade to become PFAAs, suggesting that overall while specific PFAA members may decline, others likely replace them.

In terms of biological elimination from the body, Rosato et al. (2024)⁵³ provides a review study for different PFAS, which calculates half-life in blood serum of 1.5-5.1 years for PFOA, 3.5 to 5.7 years for PFOS, and 2.8 to 8.5 years for PFHxS. As a conservative value, a half-life of 5 years is used for the sum of 20 PFAAs, which implies a year-on-year decline of 10% once new exposure ceases. This is not intended to provide a detailed and exact estimate for decline in blood serum concentrations but should provide a more realistic estimate than simply assuming that blood serum concentrations decline immediately as emissions decline. This lag effect is particularly important for scenario modeling, especially in cases where emissions are rapidly reduced.

Annual intake of PFAS via water and food was calculated using EFSA dietary reference values and food consumption surveys.

2.4.2.4. Developing ratios between emissions, environmental concentrations and blood serum levels

The universal REACH restriction dossier provides future emission estimates. However, data for predicted future environmental concentrations and blood serum concentrations is lacking. In practice, it can be argued that there is an intrinsic relationship between emissions and environmental concentrations; and likewise a relationship between environmental concentrations and human exposure. To help predict future concentrations, it was assumed that this relationship is largely fixed, i.e., if there is a proportional increase in emissions, environmental concentrations will increase by the same proportion. Based on this assumption, ratios were developed between emissions and each environmental compartment (surface water, groundwater, drinking water, soil, and food). Ratios were also developed between blood serum concentrations and human exposure pathways (drinking water and food separately).

Ratios were established between emissions, environmental concentrations, and blood serum levels for the baseline year based on the real-world monitoring and collated data. This means, for example, that for every additional tonne of PFAS emitted, a corresponding proportionate increase in surface water concentration (as ng/l) was calculated based on the known real-world values for the baseline year. These ratios were then used to project future concentrations based on emission

⁵³ Rosato et al. (2024): Estimation of per- and polyfluoroalkyl substances (PFAS) half-lives in human studies: a systematic review and meta-analysis, vol 242.

scenarios, allowing the model to estimate environmental and human exposure under different scenarios modelled in the context of this report.

As a further comment on this aspect specifically, it needs to be recognised that predicting the future environmental concentrations and blood serum concentrations under specific “what if” scenarios is hugely challenging. The approach adopted in this study provides a methodology based on first principles to help triangulate emissions, environmental concentrations and blood serum. This assumes the relationship between them is fixed (i.e., the environmental pathways and exposure pathways do not change, and increasing/decreasing the inputs on one metric (emissions) results in proportionate changes in other metrics). Over the course of a 30-year period, it is possible for specific aspects to change in unpredicted ways, but the approach adopted here is robust and internally consistent for the purposes of the study.

2.4.2.5. Developing emission projections

Data from the universal PFAS restriction dossier (published in 2023) and the restriction on use of PFAS in firefighting foams (published in 2022) has been used to estimate the future trends in use and emission for manufacture of PFAS and 15 sectors of use. Note that an update of the Background Document for the universal PFAS restriction proposal was published in late August 2025. The methodology, calculations and text in the present report were largely prepared before that date, so the present report is based on the March 2023 version of the universal PFAS restriction dossier. Absolute values of projected PFAS emissions are lower in the updated Background Document but increase more over time compared to the figures used in this study. Noting that the proportionate change in emissions is the key driver for the ratios used to calculate environmental concentrations and in turn blood serum concentrations, our estimates would have been higher if the data from the updated Background Document would have been used.

2.4.2.6. Development of the scenarios

Scenario 1 (business as usual for emissions): Environmental concentrations for the years 2020 – 2050 (with 2024 as the baseline year) were calculated using the emission estimates from the universal PFAS restriction dossier multiplied by the ratios presented in Appendix B to Annex C1 to calculate surface water, groundwater, drinking water, soil, and food concentrations. Once the environmental concentrations were predicted, the new values for drinking water and food were used to calculate blood serum concentration. This follows the approach outlined in Section 2.4.2.4, where we first use predicted emissions (and the ratios between emissions and environmental concentration) to determine changes in environmental concentrations, and then a second set of ratios (between drinking water and food to blood serum) to determine new blood serum concentrations. Changes to the area and population of

cohorts and the number of contaminated sites are also projected. The universal PFAS restriction dossier estimates that, in the business-as-usual scenario, emissions will increase by two and a half times between 2020 and 2050. Eurostat data for growth rates in the manufacturing sector between 2003 and 2023 (excluding 2020 and Covid-19 impacts) was used to estimate the number of new companies. Additionally, the annual growth rates in annual turnover for the EU27's manufacturing sector was used to represent the rate of economic activity changes. Based on this data and the increasing emissions assumed to be linked to increasing activity, the authors estimate that 75% of the increased emissions are assumed to come from pre-existing sites through on-site expansion and increase in production. 25% of the increased emissions is assumed to come from new sites. This data has been used to determine how the scale of the contamination changes over the timeseries based on the emission trends.

Scenario 2 (Drinking Water Directive): The Drinking Water Directive (DWD) sets a threshold at 100 ng/l for the sum of 20 PFAS substances; this threshold is used in the main model calculations. Additionally, the DWD 500 ng/l for Total PFAS threshold is used for TFA specifically, because TFA is not included within the sum of 20 PFAS. Apart from assuming that drinking water concentrations are capped at a maximum of 100 ng/l (for the sum of 20 PFAS), scenario 2 follows the same approach as scenario 1. This hypothetical scenario does not explore how this limit is achieved, and therefore all other aspects from scenario 1 are kept the same (in particular rates of emissions and environmental concentrations other than drinking water). Furthermore, it is assumed that TFA is capped at the Total PFAS threshold of 500 ng/l, again keeping all other aspects constant. This hypothetical scenario also explores the effects of the DWD thresholds in terms of intake of PFAS via drinking water and food to determine the overall impact on blood serum concentration.

Scenario 3 (Environmental Quality Standards Directive/GWD): This scenario assumes that full compliance is reached with the quality standard (QS) initially proposed by the Commission for surface water and groundwater, at 4.4 ng/l PFOA-equivalent. It is assumed that full compliance is achieved from the year 2030⁵⁴ onwards. Based on achieving compliance with the QS for surface water and groundwater, the scenario 3 further considers what impact that compliance will have for drinking water and human exposure. This is based on the ratios outlined earlier in

⁵⁴ Clarification note: At the time of writing this report, the proposals for adoption of new priority substances and QS have passed the Trialogue step, with transposition into national law required by 2027 (when monitoring would start) and full compliance with QS by 2039. Because there is a delay in seeing the effects of QS compliance on drinking water and blood serum concentrations, with the scenario implemented in 2039, it is likely that the full effects of the EQS (surface water) and QS (groundwater) would not be clear by the 2050 upper end of the study timeframe. Therefore, an earlier year, 2030 (just after when monitoring would commence) has been selected to illustrate the before and after situation for EQS. The scenario as presented in this study only provides a hypothetical 'what if' case.

this section⁵⁵. Note that scenario 3 follows the same approach and calculations as scenario 1, with the main alteration being that surface and groundwater concentrations are altered to meet the QS threshold from 2030 onwards.

Scenario 4 (full stop of production and uses of PFAS): The scenario assumes that, effective from 2030, there will be total stop on production and use of PFAS. However, while the scenario aims to explore a full stop to emissions (as a result of production and use ceasing), some use will continue until end of life as it is realistically not feasible to recall all items from circulation. Additionally, the methodology assumes a declining set of emissions in the years immediately before 2030 as it is unlikely that production would continue at full scale until its total stop.

2.5. Cost assessment

2.5.1. Overview

The cost assessment aims to estimate the human health and environmental costs of PFAS pollution in the EEA for the baseline year 2024, as well as for 2030, 2040 and 2050 under four hypothetical future pollution and exposure scenarios. The results are also analysed in terms of different cost elements borne by different parts of EU society, exploring differences between the scenarios, and considering the sensitivity of the results to uncertain variables. Costs are presented for the years 2024, 2030, 2040 and 2050. For each scenario, they are presented as undiscounted annual values and present values (PVs) over the period of assessment, based on a discount rate of 3%⁵⁶ for the comparison across scenarios. All monetary figures are presented in constant, 2024 Euros.

2.5.2. Human health costs

We have followed the methodology developed under Task 2 of this project to **quantify and value human health costs attributable to PFAS exposure in the EEA for four legacy PFAS (PFOA, PFOS, PFHxS and PFNA) for which sufficient evidence was identified**⁵⁷. The methods applied are based on the literature and

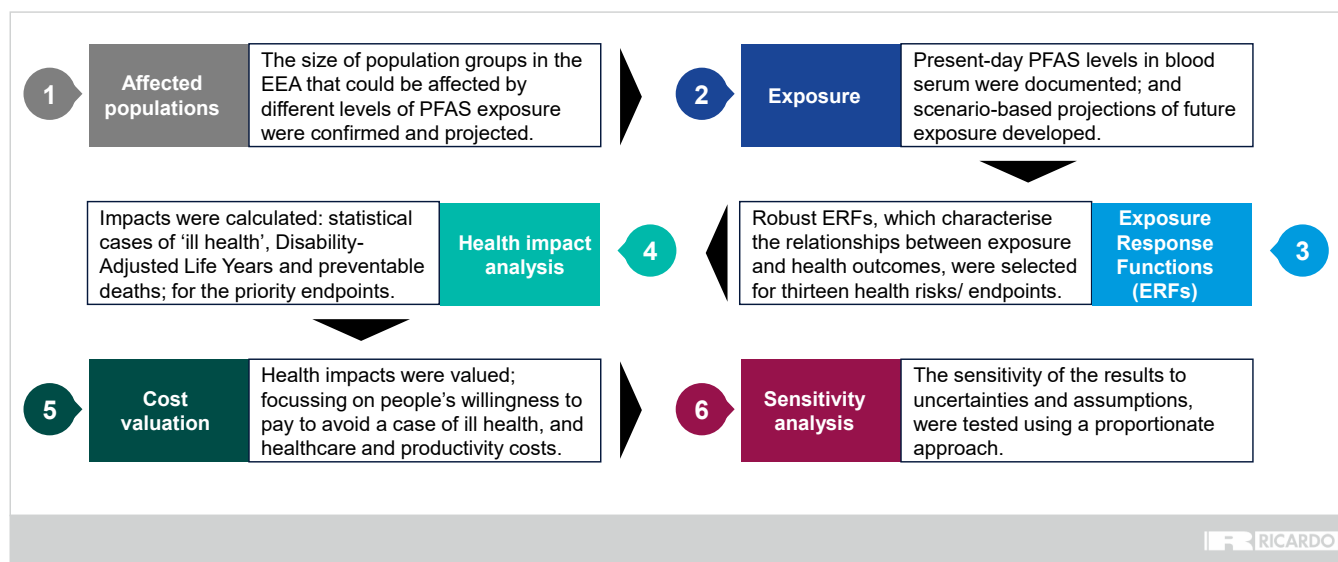
⁵⁵ Clarification note: the 'what if' scenarios are aimed at assessing a specific aspect in isolation to determine the outcome of only those aspects alone. In reality, it can be recognised that to achieve QS compliance would require regulatory intervention, additional abatement at source and end-of-pipe, and possible remediation actions. These aspects have been identified as being out of scope of this scenario, with the main aim of scenario 3 to determine the effects for human health and the environment from complying with the proposed EQS standards.

⁵⁶ In line with the European Commission's Better Regulation Toolbox, Chapter 8.

⁵⁷ Please note that the original Task 2 report (see Annex B) had considered health costs from exposure to five PFAS (including PFPeA in addition to the four PFAS mentioned in this report) .

evidence collected under Task 1, best practice guidelines, and linked to the outputs of scenario modelling of future PFAS pollution under Task 3. The figure below presents an overview of the methodology, followed by a stepwise description.

Figure 2 – Method to quantify and value the human health costs of PFAS pollution



The Table below identifies the main inputs for each of these six steps, assumptions and sources of evidence. Further detail is provided in the following sections and the 'Task 2 Report' (see Annex B) under this project.

Table 5 – Summary of the steps for the human health cost assessment, including key inputs, core assumptions and main sources

Steps	Key inputs	Core assumptions	Main sources
1. Estimating the size of the population across relevant groups	Population data	Estimates in different population groups and future projections	Scenario modelling (Annex C1: Task 3 report), Eurostat, the World Bank
2. Establishing the levels of PFAS exposure across population groups	- Definition of exposure as PFAS levels in human blood serum - Recent monitoring and case studies (e.g., Forever Pollution project, scientific literature) - Estimated prospective blood serum levels of PFOA, PFOS, PFHxS and PFNA under prospective scenarios	Scenario projections for the future (Task 3)	HMB4EU and scientific literature (Annex B: Task 2 report) ⁵⁸ , Scenario modelling (Annex C1: Task 3 report)

However, there was insufficient evidence of any associations between PFPeA and the health risks/ endpoints under consideration in this Study, and hence, it was excluded from the estimation of costs attributable to PFAS exposure.

⁵⁸ Sources include HMB4EU and related studies such as Richterova et al (2023), Uhl et al (2023), Fabelova et al (2023); and other studies such as Andersen et al (2024), Goen et al (2023),

Steps	Key inputs	Core assumptions	Main sources
3. Identification of relevant health risks or endpoints and ERFs	- Exposure-response functions (ERFs) for PFOA, PFOS, PFHxS and PFNA as outputs of scientific studies - Assessment of confidence or strength of evidence associated with up to 13 endpoints	- Levels of confidence or strength of evidence - Applicability	Scientific literature ⁵⁹
4. Quantification of impacts	- Baseline levels of risk (incidence rates), and the population size and ERFs confirmed in previous steps - Disability-Adjusted Life Years (DALYs) (including Years of Life Lost (YLL)) attributable to a case of ill health, by endpoint	- Applicability - Projections for the drawing on historical trends and relationships	IHME, Goldenman <i>et al.</i> (2019), Plass <i>et al.</i> (2023), Obsekov, Kahn and Trasande (2023) and other literature studies
5. Monetary valuation of impacts	- Unit values, such as Value Of a Life Year (VOLY), Value of a Statistical Life (VSL) and/or reference case values based on willingness to pay studies - Typical care pathways and medical cost values per case - Sickness absence valuation - Factors, including GDP deflator, wages and salaries, etc.	Applicability, focusing on 'scale' or 'magnitude'	ECHA, OECD, Better Regulation Guidelines, Eurostat, and scientific and/or grey literature
6. Sensitivity analysis	Sensitivity scenarios developed based on the evidence collected and assessed in previous steps	Levels of confidence or strength of evidence	Previous sources and tailored analysis for this study

This method has drawn on the evidence identified in the literature review conducted as part of this project, seeking to broaden and deepen analyses conducted in previous studies, such as Goldenman et al. (2019)⁶⁰. More specifically, we have:

Palesova et al (2023), Plass et al. (2023), Rihackova et al (2023), DeLuca et al (2022), Papadopoulou et al (2021), Gebbink et al (2020), Pitter et al (2020), Poonthong et al (2020), Balk et al (2019), etc.

⁵⁹ Sources are detailed on the Task 1 Report (see Section 3.1.3 of Annex A), including Mahdavi et al. (2024), Ebel et al. (2023), Hu et al. (2023), Pan et al. (2023), Pinney et al. (2023), Plass et al. (2023), Obsekov, Kahn & Trasande (2023), , Xu et al., (2023), Zhang et al. (2023), Costello et al. (2022), Bartell and Vieira (2021), Birru et al. (2021), Fenton et al. (2021), Dalsager et al. (2021), Steenland et al. (2021), Shearer et al. (2021), Banjabi et al. (2020), European Food Safety Authority (2020), Eves et al. (2020), Goldenman et al (2019), Impinen et al. (2019), Govarts et al. (2018), Lauritzen et al. (2018), Liu et al. (2018), Steenland et al. (2018), Sun et al. (2018), Wielsøe et al. (2017), Dalsager et al (2016), Khalil et al. (2016), Kim et al. (2016), Zhang et al. (2015), Johnson et al. (2014), Vagi et al. (2014), Eriksen et al. (2013), Wen et al. (2013), Buck Louis et al. (2012), Min et al. (2012), Steenland & Woskie (2012), Whitworth et al. (2012), Shankar et al. (2011), Stein et al. (2009).

⁶⁰ Goldenman et al. (2019). The cost of inaction: A socioeconomic analysis of environmental and health impacts linked to exposure to PFAS. Nordic Council of Ministers. Available at: <https://norden.diva-portal.org/smash/get/diva2:1295959/FULLTEXT01.pdf>

- Expanded the analysis to cover additional health risks or endpoints (including 13 endpoints) associated with PFAS exposure and specific PFAS types (four substances, which is more than included in the literature precedent, which typically looked at only two regulated PFAS), drawing on a literature review of the latest available evidence and the confidence in the findings of association of PFAS exposure to these health risks,
- Reflected the latest available evidence in the exposure risk relationships employed in the study, and
- Expanded the coverage of the types of costs included in the analysis beyond the monetisation of disease burden using non-market methods, by systematically including the indirect costs of healthcare and productivity losses.

However, **there remain gaps and limitations, primarily bound by the lack of evidence also faced by previous studies**. In brief, the main gaps include the:

- Lack of detailed evidence on the size of more or less exposed population groups.
- Lack of evidence of PFAS concentration in blood serum and future projections.
- Limited research into the association of PFAS in blood and health risks for the majority of PFAS, lack of quantitative exposure-risk relationships estimated, and limitations in confidence of available studies.
- Limited to no understanding of mixture/cumulative effects of exposure to multiple PFAS (and/or other chemicals or risk factors).
- Lack of readily accessible studies into the burden of disease, care pathways, medical costs, and sickness absence associated with each endpoint.

As a result, the study has limitations, primarily including **the lack of coverage of a very large number of PFAS substances and health risks, due to limitations in the availability and/or weight of evidence (i.e., the lack of PFAS substances studied, lack of endpoints examined in depth, limited understanding of the cumulative effects of PFAS exposure, etc)**.

The methodology developed for this study excludes the quantitative analysis of substances for which there is no evidence of exposure, health risk association nor exposure-response functions (ERFs) characterised in the literature, which is considered reasonable and proportionate. The literature was also uncertain on whether the impacts represented by ERFs captured the isolated effects of a substance, despite other PFAS being present in human blood. Therefore, the methodology has considered the results for each endpoint or health risk to correspond to the maximum estimated health impact for one single PFAS out of all

PFAS associated with that endpoint or health risk instead of aggregating the estimated impacts across all associated PFAS.

Overall, this has meant that **only four of potentially 10,000 substances have been considered quantitatively in this assessment, and in isolation from one another (i.e., no cumulative effects analysis)**. Furthermore, these four PFAS (namely PFOA, PFOS, PFHxS and PFNA) are already regulated in the EU in different ways, such as under POPs regulation, REACH, food safety rules, drinking water, and packaging legislation, and hence, the health impacts estimated here mainly consider the effects of legacy pollution.

This is the main limitation of this (and other studies), which, in our view, **suggests that the estimates of health costs attributable to PFAS exposure and associated monetary values in this study likely represent a lower bound to the total, potential health damage that PFAS exposure may be causing in the EEA.**

There are other limitations with quantification of health impacts, as well as their valuation (e.g., uncertainties in ERFs, monetary unit values, etc.). However, the evidence review conducted for this study suggests these limitations are dwarfed by the lack of evidence on thousands of PFAS substances and the potential health risks associated with people's exposure to them.

2.5.2.1. Step 1 Affected populations

In 2024, there were 455,271,190 people living in the EEA⁶¹. Scenario modelling was conducted to produce population estimates by cohort in the future (Task 3). We have used this and other available evidence (Eurostat, World Bank) to disaggregate this population further, into mutually exclusive groups of people with different levels of exposure and risk from PFAS pollution, such as adults (exposed workers), adults (other, general population), teenagers (general population), children in age groups (general population), pregnant women (general population) and a cross-cutting group of people living near PFAS-manufacturing or PFAS-using industrial sites in the EEA (which are excluded from the other groups). The Table below presents population estimates for 2024 and describes inputs from this project's Task 3 analysis and other key assumptions (see Section 3 of Annex C1: Task 3 Report for details).

⁶¹ Population estimates are derived from Task 3, based on data from Eurostat and the World Bank.

Table 6 – Potentially affected EEA populations by group (Sources: Task 3, Eurostat⁶², WB⁶³, Goldenman et al. (2019)⁶⁴, Frick (2021)⁶⁵ and Andersen et al. (2000)⁶⁶)

Population group	Baseline population (2024)	Proportion of females in 2024 (% of group)	Description of mapping from Task 3 and other assumptions
Total population	455,271,190	51.1%	Estimate and evolution based on Task 3.
Adults (Exposed workers)	423,204	51.6%	Estimate and evolution of 'Occupational cohort' based on Task 3.
Adults (20+) general population	350,039,568	51.0%	Estimate and evolution of 'Background cohort' and 'Elevated-Low cohort' based on Task 3, adjusted for pregnant women or people 15+ living near contaminated sites.
Teenagers (15-19 years)	23,405,944	48.8%	Estimate based on Eurostat; population groups and evolution (CAGR -1.0%) based on WB projections.
Children (5-14 years)	46,393,393	48.8%	Estimate and evolution based on Task 3, adjusted for newborns. Age group proportions based on WB projections.
Children (1-4 years)	16,615,945	48.8%	Estimate and evolution based on Task 3, adjusted for newborns. Age group proportions based on WB projections.
Newborns (0 years)	3,726,318	48.7%	Estimate based on live births (Eurostat); evolution (CAGR -0.5%) based on WB projections.
Pregnant women	4,108,444	100.0%	Estimate based on live births (Eurostat) and miscarriages (Frick (2021) and Andersen et al. (2000)); evolution (CAGR -0.5%) based on WB projections.
People (15+) living near contaminated sites	10,558,373	51.4%	Estimate and evolution of 'Elevated-High cohort' ⁶⁷ based on Task 3.

⁶² <https://ec.europa.eu/eurostat/en/web/products-eurostat-news/w/ddn-20240711-1>;
<https://ec.europa.eu/eurostat/web/interactive-publications/demography-2024>

⁶³ <https://databank.worldbank.org/source/population-estimates-and-projections>

⁶⁴ Goldenman et al. (2019). The cost of inaction: A socioeconomic analysis of environmental and health impacts linked to exposure to PFAS. Nordic Council of Ministers. Available at: <https://norden.diva-portal.org/smash/get/diva2:1295959/FULLTEXT01.pdf>

⁶⁵ Frick (2021). Advanced maternal age and adverse pregnancy outcomes. Available at: <https://www.sciencedirect.com/science/article/pii/S1521693420301127>

⁶⁶ Andersen et al. (2000). Maternal age and fetal loss: population-based register linkage study. BMJ. Jun 24; Available at <https://pmc.ncbi.nlm.nih.gov/articles/PMC27416/>

⁶⁷ The 'Elevated-High' cohort broadly corresponds to the definition of the 'elevated' exposure used by Goldenman et al. (2019), defined as being exposed to levels of PFAS above the action value of 90 ng/l, via drinking water.

2.5.2.2. Step 2 Exposure

We have gathered and reviewed available evidence of PFAS in the blood serum, in µg/L, of people living in the EEA across the relevant population groups⁶⁸, as well as time trends. Scenario modelling was conducted to produce estimates of PFAS in the blood serum under prospective scenarios (Task 3), for three population cohorts, summarised in the Table below for scenario 1. Similar estimates were developed for the other scenarios (refer to Section 3 of Annex C1: 'Task 3 report' for details).

Table 7 – Blood serum levels of PFAS, in µg/L, across population cohorts for Scenario 1, estimated under Task 3. Estimates under other scenarios can be found in the Task 3 Report (Annex C1)

Cohort	PFAS type	2024	2030	2040	2050
Background cohort	PFOA	1.81	1.71	1.55	1.44
	PFOS	5.04	3.73	2.26	1.41
	PFNA	0.77	0.90	1.16	1.54
	PFHxS	0.68	0.61	0.51	0.44
	Other PFAS	7.30	11.78	19.89	30.60
Elevated-high cohort, and occupational cohort	PFOA	19.46	18.34	16.62	15.53
	PFOS	5.65	4.18	2.53	1.58
	PFNA	0.77	0.90	1.16	1.54
	PFHxS	1.91	1.72	1.44	1.24
	Other PFAS	28.61	42.54	69.95	108.21

Please note that blood serum concentrations for the 'elevated-low' cohort are the average between the 'background' and 'elevated – high' cohorts.

⁶⁸ Sources include HMB4EU and related studies such as Richterova et al (2023), Uhl et al (2023), Fabelova et al (2023); and other studies such as Andersen et al (2024), Goen et al (2023), Palesova et al (2023), Plass et al. (2023), Rihackova et al (2023), DeLuca et al (2022), Papadopoulou et al (2021), Gebbink et al (2020), Pitter et al (2020), Poonthong et al (2020), Balk et al (2019), etc.

Despite these estimates of ‘all PFAS’ exposure, and as noted, there remain severe gaps in the evidence available on PFAS exposure by specific substances, their association with health risks, and the characterisation of exposure-response functions. **The human health cost assessment and valuation conducted in this study have thus focused on four PFAA and PFAA precursor substances: PFOA, PFOS, PFNA and PFHxS, which have been investigated in more depth in the scientific literature. Those are also the ones that are regulated in the EU, especially in the case of PFOA, PFOS and PFHxS⁶⁹.**

In addition, the evidence on exposure-response functions is available only for specific population groups, based on the relevant risks these groups face from some PFAS exposure. The groups found in the literature have been mapped against the analysis conducted under Task 3 (see Step 1). The historical evidence found in the literature for each of these groups has been triangulated with outputs from Task 3 to produce evidence-based assumptions of blood serum levels by group. The Table below provides these estimates under prospective scenario 1, with similar approaches being employed to estimate equivalent values for scenarios 2, 3 and 4. These estimates have been taken forward for use as inputs to the exposure-response functions (ERFs) as part of the analysis and valuation of human health impacts for scenario 1 (see Step 3 in the following section).

Table 8 – Blood serum levels of PFOA, PFOS, PFNA, and PFHxS, in µg/L, across European population groups in scenario 1, calculated based on the Task 3 outputs. Similar approaches were employed to estimate equivalent values for scenarios 2, 3 and 4.

Population group	PFAS type	2024	2030	2040	2050
Adults (20+) general population	PFOA	1.81 [0.40-12.01]	1.71 [0.38-11.32]	1.55 [0.34-10.26]	1.44 [0.32-9.59]
	PFOS	5.04 [1.27-22.78]	3.73 [0.94-16.85]	2.26 [0.57-10.20]	1.41 [0.35-6.37]
	PFNA	0.77 [0.22-2.08]	0.90 [0.26-2.42]	1.16 [0.33-3.12]	1.54 [0.44-4.15]

⁶⁹ Please note that these four PFAS are regulated in the EU in different ways, under the POPs Regulation, the REACH Regulation, food safety rules, the Drinking Water Directive, and packaging legislation. More specifically, PFOA is banned under the EU POPs Regulation since 2020, listed as an SVHC under REACH, and covered under the Drinking Water Directive and food safety rules and packaging regulation; PFOS is restricted under the EU POPs Regulation, listed as an SVHC under REACH, and covered under the Drinking Water Directive and food safety rules and packaging regulation; PFHxS has been banned under the EU POPs Regulation since 2023, on the Candidate List of SVHC under REACH, and covered under the Drinking Water Directive and food safety rules and packaging regulation; and PFNA is a C9 which has been banned under the C9-C14 PFCAs restriction, and covered under food safety rules and packaging regulation.

Population group	PFAS type	2024	2030	2040	2050
	PFHxS	0.68 [0.16-2.09]	0.61 [0.14-1.88]	0.51 [0.12-1.57]	0.44 [0.10-1.36]
Pregnant women, Newborns (0 years), Children (1-4 years), Children (5-14 years), Teenagers (15-19 years)	PFOA	2.04 [0.45-9.28]	1.92 [0.42-8.75]	1.74 [0.38-7.93]	1.63 [0.36-7.41]
	PFOS	10.54 [2.54-34.26]	7.80 [1.88-25.35]	4.72 [1.14-15.34]	2.95 [0.71-9.57]
	PFNA	0.56 [0.17-1.71]	1.23 [0.37-3.77]	1.59 [0.48-4.86]	2.11 [0.64-6.46]
	PFHxS	0.47 [0.04-1.11]	0.88 [0.08-2.09]	0.74 [0.06-1.75]	0.64 [0.05-1.51]
People (15+) living near contaminated sites, Adults (Exposed workers) ⁷⁰	PFOA	19.46 [1.45-396.48]	18.34 [1.37-373.76]	16.62 [1.24-338.71]	15.53 [1.16-316.46]
	PFOS	5.65 [1.65-54.35]	4.18 [1.22-40.21]	2.53 [0.74-24.34]	1.58 [0.46-15.19]
	PFNA	0.77 [0.77-61.138]	0.9 [0.9-71.22]	1.16 [1.16-91.84]	1.54 [1.54-122.11]
	PFHxS	1.91 [0.50-36.98]	1.72 [0.45-33.25]	1.44 [0.38-27.84]	1.24 [0.33-24.04]

Finally, following the approach from Obsekov, Kahn & Trasande (2023)⁷¹, a reference level of exposure was estimated for PFOA, PFOS, PFNA and PFHxS by population group, corresponding to the 10th percentile of the population group's blood serum range. The health risks associated with the exposure were estimated relative to this reference level, below which no health impacts have been attributable to PFAS exposure.

⁷⁰ Due to limited evidence regarding blood serum levels of exposed workers in Europe, it was assumed that exposed workers would typically live near contamination sites and, therefore, have blood serum levels of similar scale as that for people living near contaminated sites.

⁷¹Obsekov, Kahn & Trasande (2023). Leveraging Systematic Reviews to Explore Disease Burden and Costs of Per- and Polyfluoroalkyl Substance Exposures in the United States. Expo Health 15, 373–394. Available at: <https://doi.org/10.1007/s12403-022-00496-y>

2.5.2.3. Step 3 Health risks and exposure-risk relationships

We have conducted a literature review⁷² that resulted in a longlist of health risks and endpoints associated with PFAS exposure. Each health risk or endpoint identified was considered. Those for which there was limited weight of evidence and/or there were no exposure-response functions (ERFs) were excluded from further assessment (see Section 3.2.2 of Annex B: Task 2 Report). The following **thirteen health risks or endpoints with available and sufficient weight of evidence to justify their inclusion in the analysis were taken forward in the assessment**: lower respiratory tract infections (LRTI), maternal hypertensive disorders⁷³, low (and very low) birth weight, hypothyroidism, osteoporosis, kidney cancer, high LDL cholesterol, testicular cancer, obesity, high blood pressure, chronic kidney disease (CKD), endometriosis and female infertility.

The Table below organises these endpoints by the level of confidence of the association between the health risk and PFAS exposure (scored from 1 for 'no confidence', to 5 for 'high confidence'); and documents the affected population that has been studied in the literature, and which concerns the ERFs identified.

Table 9 – Overview of health risks / endpoints for which there are Exposure Response Functions (ERFs) that can be used to quantify and value human health impacts, level of confidence, affected population and PFAS types captured

Specific health risk/ endpoint in scope	Confidence (0- None, 5-High)	Affected population	PFAS types with ERFs identified with sufficient weight of evidence
Lower respiratory tract infections (LRTI)	4	Children (1-4 years)	PFOA, PFOS
Maternal hypertensive disorders	4	Pregnant women	PFOS
Low (and very low) birth weight	4	Newborns (0 years)	PFOA, PFOS
Hypothyroidism	4	Adult females	PFOA

⁷² Sources are detailed on the Task 1 Report (see Section 3.1.3 of Annex A), including Mahdavi et al. (2024), Ebel et al. (2023), Hu et al. (2023), Pan et al. (2023), Pinney et al. (2023), Plass et al. (2023), Obsekov, Kahn & Trasande (2023), Xu et al., (2023), Zhang et al. (2023), Costello et al. (2022), Bartell and Vieira (2021), Birru et al. (2021), Fenton et al. (2021), Dalsager et al. (2021), Steenland et al. (2021), Shearer et al. (2021), Banjabi et al. (2020), European Food Safety Authority (2020), Eves et al. (2020), Goldenman et al (2019), Impinen et al. (2019), Govarts et al. (2018), Lauritzen et al. (2018), Liu et al. (2018), Steenland et al. (2018), Sun et al. (2018), Wielsøe et al. (2017), Dalsager et al (2016), Khalil et al. (2016), Kim et al. (2016), Zhang et al. (2015), Johnson et al. (2014), Vagi et al. (2014), Eriksen et al. (2013), Wen et al. (2013), Buck Louis et al. (2012), Min et al. (2012), Steenland & Woskie (2012), Whitworth et al. (2012), Shankar et al. (2011), Stein et al. (2009).

⁷³ This includes gestational hypertension and preeclampsia.

Specific health risk/ endpoint in scope	Confidence (0- None, 5-High)	Affected population	PFAS types with ERFs identified with sufficient weight of evidence
Osteoporosis	3	Adult females	PFOA, PFHxS, PFNA
Kidney cancer	3	Adults	PFOA
High LDL cholesterol	3	Adults	PFOA, PFOS
Testicular cancer	2	Adult males	PFOA
Obesity	2	Children (5-14 years)	PFOA, PFOS
		Adults	PFOS, PFNA
High blood pressure	2	Adult males	PFOA, PFOS, PFNA
Chronic kidney disease (CKD)	2	Adults	PFOA, PFOS
Endometriosis	2	Adult females (18- 49 years)	PFOA
Time to pregnancy/ female infertility	2	Adult females (18- 49 years)	PFOA, PFOS

The ERFs used in the analysis typically followed a non-linear form, so we have suitably transformed these functions to calculate the health impact from exposure at the current and prospective future levels of PFAS in blood serum under prospective scenarios, compared to the reference levels (see Step 2 above). These ERFs were also expressed in terms of the fraction of baseline cases of ill health, by endpoint, which could be attributable to PFAS exposure.

2.5.2.4. Step 4 Health impact analysis

Building on the previous steps, we have quantified the statistical cases of ill health and the burden of disease, in terms of Disability-Adjusted Life Years (DALYs) and preventable deaths, attributable to PFOA, PFOS, PFHxS and PFNA exposure.

We found very limited to no understanding of any potential cumulative effects of PFAS exposure on health outcomes identified in the literature. When an endpoint was associated with exposure to different PFAS (e.g., PFOA and PFOS), we investigated the scientific literature underpinning the ERFs to confirm whether an attribution of health risks to the levels of specific PFAS in blood had been isolated for each individual substance (i.e., the effect of PFOA in isolation of the presence of PFOS in blood). This does not appear to be the case, however, in some cases, this remains uncertain. Thus, we have assumed that estimated health impacts from exposure to specific PFAS associated with any given endpoint (i.e., effects of PFOA and PFOS on the incidence of low birth weight) could not be aggregated. This means that, for each endpoint or health risk, the results presented in this study

correspond to the maximum estimated health impact for one single PFAS out of all PFAS associated with an endpoint (and for which ERFs have been identified).

The ‘statistical cases’ of ill health of an endpoint i (e.g., kidney cancer) attributable to PFOA, PFOS, PFHxS or PFNA pollution in period or year t were estimated, followed by a quantification of the burden of disease in terms of Disability-Adjusted Life Years and preventable deaths in period or year t drawing on evidence from the IHME Global Burden of Disease database.

We have employed the same methods to consider potential health impacts attributable to different levels of PFOA, PFOS, PFHxS and PFNA exposure under prospective scenarios. The methodology developed and applied is described in depth, including mathematically in the Task 2 (see Section 3.2.2 of Annex B) and Task 4 (see Section 3.1 of Annex D) reports.

2.5.2.5. Step 5 Human health cost valuation

We have reviewed the literature and valuation studies as well as guidelines from ECHA, OECD, etc., and developed estimates of the monetary values or costs associated with a statistical case of ill health for each of the 13 health risks or endpoints being assessed, as described in this project’s Task 2 Report (see Section 3.2.2 of Annex B). These estimates comprise the valuation of non-market disease burden (e.g., people’s willingness to pay to avoid one case of ill health), and additional healthcare and productivity (market) costs that could be incurred by each case of ill health.

The Table below presents the monetary values (or costs) by health endpoint in scope and by cost ‘category’ (i.e., non-market disease burden, healthcare costs and economic productivity losses). Please note that the Table presents approximate values for total costs per statistical case, albeit in some cases, such as for chronic conditions with high survival rates, medical costs could be underestimated.

Table 10 – Monetary values or costs associated with a ‘statistical’ case of ill health (EUR₂₀₂₄/case)⁷⁴, by endpoint and cost category

Specific health risk/ endpoint in scope	Non-market disease burden (EUR ₂₀₂₄ / case)	Healthcare costs (EUR ₂₀₂₄ / case)	Productivity Costs (EUR ₂₀₂₄ / case)
Kidney cancer	626,000	18,000	32,000
Low (and very low) birth weight	624,000	23,000	10,000
Testicular cancer	198,000	8,000	32,000

⁷⁴ All monetary values are presented in 2024 euros, having adjusted data from secondary sources using evidence from the GDP deflator where necessary.

Specific health risk/ endpoint in scope	Non-market disease burden (EUR ₂₀₂₄ / case)	Healthcare costs (EUR ₂₀₂₄ / case)	Productivity Costs (EUR ₂₀₂₄ / case)
Chronic kidney disease	175,000	5,000	13,000
Endometriosis	123,000	4,000	8,000
Lower respiratory tract infection	75,000	200	3,000
Time to pregnancy/ female infertility	41,000	8,000	3,000
High systolic blood pressure	32,000	900	3,000
Osteoporosis	14,000	2,000	3,000
Obesity	11,000	800	1,800
Maternal hypertensive disorders	6,000	4,000	10,000
High LDL cholesterol	5,000	5,000	3,000
Hypothyroidism	3,500	1,000	3,000

Note: Please see the Task 2 report (Section 3.2.2 of Annex B) for underpinning evidence/sources. In addition, please note that these figures are rounded to the nearest '000 euros, or '00 where relevant.

These values were used to calculate the monetary costs associated with the health impacts assessed under Step 4 and, thus, produce updated estimates of the human health costs from exposure to PFOA, PFOS, PFHxS or PFNA in the EEA at present and under prospective scenarios. We have maintained the assumptions of the monetary value of a life year and/or statistical life, medical costs, and sickness absence constant in real terms over time, for the purposes of this study (explained in the Section 3.2.2 of Annex B: Task 2 Report).

2.5.2.6. Step 6 Sensitivity analysis

Firstly, we conducted a quantitative sensitivity analysis by characterising low, medium and high scenarios of human health impacts and costs from exposure to four PFAS (PFOA, PFOS, PFNA, and PFHxS) and up to 13 health risks/endpoints; that is, the analysis is limited to the scope of the quantitative assessment that is viable and has been presented in previous steps. These sensitivity scenarios are explored to test how the uncertainties in the assumptions might affect the estimates of human health impacts and costs within this scope. The Table below summarises the sensitivity scenarios explored quantitatively.

Table 11 – Scenarios to test the sensitivity of our results to uncertainties and assumptions

Variables	Medium scenario	Low scenario	High scenario
PFOA, PFOS, PFNA, and PFHxS levels in human blood serum (µg/L)	The historical average, minimum and maximum blood serum levels in the scientific literature by population group and PFAS type were calculated under Task 1, and this evidence was triangulated with the outputs of the dynamic modelling of prospective scenarios under Task 3.		
Health risks or endpoints included (binary, either included or excluded based on confidence ratings)	7 endpoints included (confidence rating >2): LRTI, low (and very low) birth weight, maternal hypertensive disorders, hypothyroidism, osteoporosis, high cholesterol, kidney cancer.	4 endpoints included (confidence rating >3): LRTI, low (and very low) birth weight, maternal hypertensive disorders, hypothyroidism.	13 endpoints included (confidence rating >1): LRTI, low (and very low) birth weight, Maternal hypertensive disorders, hypothyroidism, osteoporosis, high cholesterol, kidney cancer, obesity, high blood pressure, CKD, testicular cancer, endometriosis, female infertility.
ERFs (Odds, risk or other ratios)	Central values	Lower bound	Upper bound
Non-market disease burden value per typical case (EUR/case)*	Central values	20% lower (or lower bound)	20% higher (or higher bound)
Medical costs per typical case (EUR/case)	Main evidence-based assumption	20% lower	20% higher
Sickness absence per typical case (Sick days/case)	Main evidence-based assumption	20% lower	20% higher

*This will embed sensitivities concerning both WTP inputs and DALY/case estimates.

By definition, the low and high sensitivity scenarios produce estimates that are possible but unlikely to represent the actual human health costs of PFOA, PFOS, PFHxS and PFNA pollution and should be considered lower and upper bounds in this specific context. **The main drivers of uncertainty in these estimates are:**

- The health risks or endpoints included in the analysis based on the level of confidence in the association between PFAS exposure and health risk; and
- ERF sensitivities directly taken from scientific literature.

Beyond this, there are **additional gaps and limitations, especially three, which could have substantial implications** when considering the scale of all potential human health costs of all PFAS pollution but could not be considered quantitatively in the sensitivity analysis. These are:

- Human exposure to thousands of other PFAS (that is, all other PFAS which are not PFOA, PFOS, PFHxS and PFNA and are not regulated);
- Additional health risks or endpoints which might be linked to PFAS exposure; and
- The cumulative/mixture effects of human exposure to multiple PFAS.

In more detail:

- There is a lack of evidence directly linking and/or characterising ERFs for PFAS other than PFOA, PFOS, PFHxS and PFNA. However, the 'other PFAS' are estimated to be in the thousands, and are currently unregulated, so it is likely that their impact on health will become relatively more prominent in the future as regulatory action to address PFOA, PFOS and PFHxS pollution leads to the proliferation of alternative substances that take their place (in the absence of further policy action). *This suggests that the estimates produced in this study might only be a proportion, potentially small, of the total human health costs of all PFAS pollution.*
- Scientific literature currently identifies under 30 human health risks linked to PFAS exposure, however, the weight of evidence is limited and, in more than half of these cases, the literature does not provide quantitative exposure-response functions. In addition, the available studies focus on relatively well-known and already regulated PFAS, and evidence is lacking on other substances and/or their similarities. *This also suggests that the estimates produced in this study might only be a proportion, potentially small, of the total human health costs of all PFAS pollution.*
- Finally, there is very limited to no understanding of the mixture/cumulative effects of exposure to multiple PFAS in the literature found for this study. In this study, it has not been possible to quantify the cumulative impacts of human exposure to more than one of PFOA, PFOS, PFHxS and PFNA, due to the limitations and lack of clarity of the extent to which the individual impacts of specific PFAS have been isolated in the literature. *This also suggests that the estimates produced in this study might only be a proportion, potentially small, of the total human health costs of all PFAS pollution.*

Based on this, the study authors believe that the estimates of human health costs from PFOA, PFOS, PFHxS and PFNA exposure reported subsequently represent a lower bound for the total human health damage and costs that all PFAS pollution may cause in the EEA.

Section 4.6 presents a more detail outline of the study's gaps and limitations and what these could mean for the quantitative estimates of the human health costs of PFAS pollution.

2.5.3. Remediation and treatment costs

The following stepwise methodology was used to estimate the costs for the remediation of PFAS-polluted soil and the treatment of PFAS-polluted water in the EEA. This methodology was developed in Task 2 and based on literature and evidence collected under Task 1, as well as the outputs of the scenario analysis undertaken under Task 3. The steps are summarised below.

1. Define PFAS concentration thresholds in water:

PFAS concentration thresholds for water are defined for specific scenarios. For any site exceeding these thresholds, water treatment costs have been considered in the analysis. For water treatment, thresholds have been selected to reflect the following assumptions:

In **scenario 1 (business as usual for emissions)**, it is expected that no significant additional wastewater treatment is implemented to address PFAS⁷⁵. Since the effects of the Recast Drinking Water Directive (DWD) limits are assessed separately in scenario 2, no EU-wide concentrations thresholds for drinking water are assumed in scenario 1.⁷⁶ The exposure modelling estimates concentrations of up to around 0.23 ug/L for the sum of 20 PFAS in drinking water by 2050, which would suggest that limits would not be exceeded in most cases. For simplicity, it has, therefore, been assumed that no additional drinking water treatment is implemented under scenario 1.

In **scenario 2**, additional drinking water treatment is expected to be implemented to fully comply with the proposed DWD limits of 0.1 ug/L for the sum of 20 PFAS and 0.5 µg/l for total PFAS.

In **scenario 3**, it is expected that all wastewater treatment plants will require additional treatment to achieve compliance with proposed EQSD limits.

In **scenario 4**, no specific thresholds are applied to trigger drinking water treatment or wastewater treatment, but it is assumed that the production and use of PFAS cease in the EEA, which is expected to lead to fewer contaminated sites requiring soil remediation and water treatment compared to the other scenarios.

⁷⁵ See e.g. EurEau (2021): PFAS and waste water – Current knowledge from the European water sector and the case for control at source. Briefing Note, May 2021. [https://www.eureau.org/resources/briefing-notes/5612-briefing-note-on-pfas-and-waste-water/file#:~:text=Waste%20water%20treatment%20plants%20\(WWTP,effluent%20or%20in%20sewage%20sludge](https://www.eureau.org/resources/briefing-notes/5612-briefing-note-on-pfas-and-waste-water/file#:~:text=Waste%20water%20treatment%20plants%20(WWTP,effluent%20or%20in%20sewage%20sludge). (accessed 27 June 2025).

⁷⁶ However, some additional drinking water treatment to address PFAS could still be implemented if required due to European or national limit values. National limit values for drinking water can vary between 0.002 and 7 ug/L for different PFAS species or groups, but they cover only some countries and PFAS species, cf ITRC (2024): PFAS Environmental Media Values Table Excel file. (accessed 12 June 2025)

Note that our assessment of soil remediation costs is based on numbers of contaminated sites (see next step), and not on specific thresholds. Soil remediation could not be linked to specific thresholds, because (1) the need for soil remediation of PFAS contamination is typically determined on a case-by-case basis by competent authorities following a more detailed assessment triggered when concentrations exceed national intervention values or screening thresholds, (2) for many countries and PFAS species, there are no legal limits (e.g. intervention values or screening values), and (3) it has not been possible to link monitored PFAS concentrations to specific sites⁷⁷.

2. Identify potential water treatment volumes and soil remediation sites:

For drinking water and wastewater, treatment costs are based on the volume of water treated. As a proxy for **drinking water**, the volume of public water supply to households is taken from Eurostat⁷⁸ and converted to cubic meters per capita per year. For countries for which there are gaps in the Eurostat dataset, the weighted average volume per capita per year from EEA countries where data is available (45m³ per capita per year) is applied. The per capita volume of each country is then multiplied by the population of different cohorts with different concentrations of PFAS (background, elevated-low, elevated-high and occupational) as projected by the exposure model (Task 3).

For **wastewater**, the volume of total discharges of wastewater treatment plants (urban and other) is taken from Eurostat⁷⁹. For countries for which there are gaps in the Eurostat dataset, the volume is estimated by applying the weighted average volume per capita per year from EEA countries where data is available (96m³ per capita per year) to the population of the country. Wastewater volume is projected to decrease proportionally to the EEA population in future years, which is consistent with the exposure model (Task 3).

For **soil remediation**, the most comprehensive dataset of contaminated sites potentially requiring remediation in Europe was created by the Forever

⁷⁷ The Forever Pollution Project dataset available on the CNRS PFAS Data Hub (discussed further below) provides known and presumptive PFAS contaminated sites as separate data points from measured PFAS concentrations at monitoring sites, and therefore PFAS concentrations are not directly linked to the known and presumptive PFAS contaminated sites.

⁷⁸ Eurostat (2024): Water use by supply category and economical sector [env_wat_cat_custom_12101819]. https://ec.europa.eu/eurostat/statistics-explained/images/1/1b/Water_statistics_2024_rev1.xlsx (accessed on 07/07/2025). Data for 2020. For Germany, 2020 data was unavailable, so a value of 5.2bn m³ has been used, based on a stakeholder contribution from the German water industry association DVGW (dated 27 February 2025) for the parallel European Commission study (Analysis of treatment techniques: Removal of specific pollutants and feasibility assessment of an extended producer responsibility for PFAS).

⁷⁹ Eurostat (2024): Generation and discharge of wastewater in volume [env_ww_genv_custom_17199926]. <https://ec.europa.eu/eurostat/databrowser/bookmark/42f3b4d3-3d01-43e8-9984-79bce42a46ca?lang=en> (accessed on 19/06/2025). Data for 2020.

Pollution Project and has been further developed by the French National Centre for Scientific Research (Centre national pour la recherche scientifique, CNRS). It is available on the CNRS PFAS Data Hub⁸⁰ and has also been used in the most recent and most comprehensive estimate of PFAS remediation costs in Europe (Forever Pollution Project, 2025). The dataset includes “known” PFAS producing and using sites, as well as “presumptive” PFAS using sites. The exposure model (Task 3) projects the evolution of the number of sites in the different scenarios based on projected PFAS emissions. Soil remediation is assumed to occur over an uncertain time within the assessment period (27 years from 2024 to 2050), so as a simplification and to avoid the double counting of remediation costs for the same site twice, each year the number of sites is multiplied with the average annual unit cost (unit cost divided by 27 years). For comparison, Forever Pollution Project (2025)⁸¹ assumed that remediation of the contaminated sites would take place over a period of 20 years (instead of 27 years here). Due to the uncertainty about what share of “presumptive” sites are really contaminated with PFAS, results are presented both with and without presumptive sites (in addition to known sites). While there may also be diffuse soil contamination outside of specific sites that use or produce PFAS, soil remediation generally only covers limited geographic areas around specific sites. It would not be technically or economically feasible to remediate wide-ranging diffuse contamination.

Treatment of PFAS in **landfill leachate** is an emerging area of investigation⁸² and cannot easily be linked to the scenarios (from Task 3). It is therefore only included in the sensitivity analysis.

3. Apply unit costs for soil remediation and water treatment to sites/volumes:

For the purpose of this analysis, “unit costs” means costs of remediation/treatment per relevant unit to which remediation/treatment is applied, such as a contaminated site remediated, or a volume of water treated. These unit costs have been applied to the number of sites and volumes of water that are determined in the previous steps for the different scenarios and years (based on the Task 3 exposure modelling). The unit costs are shown in the table below.

⁸⁰ <https://pdh.cnrs.fr/en/>

⁸¹ Forever Pollution Project (2025): [Unaffordable - The absurd cost of 'PFAS as usual'](#).

⁸² Forever Pollution Project (2025): [Unaffordable - The absurd cost of 'PFAS as usual'](#).

Table 12 – Remediation and treatment unit costs

Cost category	Core analysis unit cost	Sensitivity analysis unit cost	Source and justification (see Section 3.3.3 of Annex B for further details)
Soil remediation	Airports: EUR 7.4 million Industrial PFAS users: EUR 8.0 million Military bases: EUR 36.8 million PFAS manufacturer: EUR 40 million Other: EUR 6 million (all costs per site)	EUR 300,000 – 50 million per site (for all types or sites)	Source: Forever Pollution Project (FPP) (2025) ⁸³ . Unit costs are not explicitly listed in the source, but were calculated by WSP based on the source data provided by the authors in a separate spreadsheet, and the methodology description; costs shown are based on the 75 th percentile tonnes of soil per site, and 75 th percentile costs per tonne, which were recommended by the FPP authors as the best estimate. Exceptions: - For PFAS manufacturers, a cost of EUR 40 million was assumed for PFAS based on expert judgement informed by various estimates in the literature, in order to replace an outlier in Forever Pollution Project (2025). - For the sensitivity analysis, the full range of costs from Goldenman et al. (2019)⁸⁴ was used.
Drinking water treatment – PFAAs	Low: €0.17/m ³ Best: €0.42/m ³ High: €0.85/m ³	Low: €0.10/m ³ High: €32.27/m ³	Source: Parallel European Commission study “Analysis of treatment techniques: removal of specific pollutants (PFAS, Bisphenol A, pesticides and their metabolites) and feasibility assessment of an Extended Producer Responsibility system for PFAS”.
Drinking water treatment – TFA	Low: €0.51/m ³ Best: €0.69/m ³ High: €0.85/m ³	Low: €0.10/m ³ High: €32.27/m ³	Low, best and high estimate are based on the minimum, average and maximum cost across different potential treatment technologies, assuming high flow water treatment plants. The low and high sensitivity consider the full potential range of costs including low flow to very high flow treatment plants. For TFA drinking water treatment, only technologies involving reverse osmosis have been considered effective.
Wastewater treatment	Low: €0.76/m ³ Best: €1.69/m ³ High: €2.75/m ³	Low: €0.50/m ³ High: €14.55/m ³	
Landfill leachate	Not applied.	Cost per country for each EEA country (see next column)	The higher end of the range estimated by Forever Pollution Project (2025) per country is used as our sensitivity high estimate (no landfill leachate is used in the sensitivity low estimate).
Miscellaneous	5% of total remediation / treatment costs	0%-10% (arbitrary range chosen by WSP)	Based on Forever Pollution Project (2025), to account for additional miscellaneous costs not accounted for in the other rows, such as procurement of consultants, design of remediation technology, quality assurance and PFAS monitoring.

Combining steps 1-3 yields estimates of remediation and treatment costs for each of the pollution scenarios from Task 3. Note that since costs were only calculated for the years 2024, 2030, 2040 and 2050, costs for the years in between were estimated by linear interpolation for the purpose of calculating the Present Value of full cost over the full period, s used in the comparison of scenarios.

⁸³ Forever Pollution Project (2025): [Unaffordable - The absurd cost of 'PFAS as usual'](#).

⁸⁴ Goldenman et al. (2019). The cost of inaction: A socioeconomic analysis of environmental and health impacts linked to exposure to PFAS. Available at: [THE COST OF INACTION](#)

2.5.4. Ecosystem service costs

The effects of PFAS on ecosystems, and consequently ecosystem services are unknown due to methodological, knowledge and data gaps. Nevertheless, (eco)toxicological evidence, evidence of exposure, and possible pathways to impacts (considering the potentially affected species and their role in ecosystem service provisioning) can be reviewed to infer what ecosystem service losses and consequent costs to society may be taking place.

A high-level descriptive analysis of the possible effects of PFAS on ecosystem services has been prepared on this basis. Case studies of specific ecosystem service impacts have also been prepared, providing a more detailed analysis of potential costs of PFAS due to potential impacts on climate regulation and food provisioning.

While it is not currently possible to quantify the ecosystem service costs resulting from PFAS pollution, it is still important to demonstrate that those costs could be significant. Ecosystem service costs are not covered directly by the assessment of remediation/treatment costs (which represents the cost to society of achieving a clean environment, rather than the actual market costs incurred by the (eco)toxic effects of PFAS). As such, our analysis improves the comprehensiveness of the assessment, despite being of a qualitative nature.

2.6. Methodological limitations

There are a range of gaps, limitations and assumptions that were required to conduct this analysis, which we document below.

2.6.1. Concerning the human health cost assessment

The main gaps in evidence include:

- Lack of detailed evidence on the size of more or less exposed population groups. There is a lack of confirmation on the number of people potentially exposed across population groups, especially concerning workers and people living near polluted sites in the EEA (these are primarily estimates at present).
- Lack of exposure evidence and future projections. Evidence of PFAS levels in blood serum for specific populations and additional substances, noting that evidence of exposure has been found for 17 substances when there might be around 10,000 PFAS that humans could be exposed to in Europe. Studies projecting PFAS levels in blood serum into the future have not been found.

- Limited studies into risk associations, limited confidence and lack of studies characterising exposure-risk relationships. There remain limitations in the number and weight of scientific studies into the links between PFAS exposure and health risks. For some specific endpoints identified, there is currently insufficient evidence. It is also likely that there are other relevant endpoints that remain unexplored. In addition, there is a need for strengthening the coverage of substances, particularly concerning the study of quantitative exposure-risk relationships (ERFs). ERFs with sufficient evidence were identified for 13 endpoints concerning human exposure to four PFAS substances only (of the 17 for which there is exposure evidence).
- Limited to no understanding of mixture/cumulative effects of exposure. There is a very limited to no understanding of any potential mixture or cumulative effects of PFAS exposure on health outcomes identified in the literature. The ERFs identified in the literature examine the attribution of health risks to the levels of specific PFAS in blood, in isolation.
- Lack of consensus and readily accessible information regarding the burden of disease, care pathways, medical costs, and sickness absence associated with each endpoint. There is a wide range of scientific and grey literature exploring these themes or areas of research. However, there does not appear to be a consensus on the burden of disease, care, costs and sickness that might be associated with a typical case of ill health, for the endpoints in scope.

The main assumptions draw on the available evidence, literature precedent and good practices to address these gaps where that is reasonable and proportionate. Assumptions have been developed for:

- The size of the population across groups, especially concerning those such as exposed workers and people living near polluted sites; as well as their potential evolution into the future (CAGR) under prospective scenarios (based on Eurostat and World Bank data and outputs of Task 3 of this study).
- PFAS in blood serum in the future, under prospective scenarios (based on output of Task 3 of this study).
- The confidence or strength of evidence of health risk associations and ERFs, based on an assessment of the available literature, and their applicability to EEA-wide population groups.
- Typical burden of disease for a case of ill health by endpoint, in terms of Disability-Adjusted Life Years (based on Global Burden of Disease evidence available at the Institute for Health Metrics and Evaluation, IHME); the care pathways for these endpoints; and the typical sick leave taken by workers affected by a typical case.

- Unit values for VOLY, VSL (based on ECHA's latest reference values) and the resulting monetary values for the non-market disease burden by endpoint, and typical medical costs in the EEA for each typical care pathway by endpoint (monitoring, consultations, admissions, procedures, drugs, etc), and the economic costs associated with values in terms of lost output resulting from sickness absence (proposed to be proxied by average salaries and wages) and additional costs incurred by employers in sick pay.

The main limitations of the study are the lack of coverage of PFAS types and health risks due to limitations in the availability and/or weight of evidence (i.e., the lack of substances studied, lack of endpoints examined in depth, limited to no understanding of cumulative exposure impacts, etc).

The methods specified exclude the analysis of substances for which there is no exposure evidence, which is considered reasonable. Substances for which there are no ERFs with sufficient weight of evidence and/or a lack of evidence that does not allow for the reasonable quantification of impacts are also excluded. The literature was also uncertain on whether the impacts represented by the ERFs captured the isolated effects of a substance, despite other PFAS being present in human blood. Therefore, the methodology has considered the results for each endpoint or health risk to correspond to the maximum estimated health impact for one single PFAS out of all PFAS associated with that endpoint or health risk instead of aggregating the estimated impacts across all associated PFAS. This means that **the assessment is focussed on the exposure and the maximum impacts per endpoint associated with four already regulated PFAS substances**. In addition, 13 exposure-risk relationships (of the under 30 identified in the literature) are considered sufficiently evidenced and/or have ERFs established and thus can be assessed quantitatively.

This means **there could be thousands of substances and more than 10 health-risk associations that are not captured in this assessment**. The Table below considers the effects of the main limitations of this study in estimating human health costs of PFAS exposure.

Table 13 – Effects of the main limitations on the estimates of human health costs from PFAS exposure contained in this study

Main limitations	What this means for the estimates of human health costs from PFAS exposure
Lack of detailed evidence on the size of more or less exposed population groups	Unlikely to have any substantial effect
Lack of PFAS captured in the assessment due to limitations in the available evidence linking and/or characterising ERFs for thousands of PFAS (except for PFOA, PFOS, PFHxS and PFNA).	Under-estimate: this suggests that the estimates produced in this study might only be a proportion, potentially small, of the total human health costs of all PFAS pollution.

Main limitations	What this means for the estimates of human health costs from PFAS exposure
Lack of health risks covered in the assessment. Whilst under 30 human health risks are linked to PFAS exposure, the evidence is limited and, in more than half of these cases, the literature does not provide ERFs	Under-estimate: this also suggests that the estimates produced in this study might only be a proportion, potentially small, of the total human health costs of all PFAS pollution.
Limited to no understanding of the mixture/cumulative effects of exposure to multiple PFAS in the literature found for this study.	Under-estimate: this also suggests that the estimates produced in this study might only be a proportion, potentially small, of the total human health costs of all PFAS pollution.
Lack of readily accessible studies into the burden of disease, care pathways, medical costs, and sickness absence associated with each endpoint.	Unlikely to have any substantial effect

In summary, these main limitations of this **study suggest that the estimates of human health costs from PFOA, PFOS, PFHxS and PFNA exposure reported in this report represent a lower bound for the total human health damage and costs that all PFAS pollution may cause in the EEA**, even though the study is more comprehensive than the available precedent.

There are other limitations with quantification of health impacts, as well as their valuation (e.g., uncertainties in ERFs, monetary unit values, etc.). However, the evidence review conducted for this study suggests these limitations are dwarfed by the issues presented by the lack of coverage and evidence concerning thousands of substances and potential health risks associated with PFAS exposure.

2.6.2. Concerning the remediation/treatment cost assessment

The main gaps, limitations and assumptions in the methodology include:

- **Extrapolation:** In the absence of detailed site-specific assessments, there is significant uncertainty about the number of sites and extent of remediation/treatment that would be required on a national or international level, so any extrapolation to national or international totals is highly challenging.
- **Wider pollution:** Remediation/treatment can only cover part of the PFAS pollution but does not cover PFAS pollution distributed over larger areas at lower concentrations.
- **Thresholds and sites:** There are limitations in the identification of remediation/treatment sites, which are discussed in detail in Forever Pollution

Project (2025)⁸⁵. Furthermore, it is uncertain how well our assumptions⁸⁶ on how identified concentration thresholds trigger remediation/treatment at specific sites reflect reality. These assumptions may not accurately reflect the real-world distribution and concentration of PFAS and requirements for additional treatment/remediation at individual sites.

- Unit costs: Remediation/treatment costs can vary significantly on a case-by-case basis. Unit costs for remediation and treatment per site have been identified for different types of sites, but these may not represent the actual costs for all sites.
- Landfill leachate treatment: Data on the treatment of PFAS in landfill leachate is weak, and this area is still emerging. The cost estimates for landfill leachate treatment are only applied in the sensitivity analysis, indicating a lack of robust data.
- Overlap with other costs: Remediation and treatment costs are interrelated with other health and environmental cost categories. They are separate costs in their own right and can be incurred by the same and/or different stakeholders in the EEA. However, they can also overlap with other health and environmental cost categories and can be used to approximate these other health and environmental cost categories (avoided damage cost approach). The degree of these overlaps cannot be quantified.

The table below provides an overview of how the main limitations listed above are expected to affect the remediation/treatment cost estimates.

⁸⁵ Forever Pollution Project (2025): [Unaffordable - The absurd cost of 'PFAS as usual'](#)

⁸⁶ For example, regulatory thresholds for PFAS vary across countries and have only been defined for a small proportion of PFAS species. This variability can trigger different risk management measures, complicating the estimation of remediation and treatment costs. The present study has not assessed threshold exceedances at specific sites, but in scenario 2, the Proposed Recast Drinking Water Directive (DWD) limits of 0.1 µg/L for the sum of 20 PFAAs and 0.5 µg/l for total PFAS were assumed to trigger additional treatment of all drinking water in a cohort when the exposure model predicts the average drinking water concentrations to exceed these thresholds without intervention (in scenario 1). In scenario 3, it has been assumed as a simplification that all wastewater treatment plants require additional treatment to achieve compliance with proposed EQSD limits. In all scenarios, for soil remediation, it has been assumed as a simplification that known PFAS manufacturing and using sites require remediation on average once every 27 years.

Table 14 – Effects of the main limitations on the estimates of PFAS remediation/treatment costs contained in this study

Main limitations	What this means for the remediation/treatment cost estimates
Uncertainty about the number of sites and extent/ costs of remediation/ treatment required	Under-estimate/ Over-estimate: This could lead to an over or underestimate. The sensitivity analysis explores lower and higher unit costs per site remediated or per litre treated, as well as the exclusion of “presumptive” sites where the need for remediation is less certain.
Remediation/treatment cannot cover PFAS pollution distributed over larger areas at lower concentrations	Under-estimate: the estimates in this study are meant to reflect costs of remediation of specific sites, and treatment of water when regulatory thresholds are exceeded. However, this would be an underestimate for the cost of achieving a clean environment, which would require additional clean-up that is likely not feasible in reality.
Landfill leachate treatment	Under-estimate: the exclusion of landfill leachate treatment in the core estimate due to weak data likely leads to an underestimate. The potential costs of landfill leachate treatment are explored in the sensitivity analysis, which shows that the impact on the overall quantified costs is relatively minor.
Overlap with other costs	Over-estimate: Since the potential overlap could not be quantified, this could lead to an overestimate.

Based on these uncertainties, it cannot be concluded whether the remediation/treatment costs estimates in this study are likely to be over or underestimated overall.

2.6.3. Concerning the ecosystem service cost assessment

The ecosystem service assessment is constrained by substantial evidence gaps that currently prevent the development of a meaningful monetised cost estimate. For this reason, a qualitative / case study approach has been adopted.

The gaps/limitations include:

- **Lack of data on ecosystem impacts of PFAS:** There is very limited information on how PFAS (and many other chemicals) affect species at population and ecosystem levels. Such effects are difficult and resource-intensive to monitor, typically requiring long-term field studies. The assessment in this report therefore relies primarily on laboratory data.
- **Barriers to extrapolating laboratory data to real-world impacts:** Laboratory studies show that some PFAS can elicit adverse biological effects, indicating potential harm to ecosystems. However, most studies assess specific effects of individual PFAS in a single species, under short-term and controlled

exposure conditions. Concentration thresholds derived from these studies indicate hazard potential, but they cannot be directly extrapolated to infer whether ecosystem-level impacts occur at higher or lower environmental concentrations, due to the complexity of real-world conditions. In addition, PFAS are highly persistent and bioaccumulative, which may lead to higher internal (tissue) concentrations relative to external environmental levels (e.g. in water). PFAS are also present in the environment in mixtures/cocktails. Substances with similar chemical structures may act additively or synergistically, meaning that combined effects could be greater than those predicted from individual substances.

- Data gaps across PFAS substances and species: Toxicity varies widely between PFAS substances, and different biological organisms have different levels of sensitivity. Existing data covers a relatively small number of PFAS and biological species.
- Ecosystem service assessment: Costs to ecosystem services can only be estimated if impacts on ecosystem function are understood. For example, for case study 1 on algae and climate change (see Section 4.2.2 of Annex D), there is a need to better understand the extent to which PFAS inhibit the carbon sequestering capacity of algae. This requires advanced/emerging risk assessment studies.⁸⁷ There is also a need to understand the extent to which each species supports the ecosystem service. For example, there are large discrepancies between the identified estimates for the carbon capturing potential of algae.

Despite these limitations, there is a clear and scientifically plausible chain of logic that PFAS contamination is likely to cause losses of ecosystem function and services. While the magnitude of these costs cannot currently be quantified, they should not be overlooked or assumed to be insignificant.

⁸⁷ For example, Faber et al. (2021). Identifying ecological production functions for use in ecosystem services-based environmental risk assessment of chemicals. Available at: <https://www.sciencedirect.com/science/article/pii/S0048969721014777>

3. Results

3.1. Exposure scenarios

As a reminder, one of the objectives of the study was to determine the current and future pollution levels of PFAS in the European Economic Area (EEA) under four hypothetical ‘what if’ scenarios:

- **Scenario 1** – A business-as-usual (BAU) situation for emissions without intervention reflecting the regulatory status as of June 2024 (hence not reflecting the later implementation of the REACH restrictions on PFHxA and on PFAS in firefighting foams, nor the proposed universal PFAS restriction).
- **Scenario 2** – Full compliance with the recast Drinking Water Directive (DWD) thresholds of 100 ng/l for the sum of 20 PFAS and 500ng/l for “Total PFAS”.
- **Scenario 3** – Full compliance with the Commission proposed quality standard of 4.4 ng/l PFOA-equivalent for the sum of 24 PFAS under the Environmental Quality Standards and Groundwater Directives (EQSD and GWD) for surface water and groundwater, respectively.
- **Scenario 4** – A total stop of production and uses of PFAS.

The methodology and results are documented in detail in the Task 3 report (Annex C1). The results of Task 3 form the basis of the cost assessment (i.e., Task 4 estimates the societal costs associated with the pollution levels determined by Task 3). Key exposure modelling results underpinning the cost assessment are therefore presented within the following sections that present the cost assessment. However, a summary of the **key conclusions** is also provided in the following paragraphs. Due to their importance as input for the health cost assessment, an additional breakdown of blood serum concentrations for specific PFAS species by cohort and year is also provided in Annex C2.

The universal PFAS restriction dossier (2023 version of the Background Document⁸⁸) provides data for a **business-as-usual scenario** where total PFAS emissions are projected to multiply by 2.5 to 2.75 times between 2020 and 2050. This large increase in emissions means there could be a two and a half times increase of PFAS concentrations in the environmental media and human blood serum (except for certain PFAS species, whose concentrations are already declining

⁸⁸ An update of the Background Document for the universal PFAS restriction proposal was published in late August 2025. The methodology, calculations and text in the present report were largely prepared before that date, so the present report is based on the March 2023 version of the universal PFAS restriction dossier

due to existing legislation⁸⁹ and which are the ones for which health impacts are calculated). According to our calculations, there could be an increase in the **area exposed to elevated concentrations of PFAS from 8% of the area of the EEA in 2020 to 10.5% by 2050, and subsequent increase in the exposed cohorts equivalent to an additional 10 million EEA citizens moving from a background cohort level of exposure to an elevated cohort (both high and low) level of exposure**. Note that the increase in contaminated area is smaller than the increase in emissions, because the model assumes (based on literature references, including Eurostat) that increase in use and emission partly occurs at pre-existing sites where it increases the concentration but not the area of contamination.

For the baseline year (2024), 86% of the EEA population is estimated to be in the background cohort, and 14% in the elevated cohort (comprising 3% in the elevated-high, and 11% in the elevated-low sub-cohorts), and <1% in the occupational cohort. In **scenarios 1 and 2** (business as usual for emissions and DWD compliance, respectively), the increase in emissions by two and a half times the baseline year (2020 in the universal REACH restriction dossier) could mean that, **by 2050, 17% of the EEA population is in the elevated cohort**. Note that the increasing size of the affected area (and population who live there) are calculated based on the assumption that the radius around each site of contamination remains the same. As the emissions increase (as a result of increased productivity) it is calculated (based on Eurostat data) that 75% of the increase emission comes from pre-existing sites, and 25% from new sites. This means that existing sites become more contaminated, but it is only the new sites that spread the contamination and therefore the size of the elevated cohort.

Since the increase in emissions is driven by increased production and use of PFAS, it would also likely lead to a significant increase in the number of sites requiring remediation. Our calculations estimate an increase from around 11,500 known and presumptive sites in 2024 to around 14,200 sites in 2050 for both scenarios 1 and 2 (most increased emissions are assumed to come from increased production in existing sites).

Assuming the drinking water threshold of 100 ng/l for the sum of 20 PFAS is respected everywhere in the EEA, **scenario 2** is estimated to lead to a minor reduction in blood serum concentrations (<2µg/l). The majority of drinking water supplies are calculated as being well below the 100 ng/l in scenario 1, even by 2050. In cases where water was predicted to exceed the limit in scenario 1 (such as the elevated-high sub-cohort from 2020, and elevated-low sub-cohort by 2040), limiting

⁸⁹ Time series data for blood serum concentrations of four named PFAS (PFOA, PFOS, PFNA, and PFHxS) spanning 2001 to 2024 shows a declining trend over time as regulatory enforcement takes effect. The trends over the time-series are assumed to continue to apply to these four named PFAS from the baseline year 2024 until the end of the assessment period. This decrease is assumed to be compensated by increasing concentrations of other, unnamed PFAS to lead to the projected increase in overall PFAS concentrations. See also Annex C1 (Section 2.2.3) for further details on this assumption and Annex C2 for a breakdown of the projected blood serum concentrations by PFAS species.

the intake of PFAS via drinking water under scenario 2 resulted in limited reductions in blood serum concentrations, due to more significant intake of PFAS via food. Note that other pathways such as air and indoor dust would also contribute to exposure and blood serum concentrations and are not considered in this study.

The proposed water quality standard (4.4 ng/l PFOA-equivalent) considered in **scenario 3** is very low compared to surface water and groundwater concentrations (in the tens to low hundreds of ng/l, e.g., the model calculations estimate that in 2024 surface water concentrations are 1,006 ng/l (elevated-high), 600 ng/l (elevated-low), and 200 ng/l (background); for groundwater, the calculations estimate 496 ng/l (elevated high), 297 ng/l (elevated low), and 99 ng/l in the background cohort). This could result in a reduction in blood serum concentration of a similar order (95-99%) by 2050. For the background cohort, adult blood serum concentrations could decline from 14 µg/l in 2020 to 0.7 µg/l in 2050. For the elevated-high cohort, blood serum concentrations could fall drastically from 51 µg/l in 2020 to 0.7 µg/l in 2050. The number of PFAS manufacturing/using sites potentially requiring remediation is assumed to be unchanged in this scenario compared to scenarios 1 and 2, as this scenario focuses on EQS compliance only, with no assumption taken on emissions. However, if this step was considered, compliance with this proposed threshold in surface water and groundwater would be equivalent to a reduction of emissions by 99% compared to the year 2024.

Scenario 4 (the stop of PFAS production and use) models a significant reduction in emissions from 2030 (64% reduction compared to 2024), with continued decline reaching zero by 2040. Biomonitoring data suggests half-lives of between 2 and 10 years, depending on the specific PFAS. Given the heavy reduction in emissions and new exposure, the results of scenario 4 show that blood serum concentrations could fall by as much as 100% by 2050 (i.e., for both background and elevated cohorts (high and low), PFAS in blood could be eliminated by 2050, assuming a complete stop of PFAS use and emissions from 2030). The rate of decline of PFAS in blood serum after limiting exposure could take between 15 and 20 years, depending on the initial concentration level (i.e. it takes longer for elevated concentrations to reach zero). In parallel, due to the persistence of PFAS in soil, it is assumed that the extent of the contaminated area is fixed at the peak year of emissions (expected to be reached in 2026), with no decline in the area of the elevated cohort or the number of contaminated sites following declining emissions (i.e., the emissions cease but the sites remain contaminated). This could lead to continued human exposure, which has not been considered in the model, because the model assumes a direct relationship between emissions (which fall to zero by 2040 in this scenario) and exposure.

As part of the exposure assessment a sensitivity analysis was conducted to sense-check the data and understand the biggest limitations. The results of the sensitivity analysis are provided in Section 7 of Annex C1. The **main limitations** can be summarised as follows:

- The number of contaminated sites has a direct bearing on the size of the cohort populations. The sensitivity analysis partly assessed this uncertainty, illustrating the impact that “presumptive” sites have on the overall results. The study’s main results reflect a ‘best-estimate’ situation on the basis that false positives may be cancelled out by unidentified sites.
- There is a wide range in concentrations seen for PFAS in different environmental compartments and biota (including humans). This includes the fact that the analysis has focussed on PFAS as a group, with individual substances having broader/narrower ranges. PFOS has a particularly wide range of values in blood serum. The study is based on data from the last 10 years to limit some of the wider changes seen in monitoring seen since 2000. Effort has also been made to utilise large datasets (hundreds of samples) to mitigate the effect of outliers, but this means the results provide a high-level pan-European average situation, and concentrations at the local scale may vary widely.
- Projections to the year 2050 represent a challenge in that the uncertainty within the results increases over time, with the estimates for 2050 being the most uncertain. This would be the case for any study that involves the use of projections, given the complexity of the environment, society, and other factors. The study has made use of data from the REACH universal PFAS restriction proposal to support these aspects on the basis that it is the most comprehensive data available.

3.2. Human health costs

3.2.1. Current costs of PFAS pollution

Goldenman *et al.* (2019)⁹⁰ produced estimates of the monetary human health costs of PFAS pollution in the EEA ranging from €52 billion and €84 billion per year (equivalent to €64 billion and €104 billion per year in 2024 euros).

This is based on a quantification of impacts on human health for people facing different levels of PFAS exposure, following an impact pathway approach and ‘what-if’ scenarios that draw on selected studies. The total costs estimated by Goldenman *et al.* (2019), presented above, can be disaggregated as follows: €13-41 million (equivalent to €16-51 million in 2024 euros) in elevated mortality from kidney cancer due to occupational PFOA exposure; €11-35 billion (equivalent to €13-43 billion in 2024 euros) due to deaths linked to hypertension linked to PFOA exposure; and €41-

⁹⁰ Goldenman *et al.* (2019). The cost of inaction: A socioeconomic analysis of environmental and health impacts linked to exposure to PFAS. Nordic Council of Ministers. Available at: <https://norden.diva-portal.org/smash/get/diva2:1295959/FULLTEXT01.pdf>

49 billion (equivalent to €51-61 billion in 2024 euros) from all-cause premature mortality due to elevated PFAS exposure for people residing near contaminated sites, drawing on case study evidence associated with PFOA, PFOS, and PFHxS exposure. The Table below presents key insights.

Table 15 – Human health impacts quantified and monetised in Goldenman *et al.* (2019)

Affected populations	Health risk and impact quantified	Sources of evidence
Workers facing occupational exposure	Increased risk of premature mortality from attributable kidney cancer, leading to preventable deaths	Epidemiological evidence from a study of workers from West Virginia ⁹¹ extrapolated to the European context.
People residing nearby contaminated sites	Increased risk of all-cause premature mortality, leading to preventable deaths	Differences in the risk of mortality (from all causes) for adult populations found in a study based in the Veneto Region, Italy ⁹² when compared to the general population.
People drinking water and eating food with measurable PFAs concentration	Increased risk of premature mortality from attributable hypertension, leading to preventable deaths	Data from the US National Health and Nutrition Examination Survey to present quantitative differences in risk of developing hypertension (and attributable premature mortality) for people with different levels of PFOA concentration in their blood serum.

Building on this work, we have applied a revised and expanded methodology to produce updated monetary estimates of external human health costs of PFAS pollution in the EEA. More specifically, we have:

- Expanded the analysis to cover additional health risks or endpoints (including 13 endpoints) associated with PFAS exposure and specific PFAS types (four substances, which is more than included in the literature precedent, typically focussed on two regulated PFAS), drawing on a literature review of the latest available evidence and the confidence in the findings of association of PFAS exposure to these health risks,
- Reflected the latest available evidence in the exposure-risk relationships, and
- Expanded the coverage of the types of costs included in the analysis beyond the monetisation of disease burden using non-market methods, by systematically including the indirect costs of healthcare and productivity losses.

⁹¹ Steenland and Woskie (2012). Cohort mortality study of workers exposed to perfluorooctanoic acid. *American journal of epidemiology*. 176(10) pp.909–917.

⁹² Mastrantonio *et al.* (2017). Drinking water contamination from perfluoroalkyl substances (PFAS): an ecological mortality study in the Veneto Region, Italy. *The European Journal of Public Health*. Feb 1;28(1):180–185.

The results suggest that, at present, monetary **human health costs of PFOA, PFOS, PFNA and PFHxS pollution could be €39.5 [0.005-600.5]⁹³ billion/year in 2024 alone**. These estimates are broadly aligned with the scale of human health costs estimated by Goldenman *et al.* (2019), despite the differences in the updated methodology. The Table below provides a breakdown of the estimates for the burden of disease of PFAS exposure in 2024 from this study, followed by a detailed comparison of methodology and results with Goldeman *et al.* (2019) in the following Table.

⁹³ Square brackets indicate the potential range of values, considering the estimates from the sensitivity analysis described in Section 3.1.7. For example, “€39.5 [0.005-600.5] billion” indicates a medium estimate of €39.5 billion, a low sensitivity estimate of €0.005 billion, and a high sensitivity estimate of €600.5 billion.

Table 16 – Estimates for human health costs of PFOA, PFOS, PFHxS and PFNA pollution in the EEA in 2024, by health endpoint associated with exposure (medium [low-high] sensitivities)

Endpoint	Relevant cases of ill health	Attributable cases	Attributable DALYs	Attributable statistical deaths	Cost valuation (Billion euros, 2024)
Lower respiratory tract infections (LRTI)	332,300	104,300 [0-283,700]	41,700 [0-113,500]	530 [0-1,430]	8.0 [0-26.5]
Maternal hypertensive disorders	192,500	35,700 [0-118,800]	400 [0-1,200]	2 [0-10]	0.5 [0-3]
Low (and very low) birth weight	261,500	9,500 [0-43,600]	31,800 [0-145,600]	200 [0-900]	6.5 [0-34.5]
Hypothyroidism	681,900	179,600 [900-599,600]	3,600 [20-12,000]	50 [0-180]	1.5 [0.005-5.5]
Osteoporosis	3,341,100	1,012,600 [5,200-3,069,800]	81,000 [400-245,600]	0	19.0 [0.08-70]
Kidney cancer	89,800	1,300 [3-19,300]	4,400 [10-64,600]	110 [0-1,620]	1.0 [0.002-15.5]
High LDL cholesterol	12,996,800	224,800 [20-3,109,100]	6,700 [1-93,300]	160 [0-2,240]	3.0 [0.0002-48.5]
Testicular cancer	19,500	100 [0-1,000]	100 [0-1,000]	1 [0-20]	0.01 [0.0001-0.5]
Childhood obesity	7,677,900	110,800 [0-2,779,700]	6,600 [0-166,800]	50 [0-1,370]	1.5 [0-45.5]
Adult obesity	54,153,200	3,195,000 [97,200-3,195,000]	191,700 [5,800-1,91,700]	2,990 [90-2,990]	43.5 [1.0-52.0]
High blood pressure	7,598,700	747,700 [1,500-3,209,200]	127,100 [300-5,45,600]	3,200 [10-13,740]	27.0 [0.04-138.5]
Chronic kidney disease (CKD)	2,383,300	15,100 [0-372,200]	3,300 [0-81,900]	60 [0-1,540]	3.0 [0-86]
Endometriosis	135,900	20,100 [100-88,600]	13,300 [100-58,500]	0	2.5 [0.01-14.5]
Time to pregnancy/ female infertility	3,298,300	206,700 [1,600-973,400]	2,100 [20-9,700]	0	10.5 [0.07-60.5]
Total*	93,162,900	1,567,800 [900-17,863,000]	169,600 [20-1,731,000]	1,050 [0-26,030]	39.5 [0.005-600.5]

*Please note that the 'Total' figures are not a simple sum of the rows, as they are based on the sensitivity scenarios defined previously (e.g., not all endpoints are included in the low and medium scenarios). Section 2.5.2 outlines clearly the endpoints which are included in the medium, low and high sensitivities. Please note also that any other differences between the sum of values and the 'total' are due to the rounding of estimates.

Despite following different methods, the results of this study and the conclusions from Goldman et al. (2019) both suggest that the human health costs from PFAS pollution will be in the scale of multiple billions of euros per year. Given the gaps and limitations in the literature, both studies are likely to offer estimates that still represent a lower bound of total costs from all PFAS exposure in the EEA. A high-level qualitative comparison of key results across both studies is summarised in the Table below.

Table 17 – Comparison of human health cost estimates between Goldenman *et al.* (2019) and this study

Indicator or similar	Goldeman <i>et al.</i> (2019) methods	Goldeman estimates	Methods from this study	Comparable estimates from this study	Commentary
Annual impacts associated with the effects of PFAS exposure through kidney cancer for exposed workers (2024€)	Assessed impacts based on an epidemiological study in West Virginia: standardised mortality rate = 3.67 for cumulative PFOA exposure $\geq 1,819$ ppm-years (with a 20-year lag). ⁹⁴	3.6-11.8 attributable deaths €16-51 million/ year	Assessed impacts based on the latest, robust ERF available: RR = 1.16 (95%CI: 1.03-1.30) per 10 µg/L PFOA ⁹⁵ and population and blood serum levels for the 'occupational' cohort from the prospective scenario modelling.	1 [>0-9] attributable deaths €17 [0.1-85] million/ year	Estimates are broadly aligned in scale. The methods differ as Goldenman <i>et al.</i> (2019) assumes similar exposure and risk levels for the EEA workers as 1,308 workers from West Virginia from 1979–2004, whereas this study is based on the latest scientific evidence and blood serum evidence for the EEA.
Annual impacts associated with the effects of PFAS exposure through hypertension for the general population (2024€)	Assessed impacts based on two studies from the United States, with OR for hypertension = 1.63 [95% CI: 1.2-2.2] ⁹⁶ for PFOA exposure 4.0–5.5 ng/ml and an elevated risk of hypertension death RR= 0.012. ⁹⁷	3,066-10,035 attributable deaths €13-43 billion/ year	Assessed impacts based on the latest, robust ERF available: OR = 1.19 (95% CI: 1.06–1.34) per ln-unit PFOS ⁹⁸ and population and blood serum levels for the 'background' cohort from the prospective scenario modelling.	2,998 [>0-13,139] attributable deaths €25 [0-132] billion/ year	These estimates are similar in scale. The methods differ, as Goldenman <i>et al.</i> (2019) assumes similar exposure and risk levels for the EEA as the US from 2003-2004 and 2005-2006. whereas this study is based on the latest scientific evidence and blood serum evidence for the EEA.

⁹⁴ Steenland & Woskie (2012). Cohort mortality study of workers exposed to perfluorooctanoic acid. American journal of epidemiology, 176(10), 909–917. Available at: <https://doi.org/10.1093/aje/kws171>

⁹⁵ Bartell and Vieira (2021). Critical review on PFOA, kidney cancer, and testicular cancer. Journal of the Air & Waste Management Association (1995), 71(6), 663–679. Available at: <https://doi.org/10.1080/10962247.2021.1909668>

⁹⁶ Min *et al.* (2012). Perfluorooctanoic acid exposure is associated with elevated homocysteine and hypertension in US adults. Occupational and environmental medicine, 69(9), 658–662. Available at: <https://doi.org/10.1136/oemed-2011-100288>

⁹⁷ Zhou *et al.* (2018). Uncontrolled hypertension increases risk of all-cause and cardiovascular disease mortality in US adults: the NHANES III Linked Mortality Study. Scientific reports, 8(1), 9418. Available at: <https://doi.org/10.1038/s41598-018-27377-2>

⁹⁸ Pan *et al.* (2023). The relationship between perfluoroalkyl substances and hypertension: A systematic review and meta-analysis, Environmental Research, 232, 116362. Available at: <https://doi.org/10.1016/j.envres.2023.116362>

Indicator or similar	Goldeman et al. (2019) methods	Goldeman estimates	Methods from this study	Comparable estimates from this study	Commentary
Annual impacts from all-cause premature mortality due to elevated PFAS exposure for people residing near contaminated sites (2024€)	Assessed impacts based on an epidemiological study using 1980-2013 evidence from the Veneto Region, Italy: RR =1.11 [95% CI: 1.10-1.12] in contaminated areas with PFAS in excess of at least one of the Italian National Health Institute (ISS) performance limits of 30 ng/l for PFOS, 500 ng/l for PFOA and 500 ng/l for the other PFAS in drinking water. ⁹⁹	11,745-13,843 attributable deaths €51-61 billion/year	Assessed impacts based on the latest, robust ERFs available across 13 endpoints (in the high sensitivity scenario) and population and blood serum levels for the 'exposed' cohort from the prospective scenario modelling.	<i>High sensitivity:</i> 4,053 attributable deaths 93.5 billion/year	Estimates developed by Goldeman <i>et al.</i> (2019) are comparable in scale, and the approach and evidence comparable in level of confidence to the high-sensitivity scenario from this current study. The methods differ in the way exposure is defined, as Goldenman et al. (2019) is based on drinking water levels whereas this study is based on blood serum levels and ERF employed. In addition, Goldenman et al. (2019) assume that 3% of the population is exposed to source levels of PFAS above the limit value via municipal drinking water ¹⁰⁰ whereas this study uses the latest evidence from the Forever Pollution project (see Annex C1: Task 3 report).
Total, annual impacts on human health from PFAS exposure (2024€)	The study assessed impacts as described above: kidney cancer due to occupational PFOA exposure; hypertension linked to background PFOA exposure; and all-cause premature mortality due to elevated PFAS exposure	14,815-23,890 attributable deaths €64-104 billion/year	This study assessed impacts based on the latest, robust ERFs available across 13 endpoints (in the high sensitivity scenario), using population and blood serum from the prospective scenario modelling.	<i>High sensitivity:</i> 26,030 attributable deaths 600.5 billion/year	The methods are substantially different, as described above. The approach employed by Goldeman <i>et al.</i> (2019) is comparable in level of confidence captured in the high-sensitivity scenario of this current study, which presents a 5-10x larger estimate of human health costs compared to Goldenman et al. (2019).

⁹⁹ Mastrantonio et al. (2017). Drinking water contamination from perfluoroalkyl substances (PFAS): an ecological mortality study in the Veneto Region, Italy. *European journal of public health*, 28(1), 180–185. Available at: <https://doi.org/10.1093/eurpub/ckx066>

¹⁰⁰ Holmström et al. (2014). Nationell screening av perfluorerade föroreningar (PFAA) i dricksvatten. Rapport no 2014/20 (In Swedish). Available at: https://vav.griffel.net/filer/SVU-rapport_2014-20.pdf

3.2.2. Future costs Scenario 1: Business as usual for emissions

Under this scenario 1 (Business-as-usual scenario reflecting the regulatory status as of June 2024), the predicted emissions from the universal PFAS restriction dossier (published in 2023) suggest that between 2020 and 2050, PFAS emissions could increase by two and a half times from 11,600 tonnes per annum in 2020 to 29,400 tonnes per annum in 2050. This study's Task 3 has estimated that total blood serum levels of PFAS concentrations could also more than double in line with emissions, for example from 15.6 µg/l for adults in the background cohort in 2024 to 35.4 µg/l in 2050.

However, as observed in historical trends driven, at least partly, by PFAS-related restrictions in place, the levels of PFOA, PFOS and PFHxS in human blood would continue to decline over time whereas the levels of other PFAS, including PFNA, would increase also in line with historical trends (see previous reports, including an evidence review and methodological specification, in Section 3.2.2 of Annex B: Task 2 report and Section 2.2.3 of Annex C1: Task 3 report).

The Table below presents the estimated blood serum levels for PFOA, PFOS, PFNA, PFHxS and 'other PFAS' from the Task 3 modelling. The estimation of human health impacts and costs in this study is based upon the estimated levels of PFOA, PFOS, PFNA and PFHxS and the identified ERFs.

Table 18 – Blood serum levels of PFAS, in µg/L, across population cohorts for Scenario 1, estimated under Task 3

Cohort	PFAS type	2024	2030	2040	2050
Background cohort	PFOA	1.81	1.71	1.55	1.44
	PFOS	5.04	3.73	2.26	1.41
	PFNA	0.77	0.90	1.16	1.54
	PFHxS	0.68	0.61	0.51	0.44
	Other PFAS	7.30	11.78	19.89	30.60
Elevated-high cohort, and occupational cohort	PFOA	19.46	18.34	16.62	15.53
	PFOS	5.65	4.18	2.53	1.58
	PFNA	0.77	0.90	1.16	1.54
	PFHxS	1.91	1.72	1.44	1.24
	Other PFAS	28.61	42.54	69.95	108.21

The declining blood serum levels of PFOA, PFOS and PFHxS, coupled with a declining population between 2024-2050, could result in a decline in the combined disease burden of PFOA, PFOS, PFHxS, and PFNA exposure. However, the rapidly increasing blood serum levels of 'other PFAS' types that are not yet sufficiently studied in the scientific literature is likely to result in an increase in the combined disease burden from all PFAS pollution between 2025-2050.

Monetary human health costs associated with exposure to the four substances studies could decline from €39.5 [0.005-600.5] billion/year in 2024 to €27.0 [0.004-456.5] billion in 2040 and increase slightly to €29.5 [0.004-426.0] billion by 2050, in scenario 1. The slight increase in disease burden and human health costs from 2040 to 2050 is driven by a potential increase in PFNA levels in blood serum, which is sufficient in scale to reverse the declining trend driven by the general decline in PFOS, PFOA, and PFHxS blood serum levels. The Table below presents estimates of disease burden and human health costs for 2024, 2030, 2040 and 2050 in scenario 1.

Table 19 – Estimates of disease burden and human health costs per year attributable to PFOA, PFOS, PFHxS and PFNA pollution in the EEA, capturing health endpoints for which evidence is available: Scenario 1 (medium [low-high] sensitivities)

Metrics	2024	2030	2040	2050
Attributable DALYs	169,600 [20-1,731,000]	126,100 [20-1,526,600]	113,900 [10-1,330,000]	125,400 [10-1,264,100]
Attributable statistical deaths	1,050 [0-26,030]	640 [0-22,220]	460 [0-19,310]	400 [0-18,640]
Human health costs (Billion euros, 2024€)	39.5 [0.005-600.5]	29.5 [0.005-529.5]	27.0 [0.004-456.5]	29.5 [0.004-426.0]

Note: The sensitivities are based on the sensitivity scenarios defined previously (e.g., not all endpoints are included in the low and medium scenarios). Please refer to Section 2.5.2 for the endpoints which are included in the medium, low and high sensitivities.

In the medium scenario, around 60-80% of the human health costs from PFOA, PFOS, PFHxS and PFNA exposure are attributable to cases of osteoporosis in women, followed by cases of LRTI in children aged 1-4 years, which accounts for 10-15% of total health costs per year over the period. In the high-sensitivity scenario, however, 13-15% of total human health costs from exposure are attributable to osteoporosis cases, whereas 22-24% of the total costs per year are attributable to high blood pressure cases, and 9-14% to chronic kidney disease.

Non-market disease burden accounts for the majority of the estimated human health costs, followed by productivity costs and healthcare costs. The Table below provides a breakdown of the estimated costs by cost category for 2024, 2030, 2040 and 2050.

Table 20 – Estimates of human health costs per year attributable to PFOA, PFOS, PFHxS and PFNA pollution in the EEA, by cost category, capturing health endpoints for which evidence is available: Scenario 1 (Billion euros, 2024€) (medium [low-high] sensitivities)

Cost category	2024	2030	2040	2050
Non-market disease burden (Billion euros, 2024€)	30.5 [0.002-477.0]	23.5 [0.002-421.0]	22.5 [0.002-364.5]	25.5 [0.001-339.0]
Healthcare costs (Billion euros, 2024€)	2.5 [0.002-45.0]	2.0 [0.002-40.0]	1.5 [0.002-34.5]	1.5 [0.001-33.0]
Productivity costs (Billion euros, 2024€)	6.0 [0.001-78.5]	4.0 [0.001-68.5]	3.0 [0.001-57.5]	3.0 [0.001-54.0]
Total human health costs (Billion euros, 2024€)	39.5 [0.005-600.5]	29.5 [0.005-529.5]	27.0 [0.004-456.5]	29.5 [0.004-426.0]

Note: The sensitivities are based on the sensitivity scenarios defined previously (e.g., not all endpoints are included in the low and medium scenarios). Please refer to Section 2.5.2 for the endpoints which are included in the medium, low and high sensitivities. Please note also that any other differences between the sum of values and the 'total' are due to the rounding of estimates.

The majority of the population in the EEA is exposed to background levels of PFOA, PFOS, PFHxS and PFNA and, thus, this cohort accounts for the majority of the human health costs from exposure in the medium and high-sensitivity scenarios. However, high levels of exposure in the elevated cohort drive the human health costs in the low-sensitivity scenario. The Table below provides a breakdown of the estimated costs by cohort for 2024, 2030, 2040 and 2050.

Table 21 – Estimates of human health costs per year attributable to PFOA, PFOS, PFHxS and PFNA pollution in the EEA, by cohort capturing health endpoints for which evidence is available: Scenario 1 (Billion euros, 2024€) (medium [low-high] sensitivities)

Cohort	2024	2030	2040	2050
Background cohort (Billion euros, 2024€)	32.5 [0-506.5]	24.5 [0-446.5]	22.0 [0-385.5]	24.0 [0-359.5]
Elevated cohort (Billion euros, 2024€)	7.0 [0.005-93.5]	5.0 [0.005-82]	5.0 [0.004-70.5]	5.5 [0.004-65.5]
Occupational cohort (Billion euros, 2024€)	0.1 [0.0002-1.0]	0.08 [0.0002-1.0]	0.08 [0.0002-1.0]	0.09 [0.0001-0.5]
Total human health costs (Billion euros, 2024€)	39.5 [0.005-600.5]	29.5 [0.005-529.5]	27.0 [0.004-456.5]	29.5 [0.004-426.0]

Note: The sensitivities are based on the sensitivity scenarios defined previously (e.g., not all endpoints are included in the low and medium scenarios). Please refer to Section 2.5.2 for the endpoints which are included in the medium, low and high sensitivities. Please note also that any other differences between the sum of values and the 'total' are due to the rounding of estimates.

The majority of the population in the EEA are adults over 20 years of age, which means that, in absolute terms, the majority of human health costs are attributable to this group. However, human health costs estimated per person are especially high for newborns (0 years), children (1-4 years), people (15+ years) residing near contaminated sites, and exposed workers. The Table below provides a breakdown of the estimated costs per person by population group for 2024, 2030, 2040 and 2050.

Table 22 – Estimates of human health costs per person per year attributable to PFOA, PFOS, PFHxS and PFNA pollution in the EEA, by population group, capturing health endpoints for which evidence is available: Scenario 1 (Euros/person, 2024€) (medium [low-high] sensitivities)

Cohort	2024	2030	2040	2050
Adults (20+) (General population) (Euros/person, 2024€)	100 [0-2,800]	100 [0-2,600]	100 [0-2,400]	100 [0-2,400]
Newborns (0 years) (Euros/person, 2024€)	1,700 [0-9,200]	1,000 [0-7,700]	300 [0-5,300]	300 [0-4,800]
Children (1-4 years) (Euros/person, 2024€)	1,000 [0-3,200]	600 [0-3,000]	500 [0-2,600]	400 [0-2,600]
Children (5-14 years) (Euros/person, 2024€)	0 [0-1,300]	0 [0-1,200]	0 [0-1,000]	0 [0-800]
Teenagers (15-19 years) (Euros/person, 2024€)	0 [0-600]	0 [0-600]	0 [0-500]	0 [0-500]
Pregnant women (Euros/person, 2024€)	200 [0-700]	100 [0-600]	0 [0-300]	0 [0-30]
People (15+) living near contaminated sites (Euros/person, 2024€)	400 [1-3,800]	300 [1-3,200]	300 [1-2,700]	300 [1-2,300]
Adults (Exposed workers) (Euros/person, 2024€)	400 [1-3,500]	300 [1-2,900]	300 [1-2,400]	300 [1-2,100]

Note: The sensitivities are based on the sensitivity scenarios defined previously (e.g., not all endpoints are included in the low and medium scenarios). Please refer to Section 2.5.2 for the endpoints which are included in the medium, low and high sensitivities. Please note also that any other differences between the sum of values and the 'total' are due to the rounding of estimates.

3.2.3. Future costs Scenario 2: Drinking Water Directive (DWD)

In this scenario, Task 3 finds that the overall impact on blood serum concentrations is minimal because drinking water accounts only for a relatively small share of human exposure. Moreover, food is the dominant pathway for human exposure and the reduction in exposure from drinking water is offset by the increases in food concentrations as irrigation, rainfall, and existing concentrations in soil and groundwater are all unaffected by drinking water treatment. Therefore, the blood serum levels of PFOA, PFOS, PFHxS and PFNA are similar to the business-as-usual trends from scenario 1. The Table below presents the estimated blood serum levels for PFOA, PFOS, PFNA, PFHxS and 'other PFAS' from the Task 3 modelling. The estimation of human health impacts and costs in this study is based upon the estimated levels of PFOA, PFOS, PFNA and PFHxS and the identified ERFs.

Table 23 – Blood serum levels of PFAS, in µg/L, across population cohorts for scenario 2, estimated under Task 3

Cohort	PFAS type	2024	2030	2040	2050
Background cohort	PFOA	1.81	1.71	1.55	1.44
	PFOS	5.04	3.73	2.26	1.41
	PFNA	0.77	0.90	1.16	1.54
	PFHxS	0.68	0.61	0.51	0.44
	Other PFAS	7.30	11.78	19.89	30.60
Elevated-high cohort, and occupational cohort	PFOA	19.46	18.34	16.62	15.53
	PFOS	5.65	4.18	2.53	1.58
	PFNA	0.77	0.90	1.16	1.54
	PFHxS	1.91	1.72	1.44	1.24
	Other PFAS	28.61	42.54	69.95	108.21

The estimated disease burden in scenario 2 is similar to scenario 1, with a slightly lower number of attributable DALYs and statistical deaths in 2040 and 2050. Overall, the monetary human health costs associated with exposure to these four substances are comparable to scenario 1 and could decline from €39.5 [0.005-600.5] billion/year in 2024 to €27.0 [0.004-456.5] billion in 2040 and increase slightly to €29.5 [0.004-426.0] billion by 2050. However, the rapidly increasing blood serum levels of ‘other PFAS’ types that are not yet sufficiently studied in the scientific literature could result in an increase in the combined disease burden from all PFAS pollution between 2025-2050.

The slight increase in disease burden and human health costs from 2040 to 2050 is driven by a potential increase in PFNA levels in blood serum, which is sufficient in scale to reverse the declining trend driven by the general decline in PFOS, PFOA, and PFHxS blood serum levels. The Table below presents the estimated burden of disease and human health costs for 2024, 2030, 2040 and 2050.

Table 24 – Estimates of disease burden and human health costs per year attributable to PFOA, PFOS, PFHxS and PFNA pollution in the EEA, capturing health endpoints for which evidence is available: Scenario 2 (medium [low-high] sensitivities)

Metrics	2024	2030	2040	2050
Attributable DALYs	169,600 [20-1,731,000]	126,100 [20-1,526,600]	113,800 [10-1,329,900]	125,300 [10-1,264,100]

Metrics	2024	2030	2040	2050
Attributable statistical deaths	1,050 [0-26,030]	640 [0-22,220]	460 [0-19,300]	400 [0-18,640]
Human health costs (Billion euros, 2024€)	39.5 [0.005-600.5]	29.5 [0.005-529.5]	27.0 [0.004-456.5]	29.5 [0.004-426.0]

Note: The sensitivities are based on the sensitivity scenarios defined previously (e.g., not all endpoints are included in the low and medium scenarios). Please refer to Section 2.5.2 for the endpoints which are included in the medium, low and high sensitivities.

The detailed description and breakdown of costs by endpoint, cost category, cohort and population group under scenario 2 is similar to that in scenario 1.

3.2.4. Future costs Scenario 3: Environmental Quality Standards (EQS)

Under scenario 3, compliance with the EQS levels proposed by the Commission is modelled to be achieved from 2030. Further, it is assumed that PFAS blood serum concentrations decay with a half-life of 5 years, which means a 100% reduction in blood serum could be realised after 10 years from when intake is totally stopped. Therefore, the benefits of capping groundwater and surface water concentrations from 2030 onwards (and the resulting decreases in PFAS intake via drinking water and food) would be fully realised by 2040.

As a result, the prospective analysis under Task 3 finds that blood serum concentrations of PFAS could decline by more than 95% (compared to 2024 levels) by 2050. For the 'background' cohort, adult blood serum concentrations decline from 15.6 µg/l in 2024 to 0.7 µg/l in 2050. For the elevated-high exposure cohort, the biggest declines are seen, falling from 56.4 µg/l in 2024 to 0.5 µg/l in 2050. The Table below presents the estimated blood serum levels for PFOA, PFOS, PFNA, PFHxS and 'other PFAS' from the Task 3 modelling. The estimation of human health impacts and costs in this study is based upon the estimated levels of PFOA, PFOS, PFNA and PFHxS and the identified ERFs.

Table 25 – Blood serum levels of PFAS, in µg/L, across population cohorts for Scenario 3, estimated under Task 3

Cohort	PFAS type	2024	2030	2040	2050
Background cohort	PFOA	1.81	1.15	0.04	0.03
	PFOS	5.04	2.51	0.06	0.03
	PFNA	0.77	0.60	0.03	0.03
	PFHxS	0.68	0.41	0.01	0.01

Cohort	PFAS type	2024	2030	2040	2050
	Other PFAS	7.30	7.93	0.54	0.60
Elevated-high cohort, and occupational cohort	PFOA	19.46	12.30	0.09	0.06
	PFOS	5.65	2.80	0.01	0.01
	PFNA	0.77	0.60	0.03	0.03
	PFHxS	1.91	1.15	0.01	0.00
	Other PFAS	28.61	28.52	0.36	0.40

The decline in PFAS pollution and thus people's exposure to PFAS estimated under scenario 3, coupled with a declining population, could result in a decrease of attributable health burden and monetary costs over the period, with an evolution from €39.5 [0.005-600.5] billion/year in 2024 to €12.0 [0.001-373.5] billion in 2030. The prospective scenario analysis expects negligible levels of PFAS in human blood serum in 2040 and 2050, which translates to no health impacts or monetary costs in the medium and low-sensitivity scenarios over this period, although some health impacts are estimated in the high-sensitivity scenario with monetary costs of €3.5 billion in 2040 and €3.2 billion in 2050. In addition, the blood serum levels of 'other PFAS' types that are not yet sufficiently studied in the scientific literature (and thus not quantified) could result in additional disease burden between 2025-2050.

The Table below presents the estimated burden of disease and human health costs for 2024, 2030, 2040 and 2050.

Table 26 – Estimates of disease burden and human health costs per year attributable to PFOA, PFOS, PFHxS and PFNA pollution in the EEA, capturing health endpoints for which evidence is available: Scenario 3 (medium [low-high] sensitivities)

Metrics	2024	2030	2040	2050
Attributable DALYs	169,600 [20-1,731,000]	50,300 [0-1,160,700]	0 [0-12,500]	0 [0-11,700]
Attributable statistical deaths	1,050 [0-26,030]	240 [0-16,180]	0 [0-180]	0 [0-170]
Human health costs (Billion euros, 2024€)	39.5 [0.005-600.5]	12.0 [0.001-373.5]	0 [0-3.5]	0 [0-3.2]

Note: The sensitivities are based on the sensitivity scenarios defined previously (e.g., not all endpoints are included in the low and medium scenarios). Please refer to Section 2.5.2 for the endpoints which are included in the medium, low and high sensitivities.

In the medium scenario, around 70% of the human health costs from PFOA, PFOS, PFHxS and PFNA exposure in 2030 are attributable to cases of osteoporosis in

women, followed by cases of LRTI in children aged 1-4 years, which accounts for 15% of total costs in 2030. In the high-sensitivity scenario, 17% of total human health costs from exposure is attributable to osteoporosis cases; 23%, attributable to high blood pressure cases; and 14%, attributable to adult obesity in 2030. In 2040 and 2050, adult obesity, osteoporosis and high blood pressure account for the entirety of the disease burden and costs to human health, at around 60%, 25% and 15% respectively.

Non-market disease burden accounts for most of the estimated human health costs, followed by productivity costs and healthcare costs. The Table below provides a breakdown of the estimated costs by cost category for 2024, 2030, 2040 and 2050.

Table 27 – Estimates of human health costs per year attributable to PFOA, PFOS, PFHxS and PFNA pollution in the EEA, by cost category, capturing health endpoints for which evidence is available: Scenario 3 (Billion euros, 2024€) (medium [low-high] sensitivities)

Cost category	2024	2030	2040	2050
Non-market disease burden (Billion euros, 2024€)	30.5 [0.002-477.0]	10.0 [0.0003-291.5]	0 [0-2.9]	0 [0-2.6]
Healthcare costs (Billion euros, 2024€)	2.5 [0.002-45.0]	0.5 [0.0003-31.0]	0 [0-0.2]	0 [0-0.2]
Productivity costs (Billion euros, 2024€)	6.0 [0.001-78.5]	1.5 [0.0002-51.0]	0 [0-0.4]	0 [0-0.4]
Total human health costs (Billion euros, 2024€)	39.5 [0.005-600.5]	12.0 [0.001-373.5]	0 [0-3.5]	0 [0-3.2]

Note: The sensitivities are based on the sensitivity scenarios defined previously (e.g., not all endpoints are included in the low and medium scenarios). Please refer to Section 2.5.2 for the endpoints which are included in the medium, low and high sensitivities. Please note also that any other differences between the sum of values and the 'total' are due to the rounding of estimates.

The majority of the population in the EEA is exposed to background levels of PFAS and, thus, this cohort accounts for the majority of the human health costs from PFAS exposure in the medium and high-sensitivity scenarios. However, high levels of exposure in the elevated cohort drive the human health costs in the low-sensitivity scenario. The Table below provides a breakdown of the estimated costs by cohort for 2024, 2030, 2040 and 2050.

Table 28 – Estimates of human health costs per year attributable to PFOA, PFOS, PFHxS and PFNA pollution in the EEA, by cohort capturing health endpoints for which evidence is available: Scenario 3 (Billion euros, 2024€) (medium [low-high] sensitivities)

Cohort	2024	2030	2040	2050
Background cohort (Billion euros, 2024€)	32.5 [0-506.5]	9.5 [0-316.5]	0 [0-3.0]	0 [0-2.8]
Elevated cohort (Billion euros, 2024€)	7.0 [0.005-93.5]	2.0 [0.001-56.5]	0 [0-0.5]	0 [0-0.4]
Occupational cohort (Billion euros, 2024€)	0.1 [0.0002-1]	0 [0-0.5]	0	0
Total human health costs (Billion euros, 2024€)	39.5 [0.005-600.5]	12.0 [0.001-373.5]	0 [0-3.5]	0 [0-3.2]

Note: The sensitivities are based on the sensitivity scenarios defined previously (e.g., not all endpoints are included in the low and medium scenarios). Please refer to Section 2.5.2 for the endpoints which are included in the medium, low and high sensitivities. Please note also that any other differences between the sum of values and the 'total' are due to the rounding of estimates.

The majority of the population in the EEA are adults over 20 years of age, which means that, in absolute terms, the majority of human health costs are attributable to this group. However, human health costs estimated per person in 2030 are especially high for newborns (0 years), children (1-4 years), people (15+ years) residing near contaminated sites, and exposed workers. In 2040 and 2050, the costs are borne entirely by adults in the general population, people (15+ years) residing near contaminated sites, and exposed workers as these are the groups affected by osteoporosis, high blood pressure and adult obesity. The Table below provides a breakdown of the estimated costs per person by population group for 2024, 2030, 2040 and 2050.

Table 29 – Estimates of human health costs per person per year attributable to PFOA, PFOS, PFHxS and PFNA pollution in the EEA, by population group, capturing health endpoints for which evidence is available: Scenario 3 (Euros/person, 2024€) (medium [low-high] sensitivities)

Cohort	2024	2030	2040	2050
Adults (20+) (General population) (Euros/person, 2024€)	100 [0-2,800]	50 [0-2,000]	0 [0-15]	0 [0-10]
Newborns (0 years) (Euros/person, 2024€)	1,700 [0-9,200]	100 [0-5,800]	0	0
Children (1-4 years) (Euros/person, 2024€)	1,000 [0-3,200]	200 [0-2,300]	0	0
Children (5-14 years) (Euros/person, 2024€)	0 [0-1,300]	0 [0-600]	0	0
Teenagers (15-19 years) (Euros/person, 2024€)	0 [0-600]	0 [0-300]	0	0
Pregnant women (Euros/person, 2024€)	200 [0-700]	0 [0-400]	0	0

Cohort	2024	2030	2040	2050
People (15+) living near contaminated sites (Euros/person, 2024€)	400 [1-3,800]	100 [>0-2,300]	0 [0-15]	0 [0-10]
Adults (Exposed workers) (Euros/person, 2024€)	400 [1-3,500]	100 [>0-2,000]	0 [0-15]	0 [0-10]

Note: The sensitivities are based on the sensitivity scenarios defined previously (e.g., not all endpoints are included in the low and medium scenarios). Please refer to Section 2.5.2 for the endpoints which are included in the medium, low and high sensitivities. Please note also that any other differences between the sum of values and the 'total' are due to the rounding of estimates.

3.2.5. Future costs Scenario 4: Total stop of production and use of PFAS

In this scenario, Task 3 finds that there could be a rapid decline of PFAS emissions around 2030, but the remaining in-use consumer stockpiles continue to produce emissions, leading to a slower subsequent decline, reaching zero PFAS emissions by 2040. In more detail, under this scenario, a 64% reduction in PFAS emissions is estimated for 2030, and a 100% reduction by 2040, when compared to 2024.

As a result, blood serum concentrations are estimated to reach zero levels by 2050, due to the assumed half-life of 5 years and 10-year lag in the elimination of blood serum concentrations after new exposure ceases. The Table below presents the estimated blood serum levels for PFOA, PFOS, PFNA, PFHxS and 'other PFAS' from the Task 3 modelling. The estimation of human health impacts and costs in this study is based upon the estimated levels of PFOA, PFOS, PFNA and PFHxS and the identified ERFs.

Table 30 – Blood serum levels of PFAS, in µg/L, across population cohorts for Scenario 4, estimated under Task 3

Cohort	PFAS type	2024	2030	2040	2050
Background cohort	PFOA	1.81	1.30	0.18	0.00
	PFOS	5.04	2.84	0.26	0.00
	PFNA	0.77	0.68	0.14	0.00
	PFHxS	0.68	0.47	0.06	0.00
	Other PFAS	7.30	8.97	2.33	0.00
Elevated-high cohort, and occupational cohort	PFOA	19.46	13.98	1.94	0.00
	PFOS	5.65	3.19	0.30	0.00
	PFNA	0.77	0.68	0.14	0.00
	PFHxS	1.91	1.31	0.17	0.00

Cohort	PFAS type	2024	2030	2040	2050
	Other PFAS	28.61	32.41	8.18	0.00

Similar to scenario 3, the decline and subsequent elimination of PFAS pollution and exposure estimated under scenario 4, coupled with a declining population, could result in a decrease of the human health burden and monetary costs over the period from €39.5 [0.005-600.5] billion/year in 2024 to €17 [0.002-412.5] billion in 2030, and decline further to €0.5 [0-21.5] billion/year in 2040. In 2050, the prospective scenario analysis estimates zero levels of PFAS in human blood serum and, thus, no health impacts or monetary costs are estimated. In addition, the blood serum levels of 'other PFAS' types that are not yet sufficiently studied in the scientific literature (and thus not quantified) could result in additional disease burden between 2025-2040. The Table below presents the estimated burden of disease and human health costs for 2024, 2030, 2040 and 2050.

Table 31 – Estimates of disease burden and human health costs per year attributable to PFOA, PFOS, PFHxS and PFNA pollution in the EEA, capturing health endpoints for which evidence is available: Scenario 4 (medium [low-high] sensitivities)

Metrics	2024	2030	2040	2050
Attributable DALYs	169,600 [20-1,731,000]	71,600 [0-1,257,600]	2,300 [0-51,600]	0
Attributable statistical deaths	1,050 [0-26,030]	340 [0-17,710]	0 [0-910]	0
Human health costs (Billion euros, 2024€)	39.5 [0.005-600.5]	17.0 [0.002-412.5]	0.5 [0-21.5]	0

Note: The sensitivities are based on the sensitivity scenarios defined previously (e.g., not all endpoints are included in the low and medium scenarios). Please refer to Section 2.5.2 for the endpoints which are included in the medium, low and high sensitivities.

In the medium scenario, around 65-85% of the human health costs from PFOA, PFOS, PFHxS and PFNA exposure in 2030 and 2040 are attributable to cases of osteoporosis in women, whereas LRTI in children aged 1-4 years accounts for 15% of total costs in 2030, but negligible costs thereafter. In the high-sensitivity scenario, however, 16% of total human health costs from exposure in 2030 is attributable to osteoporosis cases; 23% is attributable to high blood pressure cases; and 12% each attributable to adult obesity and female infertility in 2030. High blood pressure (20%), chronic kidney disease (20%) and high LDL cholesterol (20%) account for more than half of the disease burden and costs to human health in the high-sensitivity scenario in 2040.

Non-market disease burden accounts for the majority of the estimated human health costs, followed by productivity costs and healthcare costs. The Table below provides a breakdown of the estimated costs by cost category for 2024, 2030, 2040 and 2050.

Table 32 – Estimates of human health costs per year attributable to PFOA, PFOS, PFHxS and PFNA pollution in the EEA, by cost category, capturing health endpoints for which evidence is available: Scenario 4 (Billion euros, 2024€) (medium [low-high] sensitivities)

Cost category	2024	2030	2040	2050
Non-market disease burden (Billion euros, 2024€)	30.5 [0.002-477.0]	14.0 [0.001-323.5]	0.5 [0-18.0]	0
Healthcare costs (Billion euros, 2024€)	2.5 [0.002-45.0]	1.0 [0.001-33.5]	0 [0-1.5]	0
Productivity costs (Billion euros, 2024€)	6.0 [0.001-78.5]	2.0 [0-55.5]	0 [0-2.0]	0
Total human health costs (Billion euros, 2024€)	39.5 [0.005-600.5]	17.0 [0.002-412.5]	0.5 [0-21.5]	0

Note: The sensitivities are based on the sensitivity scenarios defined previously (e.g., not all endpoints are included in the low and medium scenarios). Please refer to Section 2.5.2 for the endpoints which are included in the medium, low and high sensitivities. Please note also that any other differences between the sum of values and the 'total' are due to the rounding of estimates.

The majority of the population in the EEA is exposed to background levels of PFAS and, thus, this cohort accounts for the majority of the human health costs from PFAS exposure in the medium and high-sensitivity scenarios. However, high levels of exposure in the elevated cohort drive the human health costs in the low-sensitivity scenario. The Table below provides a breakdown of the estimated costs by cohort for 2024, 2030, 2040 and 2050.

Table 33 – Estimates of human health costs per year attributable to PFOA, PFOS, PFHxS and PFNA pollution in the EEA, by cohort capturing health endpoints for which evidence is available: Scenario 4 (Billion euros, 2024€) (medium [low-high] sensitivities)

Cohort	2024	2030	2040	2050
Background cohort (Billion euros, 2024€)	32.5 [0-506.5]	14.0 [0-349.0]	0.5 [0-17.7]	0
Elevated cohort (Billion euros, 2024€)	7.0 [0.005-93.5]	3.0 [0.002-62.5]	0 [0-3.7]	0
Occupational cohort (Billion euros, 2024€)	0.1 [0.0002-1]	0 [0-0.5]	0 [0-0.1]	0
Total human health costs (Billion euros, 2024€)	39.5 [0.005-600.5]	17.0 [0.002-412.5]	0.5 [0-21.5]	0

Note: The sensitivities are based on the sensitivity scenarios defined previously (e.g., not all endpoints are included in the low and medium scenarios). Please refer to Section 2.5.2 for the endpoints which are included in the medium, low and high sensitivities. Please note also that any other differences between the sum of values and the 'total' are due to the rounding of estimates.

The majority of the population in the EEA are adults over 20 years of age, which means that, in absolute terms, the majority of human health costs are attributable to this group. However, human health costs estimated per person in 2030 are especially high for newborns (0 years), children (1-4 years), people (15+ years) residing near contaminated sites, and exposed workers.

In 2040, the costs could be entirely borne by adults in the general population, people (15+ years) residing near contaminated sites, and exposed workers. This is because these are the groups affected by the endpoints contributing to the attributable costs in these years (i.e., adult obesity, CKD, high blood pressure, high LDL cholesterol, hypothyroidism, osteoporosis, kidney cancer, endometriosis and female infertility). The Table below provides a breakdown of the estimated costs per person by population group for 2024, 2030, 2040 and 2050.

Table 34 – Estimates of human health costs per person per year attributable to PFOA, PFOS, PFHxS and PFNA pollution in the EEA, by population group, capturing health endpoints for which evidence is available: Scenario 4 (Euros/person, 2024€) (medium [low-high] sensitivities)

Cohort	2024	2030	2040	2050
Adults (20+) (General population) (Euros/person, 2024€)	100 [0-2,800]	100 [0-2,200]	5 [0-110]	0
Newborns (0 years) (Euros/person, 2024€)	1,700 [0-9,200]	300 [0-6,400]	0	0
Children (1-4 years) (Euros/person, 2024€)	1,000 [0-3,200]	300 [0-2,500]	0	0
Children (5-14 years) (Euros/person, 2024€)	0 [0-1,300]	0 [0-700]	0	0

Cohort	2024	2030	2040	2050
Teenagers (15-19 years) (Euros/person, 2024€)	0 [0-600]	0 [0-400]	0	0
Pregnant women (Euros/person, 2024€)	200 [0-700]	0 [0-400]	0	0
People (15+) living near contaminated sites (Euros/person, 2024€)	400 [1-3,800]	200 [>0-2,500]	10 [0-160]	0
Adults (Exposed workers) (Euros/person, 2024€)	400 [1-3,500]	200 [>0-2,200]	10 [0-150]	0

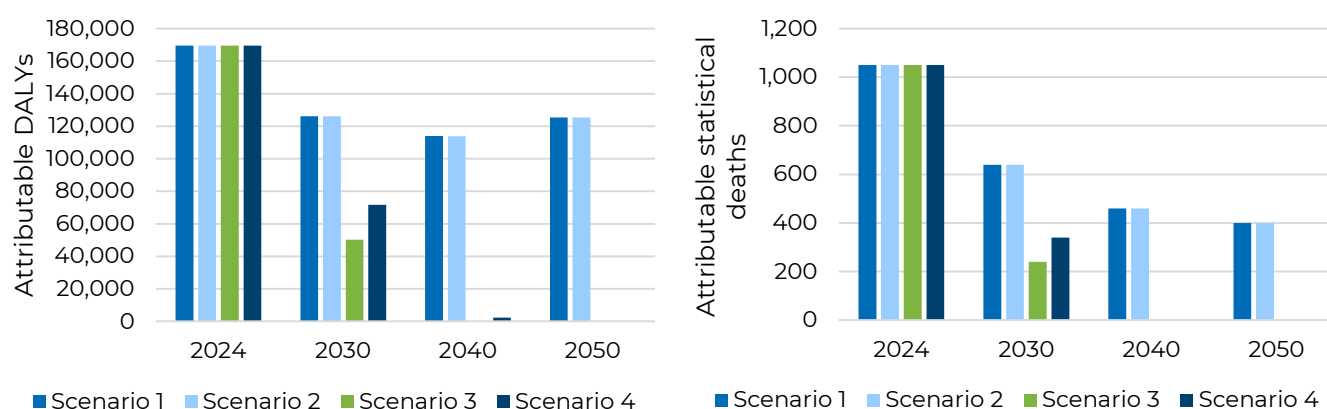
Note: The sensitivities are based on the sensitivity scenarios defined previously (e.g., not all endpoints are included in the low and medium scenarios). Please refer to Section 2.5.2 for the endpoints which are included in the medium, low and high sensitivities. Please note also that any other differences between the sum of values and the 'total' are due to the rounding of estimates.

3.2.6. Comparison of scenarios

In terms of health impacts of the 4 legacy PFAS for which there is sufficient literature, scenario 1 and scenario 2 could lead to the highest disease burden and costs to human health over 2024-2050, followed by scenario 4 and scenario 3, primarily driven by the reductions in PFAS emissions and human health exposure estimated under these prospective scenarios in Task 3.

The medium sensitivity estimates for attributable DALYs and statistical deaths per year across scenarios are presented in the Figure below for an easier visualisation of the evolution over time across scenarios.

Figure 3 – Estimates of DALYs and statistical deaths per year attributable to PFOA, PFOS, PFHxS and PFNA pollution in the EEA, by scenario (medium sensitivity)



The Table below presents a comparison of the total human health costs per year attributable to PFOA, PFOS, PFHxS and PFNA pollution in the EEA, across the four scenarios.

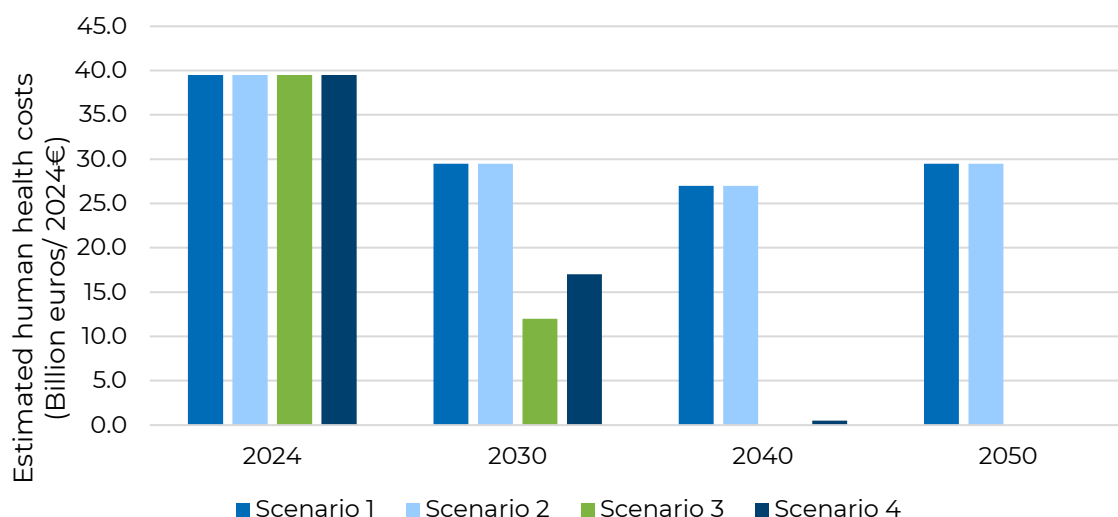
Table 35 – Estimates of human health costs per year attributable to PFOA, PFOS, PFHxS and PFNA pollution in the EEA, by scenario, capturing health endpoints for which evidence is available (Billion euros, 2024€) (medium [low-high] sensitivities)

Scenario	2024	2030	2040	2050
Scenario 1 : Business-as-usual for emissions	39.5 [0.005-600.5]	29.5 [0.005-529.5]	27.0 [0.004-456.5]	29.5 [0.004-426.0]
Scenario 2: Drinking Water Directive (DWD)	39.5 [0.005-600.5]	29.5 [0.005-529.5]	27.0 [0.004-456.5]	29.5 [0.004-426.0]
Scenario 3: Environmental Quality Standards (EQS)	39.5 [0.005-600.5]	12.0 [0.001-373.5]	0 [0-3.5]	0 [0-3.2]
Scenario 4: Total stop of production and use of PFAS	39.5 [0.005-600.5]	17.0 [0.002-412.5]	0.5 [0-21.5]	0

Note: The sensitivities are based on the sensitivity scenarios defined previously (e.g., not all endpoints are included in the low and medium scenarios). Please refer to Section 2.5.2 for the endpoints which are included in the medium, low and high sensitivities.

The Figure below presents the medium sensitivity estimates of human health costs over 2024-2050 to visualise, with more ease, the evolution of human health costs comparatively across scenarios.

Figure 4 – Estimates of human health costs per year attributable to PFOA, PFOS, PFHxS and PFNA pollution in the EEA, by scenario (Billion euros, 2024€) (medium sensitivity)



Scenario 1 (business-as-usual for emissions) projects increasing emissions of PFAS and associated pollution. However, this does not apply to all PFAS. There is a small subset of PFAS that are already regulated in the EU, namely PFOA, PFOS, and PFHxS, for which historical evidence presents declining trends in emissions and blood serum levels, and this is also projected for the future. These also happen to be

the most investigated PFAS, for which there is an evidence base of exposure links to health impacts. A fourth regulated substance, PFNA, for which there is also evidence of exposure links to human health was considered in this analysis, which follows an increasing trend instead. **Under this scenario 1, the present value of human health costs from PFOA, PFOS, PFHxS and PFNA pollution over the period 2024-2050 is estimated at €360 [0.052-5,750] billion, which is equivalent to an annualised cost of €19 [0.003-313] billion per year.**

The results from the implementation of the DWD thresholds under scenario 2 are comparable to scenario 1, since drinking water only accounts for a small fraction of human exposure and the majority of drinking water supplies might be below the threshold, even by 2050, under a baseline case. **The present value of human health costs from PFOA, PFOS, PFHxS and PFNA pollution over 2024-2050 under scenario 2 is therefore also estimated at €360 [0.051-5,750] billion, which is equivalent to an annualised cost of €19 [0.003-313] billion per year.**

Under Task 3, compliance with the EQS threshold in scenario 3 is modelled to be equivalent in our analysis to a 99% reduction in emissions in 2030 (compared to 2024), which results in a decline of more than 95% in blood serum levels of PFAS across exposure cohorts by 2040 (compared to 2024). **Under this scenario 3, the present value of human health costs from PFOA, PFOS, PFHxS and PFNA pollution over the period 2024-2050 is estimated at €240 [0.03-4,350] billion euros, equivalent to an annual cost of €13 [0.002-237] billion per year.**

The total stop of production and use of PFAS in scenario 4 is modelled to lead to a 64% reduction in emissions by 2030 and nearly 100% by 2040 (compared to 2024). As a result, for all exposure cohorts, PFAS in blood could decline by around 60% in 2040 (compared to 2024) and could be eliminated by 2050. Compared to scenario 3, the decline in blood serum concentrations occurs later on in scenario 4 due to the continuing (but declining) emissions from in-use stockpiles. **As a result, the present value of human health costs from PFOA, PFOS, PFHxS and PFNA pollution over the period 2024-2050 under scenario 4 is slightly higher than under scenario 3, estimated at €260 [0.033-4,500] billion euros, equivalent to an annual cost of €14 [0.002-245] billion per year.**

The Table below presents these results, along with the annual average burden of disease for the four scenarios over the period 2024-2050.

Table 36 – Prospective human health costs of PFOA, PFOS, PFHxS and PFNA pollution in the EEA, as average/year and total over the period 2024-2050

Metrics	Scenario 1 (business-as-usual for emissions)	Scenario 2 (DWD)	Scenario 3 (EQS)	Scenario 4 (stop of production and use)
Attributable DALYs (average/year)	131,200 [16-1,489,500]	131,180 [15-1,489,500]	56,310 [5-892,400]	65,030 [6-942,700]

Metrics	Scenario 1 (business-as-usual for emissions)	Scenario 2 (DWD)	Scenario 3 (EQS)	Scenario 4 (stop of production and use)
Attributable statistical deaths (average/year)	660 [0-21,850]	660 [0-21,850.0]	320 [0-12,980]	360 [0-13,820]
Equivalent Annual Cost to human health (Billion euros/year, 2024€)	19 [0.003-313]	19 [0.003-313]	13 [0.002-237]	14 [0.002-245]
Present Value of total costs to human health over 2024-2050 (Billion euros, 2024€)	360 [0.052-5,750]	360 [0.051-5,750]	240 [0.03-4,350]	260 [0.033-4,500]

Note: The sensitivities are based on the sensitivity scenarios defined previously (e.g., not all endpoints are included in the low and medium scenarios). Please refer to Section 2.5.2 for the endpoints which are included in the medium, low and high sensitivities.

When compared against scenario 1 (business as usual for emissions), scenario 2 results in negligible differences in costs to human health because, as noted, drinking water only accounts for a small fraction of human exposure and the majority of drinking water supplies might be below the threshold, even by 2050. Compared to scenario 4, scenario 3 results in a larger reduction against scenario 1 in 2030 and 2040, eventually leading to comparable results in 2050. The percentage reductions against scenario 1 are presented in the Table below.

Table 37 – Estimates of percentage reduction in human health costs attributable to PFOA, PFOS, PFHxS and PFNA pollution in the EEA, when compared to scenario 1 (medium [low-high] sensitivities)

Scenario (compared to Scenario 1: Business as usual for emissions)	2030	2040	2050
Scenario 2: Drinking Water Directive (DWD)	-0.01% [0% , -0.5%]	-0.02% [0% , -1.4%]	-0.03% [0% , -2.5%]
Scenario 3: Environmental Quality Standards (EQS)	-60% [-29% , -86%]	-100% [-99% , -100%]	-100% [-99% , -100%]
Scenario 4: Total stop of production and use of PFAS	-43% [-22% , -64%]	-98% [-95% , -100%]	-100%

Note: The sensitivities are based on the sensitivity scenarios defined previously (e.g., not all endpoints are included in the low and medium scenarios). Please refer to Section 2.5.2 for the endpoints which are included in the medium, low and high sensitivities.

In summary, the persistence of PFAS in human blood serum (represented by an average half-life of 5 years) implies a lag between action and impact, with a delay in the estimated decline in blood serum levels and knock-on implications in the human health costs of PFAS pollution. The results suggest that **early action can lead to a faster reduction in the level of PFAS in human blood serum, and as a result, a faster, larger reduction in total human health costs of PFAS exposure.**

3.3. Soil remediation / water treatment costs

3.3.1. Current costs of PFAS pollution

Based on the method, inputs and assumptions summarised above, we estimate the annual remediation cost associated with PFAS pollution in the EEA in 2024 to be around €87 million when only considering known PFAS manufacturing/using sites, or €3.8 billion when considering known and presumptive PFAS manufacturing/using sites¹⁰¹. “Known” and “presumptive” refers to sites identified by the Forever Pollution Project as being known to manufacture or use PFAS (and thus as certain or likely to be contaminated), or as being presumed to be contaminated based on likely PFAS use or PFAS waste¹⁰². The number of these sites was projected for the exposure scenarios in the present study (see Section 2.4), and the terminology of known and presumptive sites has been adopted from the Forever Pollution Project.

3.3.2. Future costs Scenario 1: Business as usual for emissions

As discussed in Task 3, in scenario 1, PFAS emissions are expected to increase significantly over the assessment period, which is expected to be associated with an increase in the number of PFAS manufacturing and PFAS using sites (see [Table 38](#)), and therefore PFAS contaminated sites that require soil remediation.

¹⁰¹ These totals include miscellaneous costs such as procurement of consultants, design of remediation technology, quality assurance and PFAS monitoring.

¹⁰² For a more detailed explanation, see: <https://pdh.cnrs.fr/en/methodology/#3-pfas-contamination-sites>

Table 38 – Prospective numbers of PFAS manufacturing and PFAS using sites in the EEA: Scenario 1 (business-as-usual for emissions)

	2024	2030	2040	2050
Number of PFAS manufacturing sites	17	18	19	21
Number of highly certain PFAS industrial using sites (starting from “known” contaminated sites in FPP)	190	197	212	235
Number of less certain PFAS using sites (starting from “presumptive” contaminated sites in FPP)	11,264	11,686	12,586	13,949
<i>Airports*</i>	812	842	907	1,006
<i>Firefighting training sites*</i>	1,067	1,107	1,192	1,321
<i>Industrial sites</i>	5,248	5,445	5,864	6,499
<i>Military sites*</i>	457	474	511	566
<i>Waste management sites</i>	3,680	3,818	4,112	4,557

*The ‘what if’ scenarios presented in this study are based on the legislative state of play as of June 2024. In reality, under the EU restriction on PFAS in firefighting foams, emissions from sites marked with an asterisk could be expected to cease by 2035. Note that the restriction on PFAS used in fire-fighting foams has not been included into the scenario 1 used in this study, which was developed before the finalisation of that restriction.

The annual remediation cost estimates for scenario 1 are shown in [Table 39](#). The expected increase in sites is reflected in an increase in the annual soil remediation costs in the EEA from around €82 million in 2024 to around €103 million in 2050 when only considering known sites, or from around €3.6 billion in 2024 to €4.5 billion in 2050 when considering both known and presumptive sites (not including miscellaneous costs which are shown separately and included in the total costs in [Table 39](#)).

However, note that the current assessment assumes that the same site is only remediated once within the assessment period. In reality, the continuing emissions in this scenario could require some sites to be remediated again. Therefore, **the estimate is likely an underestimate.**

For comparison, Goldenman et al. (2019) estimated non-health costs of PFAS contamination (the majority of which was soil remediation) of €16.9 billion over 20 years (so on average €0.8 billion per year). **Forever Pollution Project (2025) estimated** costs of €4.3 billion/year to remediate legacy soil contamination, plus €15.9 billion/year for future soil contamination. Since Forever Pollution Project (2025) included presumptive sites, and since we assumed that each site is only remediated once within our 27-year assessment period, **the most appropriate comparison** would be between our best estimate with presumptive sites (€3.6 billion in 2024 to €4.5 billion in 2050) and the Forever Pollution Project’s estimate for remediating legacy sites (€4.3 billion/year), which are in the same order of magnitude. The “emerging scenario” estimate of €15.9 billion/year for the remediation of future soil contamination with yet unregulated PFAS in Forever Pollution Project (2025) “assumes that ongoing contamination results in a continuous need beyond 20 years (as in the legacy scenario) as new soil sites keep emerging.” Our estimates also include new sites from continuing PFAS emissions, but our estimates are closer to

Forever Pollution Project's "legacy scenario" which covers remediation of existing sites over the next 20 years, because of our assumptions that (1) each site is only remediated once within our 27-year assessment period, and (2) only 25% of predicted future emission increases are associated with new sites, while 75% of the increased emissions come from pre-existing sites through on-site expansion and increase in production (see Section 2.3 of Annex C1).

Note that scenario 1 reflects the regulatory situation from June 2024 and therefore does not consider the REACH restriction on PFAS in firefighting foams (i.e., it is assumed that PFAS emissions from use in firefighting foams continue). Since the majority of PFAS emissions at airports, military sites, and some other contaminated sites come from firefighting foams, it would be expected that the number of these sites would not continue to increase as a result of the firefighting foam restriction. However, existing sites would still require remediation. The exposure modelling in Task 3 projected an increase from 2,336 airports, firefighting training sites and military sites (out of a total of 11,264 presumptive sites) in 2024 to 2,893 (out of a total of 13,949 presumptive sites) in 2050. This means sites related to firefighting foam use account only for a small share of the projected increase in sites, and therefore considering the REACH restriction on PFAS in firefighting foams would only have a relatively small impact on the overall results.

As discussed in the previous section, in scenario 1, it is assumed that no significant additional drinking water or wastewater treatment cost are incurred to remove PFAS. These costs are discussed in scenarios 2 and 3 below.

Table 39 – Prospective treatment/remediation costs per year of PFAS pollution in the EEA: Scenario 1 (business-as-usual for emissions) (€ millions, in 2024 value)

Cost category / estimate*	2024	2030	2040	2050
Soil remediation - PFAS manufacturers (known)				
Best estimate	25	25	28	31
Sensitivity high	31	31	35	39
Sensitivity low	0	0	0	0
Soil remediation – Industrial PFAS users (known)				
Best estimate	57	60	64	72
Sensitivity high	359	372	400	448
Sensitivity low	2	2	2	3
Soil remediation - Airports (presumptive)				
Best estimate	227	237	255	283
Sensitivity high	1,535	1,600	1,722	1,911
Sensitivity low	0	0	0	0

Cost category / estimate*	2024	2030	2040	2050
Soil remediation - Military (presumptive)				
Best estimate	634	658	711	791
Sensitivity high	861	894	967	1,074
Sensitivity low	0	0	0	0
Soil remediation - Industrial PFAS users (presumptive)				
Best estimate	1,595	1,656	1,782	1,975
Sensitivity high	9,969	10,348	11,137	12,343
Sensitivity low	0	0	0	0
Soil remediation – Other (presumptive)				
Best estimate	1,082	1,122	1,208	1,339
Sensitivity high	9,015	9,354	10,069	11,161
Sensitivity low	0	0	0	0
Landfill leachate treatment				
Sensitivity high	203	203	203	203
Sensitivity low	0	0	0	0
Drinking water treatment / Wastewater treatment	No significant drinking water or wastewater treatment is assumed to occur specifically to remove PFAS in this scenario.			
Miscellaneous				
Best estimate <u>without</u> presumptive sites	4	4	5	5
Best estimate <u>with</u> presumptive sites	181	188	202	225
Sensitivity high	2,197	2,280	2,453	2,718
Sensitivity low	0	0	0	0
Total				
Best estimate <u>without</u> presumptive sites	87	89	97	108
Best estimate <u>with</u> presumptive sites	3,801	3,946	4,251	4,715
Sensitivity high	24,171	25,083	26,986	29,897
Sensitivity low	2	2	3	3

* The different estimates (best estimate, sensitivity low and sensitivity high) reflect the potential variation in the unit costs per site remediated, and assume no remediation of presumptive sites for the low sensitivity. The categories of “known” and “presumptive” soil remediation sites are based on the categories developed by the Forever Pollution Project, “Other” sites include firefighting training sites and waste management sites.

3.3.3. Future costs Scenario 2: Drinking Water Directive (DWD)

Table 40 shows the concentrations of PFAS (sum of 20 PFAS) in drinking water predicted by the exposure modelling from Task 3. Increasing volumes of drinking water are expected to reach the proposed Recast Drinking Water Directive (DWD)

limit of 0.1 ug/L for the sum of 20 PFAS (from 0% of drinking water in 2024, to 2.9% in 2030, 3.2% in 2040, and 18.1% in 2050).

Table 40 – Prospective concentrations for sum of 20 PFAS in drinking water by cohort in the EEA: Scenario 2 (Drinking Water Directive) (ng/l)

Cohort	2024	2030	2040	2050
Background cohort	22	26	36	50
Elevated-low sub-cohort	61	73	100	100*
Elevated-high sub-cohort	100	100*	100*	100*

**) Value exceeds the DWD limit of 100 ng/l for 20 PFAS under scenario 1, but is assumed to remain capped at the limit under scenario 2 due to drinking water treatment.*

The resulting annual drinking water treatment cost estimates for scenario 2 are shown in [Table 41](#). Other cost categories in this scenario are assumed not to deviate from scenario 1 and are therefore not repeated here, but they are included in the total costs of the scenario presented in the table.

As a result of the increasing volumes of drinking water exceeding DWD limits, annual costs in the EEA for additional water treatment to reach DWD thresholds are estimated to increase to around €264 million in 2030, €276 million in 2040, and €1.4 billion in 2050 (best estimates). The ranges from the low to the high estimate (or the low sensitivity to high sensitivity) shown in the table reflect the potential variation in the unit costs per m³ of water treated. For comparison, Forever Pollution Project (2025) assumed that 5% of drinking water required additional treatment for legacy PFAS at a cost of €347 million/year.

Due to the significant uncertainties regarding TFA (see Annex C1, Section 3.6.1), drinking water treatment costs for TFA have been calculated separately. The inclusion of TFA would increase the drinking water treatment costs dramatically. Assuming that Member States apply the Total PFAS threshold of 500 ng/l, drinking water treatment costs of around €14-15 billion would be estimated to be incurred in the EEA per year. These much higher costs (compared to PFAAs) reflect that TFA concentrations are already widely observed to exceed the proposed threshold, as well as the assumption that more costly technologies are required to remove TFA (reverse osmosis, as was also assumed by Forever Pollution Project (2025)). **For comparison, Forever Pollution Project (2025)** estimated that around €18 billion per year would be required to treat all drinking water in the EU for TFA, which is the same order of magnitude as our estimates. The differences between our estimates and those of Forever Pollution Project (2025) are due to a different approach and different unit costs. We used volumes of water treated and multiplied with a unit cost per volume from a parallel Commission study. Forever Pollution Project (2025) estimated numbers of treatment plants and multiplied with unit costs per plant from the US EPA and the [Minnesota Pollution Control Agency](#).

Note that TFA drinking water treatment costs are not additive to PFAAs drinking water treatment costs, because the additional water treatment to remove TFA would

also remove PFAAs. The table below shows a total for remediation and treatment costs without TFA treatment, and another total “with TFA treatment”, where both TFA and PFAA would be removed.

Table 41 – Prospective treatment/remediation costs of PFAS pollution per year in the EEA: Scenario 2 (Drinking Water Directive) (€ millions in 2024 value)

Cost category / estimate*	2024	2030	2040	2050
Soil remediation - PFAS manufacturer (known)	Same as scenario 1			
Landfill leachate treatment	Same as scenario 1			
Drinking water treatment - PFAAs				
Best estimate	0	264	276	1,446
High estimate	0	537	562	2,943
Low estimate	0	109	114	599
Sensitivity high	0	20,508	21,448	112,318
Sensitivity low	0	63	66	345
Wastewater treatment	No significant wastewater treatment is assumed to occur specifically to remove PFAS in this scenario.			
Miscellaneous				
Best estimate	181	201	216	297
High estimate	181	215	231	372
Low estimate	4	10	10	35
Sensitivity high	2,197	4,331	4,598	13,950
Sensitivity low	0	0	0	0
Total (without TFA treatment)				
Best estimate	3,801	4,223	4,541	6,233
High estimate	3,801	4,510	4,841	7,805
Low estimate	87	204	217	737
Sensitivity high	24,171	47,642	50,579	153,447
Sensitivity low	2	65	69	348
Drinking water treatment – TFA and PFAAs				
Best estimate	15,416	15,140	14,692	14,258
High estimate	18,893	18,555	18,006	17,474
Low estimate	11,473	11,268	10,934	10,611
Sensitivity high	721,061	708,175	687,230	666,904
Sensitivity low	2,216	2,176	2,112	2,050
Total (with TFA treatment)				
Best estimate	19,988	19,843	19,678	19,685
High estimate	23,639	23,429	23,158	23,062
Low estimate	12,133	11,920	11,578	11,249
Sensitivity high	817,338	804,076	782,939	763,491

Cost category / estimate*	2024	2030	2040	2050
Sensitivity low	2,218	2,179	2,115	2,053

* The different estimates (best, low, high sensitivity low and sensitivity high) reflect the potential variation in the unit costs per m³ of water treated. For total costs, the best, high and sensitivity high estimates include soil remediation of known and presumptive sites, whereas the low and sensitivity low estimates only include known sites.

3.3.4. Future costs Scenario 3: Environmental Quality Standards (EQS)

Table 42 shows the concentrations of PFAS (sum of 20 PFAS) in surface and ground water predicted by the exposure modelling from Task 3 for scenario 3. This shows that concentrations are already exceeding the EQS in all cohorts in 2024. Scenario 3 assumes that all proposed EQS for water are fulfilled in 2030. We assume here that, to achieve such a hypothetical outcome, all wastewater needs to be treated (however, it is very likely that in addition to this, emissions would also need to be drastically reduced in order to be able to achieve EQS, but here we focus on wastewater treatment only).

Table 42 – Prospective concentrations for sum of 24 PFAS in drinking water by cohort in the EEA: Scenario 3 (Environmental Quality Standards) (ng/l)

Compartment / Cohort	2024	2030	2040	2050
Surface water				
Background cohort	201	4*	4*	4*
Elevated-low sub-cohort	603	4*	4*	4*
Elevated-high sub-cohort	1,006	4*	4*	4*
Groundwater				
Background cohort	99	4*	4*	4*
Elevated-low sub-cohort	298	4*	4*	4*
Elevated-high sub-cohort	496	4*	4*	4*

*) Value exceeds the EQS of 4.4 ng/l for 24 PFAS under scenario 1, but is assumed to remain capped at the limit under scenario 3 due to wastewater treatment (and possibly other measures not modelled in this scenario).

The annual wastewater treatment cost estimates for scenario 3 are shown in Table 43. Additional treatment costs in the EEA to remove PFAS from wastewater are estimated to decrease slowly from around €73 billion in 2024 to around €71 billion in 2030, €69 billion in 2040, and €67 billion in 2050 (best estimates). The decrease reflects a decline in the EEA population, which is assumed to lead to an equivalent decline in the amount of wastewater generated. The ranges from the low to the high estimate (or the low sensitivity to high sensitivity) shown in the table reflect the potential variation in the unit costs per m³ of water treated. **For comparison, Forever Pollution Project (2025)** estimated costs of €67 billion/year to treat short chain PFAS in all large wastewater treatment plants in the EU as well as the associated sludge, so in the same order of magnitude.

Other cost categories in this scenario are assumed not to deviate from scenario 1 and are therefore not repeated here, but they are included in the total costs of the scenario presented in [Table 43](#). However, note that in reality, it is likely that wastewater treatment alone would not be sufficient to ensure compliance with the proposed EQS. A reduction of PFAS production, use and emissions may also be required, which would affect other costs (notably new soil remediation costs).

Table 43 – Prospective treatment/remediation costs per year of PFAS pollution in the EEA: Scenario 3 (Environmental Quality Standards) (€ millions in 2024 value)

Cost category / estimate*	2024	2030	2040	2050
Soil remediation - PFAS manufacturer (known)	Same as scenario 1			
Landfill leachate treatment	Same as scenario 1			
Drinking water treatment	Same as scenario 1			
Wastewater treatment				
Best estimate	72,785	71,485	69,369	67,316
High estimate	118,433	116,317	112,874	109,533
Low estimate	32,549	31,967	31,021	30,103
Sensitivity high	626,142	614,956	596,754	579,091
Sensitivity low	21,557	21,172	20,545	19,937
Miscellaneous				
Best estimate	3,820	3,762	3,671	3,820
High estimate	6,103	6,004	5,846	6,103
Low estimate	1,632	1,603	1,556	1,632
Sensitivity high	64,812	63,776	62,129	64,812
Sensitivity low	0	0	0	0
Total				
Best estimate	80,226	79,005	77,089	80,226
High estimate	128,156	126,079	122,769	128,156
Low estimate	34,263	33,654	32,669	34,263
Sensitivity high	712,927	701,535	683,416	712,927
Sensitivity low	21,559	21,174	20,548	21,559

* The different estimates (best, low, high sensitivity low and sensitivity high) reflect the potential variation in the unit costs per m³ of water treated. For total costs, the best, high and sensitivity high estimates include soil remediation of known and presumptive sites, whereas the low and sensitivity low estimates only include known sites.

3.3.5. Future costs Scenario 4: Total stop of production and use of PFAS

The annual remediation cost estimates for scenario 4 are shown in [Table 44](#). As discussed in Task 3, in scenario 4, PFAS emissions are expected to fall significantly over the assessment period. However, the Task 3 report (Annex C1, Section 2.2.2)

also discussed that, due to the persistence of PFAS in soil, it is assumed that the number of contaminated sites remains constant at its peak level (i.e., the emissions cease but the sites remain contaminated). This is reflected in constant annual soil remediation costs in the EEA of around €83 million when only considering known sites, or around €3.7 billion when considering both known and presumptive sites (not including miscellaneous costs which are shown separately and included in the total costs in [Table 44](#)).

It is assumed that no significant drinking water or wastewater treatment is occurring specifically to remove PFAS in scenario 4.

Table 44 – Prospective treatment/remediation costs per year of PFAS pollution in the EEA: Scenario 4 (Total stop of production and uses of PFAS) (€ millions in 2024 value)

Cost category / estimate*	2024	2030	2040	2050
Soil remediation - PFAS manufacturer (known)				
Best estimate	25	25	25	25
Sensitivity high	31	31	31	31
Sensitivity low	0	0	0	0
Soil remediation - Industrial PFAS users (known)				
Best estimate	57	58	58	58
Sensitivity high	359	361	361	361
Sensitivity low	2	2	2	2
Soil remediation - Airports (presumptive)				
Best estimate	227	230	230	230
Sensitivity high	1,535	1,556	1,556	1,556
Sensitivity low	0	0	0	0
Soil remediation - Military (presumptive)				
Best estimate	634	642	642	642
Sensitivity high	861	872	872	872
Sensitivity low	0	0	0	0
Soil remediation - Industrial PFAS users (presumptive)				
Best estimate	1,595	1,612	1,612	1,612
Sensitivity high	9,969	10,078	10,078	10,078
Sensitivity low	0	0	0	0
Soil remediation – Other (presumptive)				
Best estimate	1,082	1,094	1,094	1,094
Sensitivity high	9,015	9,119	9,119	9,119
Sensitivity low	0	0	0	0

Cost category / estimate*	2024	2030	2040	2050
Landfill leachate treatment	Same as scenario 1			
Drinking water treatment / Wastewater treatment	Same as scenario 1			
Miscellaneous				
Best estimate <u>without</u> presumptive sites	4	4	5	5
Best estimate <u>with</u> presumptive sites	181	183	183	183
Sensitivity high	2,197	2,222	2,222	2,222
Sensitivity low	0	0	0	0
Total				
Best estimate <u>without</u> presumptive sites	87	87	87	87
Best estimate <u>with</u> presumptive sites	3,801	3,845	3,845	3,845
Sensitivity high	24,171	24,442	24,442	24,442
Sensitivity low	2	2	2	2

* The different estimates (best estimate, sensitivity low and sensitivity high) reflect the potential variation in the unit costs per site remediated, and assume no remediation of presumptive sites for the low sensitivity. The categories of “known” and “presumptive” soil remediation sites are based on the categories developed by the Forever Pollution Project, “Other” sites include firefighting training sites and waste management sites. “Other” sites include firefighting training sites and waste management sites.

3.3.6. Comparison of scenarios

Table 45 shows the total EEA present value (PV) of the treatment and remediation costs of each scenario across the assessment period (2024-2050), as well as the equivalent annual costs (EAC).

The present value of treatment/remediation costs over the whole period is around €78 billion in **scenario 1 (business as usual for emissions)**. Around €1.8 billion of these costs are associated with the remediation of known PFAS manufacturing/using sites, while the rest is associated with sites where PFAS use and contamination is presumed by the Forever Pollution Project.

The present value of treatment/remediation costs over the period is around €86 billion in **scenario 2**, which is about €8 billion higher than scenario 1 due to additional drinking water treatment costs to remove PFAAs. When considering drinking water treatment costs for removing TFA (as well as PFAAs), the present value over the period is far higher, at around €376 billion (about €298 billion higher than scenario 1).

Scenario 3 is associated with the highest total treatment/remediation costs by far, with a present value of costs over the whole period estimated at €1.5 trillion. This is about €1.4 trillion higher than scenario 1. This is because **wastewater treatment** costs could be much higher than the other cost categories (notably drinking water

treatment costs and soil remediation costs), which is consistent with the findings of Forever Pollution Project (2025)¹⁰³.

The **stop of production and use of PFAS in scenario 4** reduces the present value of water treatment and soil remediation costs over the period by about €5 billion compared to scenario 1, to around €73 billion. As discussed in Section 3.3.5, the reduction compared to scenario 1 is only modest because it is assumed that the number of contaminated sites remains constant at its peak level (i.e., the emissions cease but the sites remain contaminated) to reflect the persistence of PFAS in soil. This is reinforced by the assumption that sites are only remediated once within the assessment period, even in scenario 1 where emissions continue.

Table 45 – Prospective treatment/remediation costs of PFAS pollution in the EEA: Total present value over the period 2024-2050 and equivalent annual costs (€ billions in 2024 value)

Scenario	Absolute value		Relative to Scenario 1	
	Total present value (PV)	Equivalent annual cost (EAC)	Total present value (PV)	Equivalent annual cost (EAC)
Scenario 1	78.3	4.3	-	-
Scenario 2 (without TFA treatment)	85.8	4.7	7.5	0.4
Scenario 2 (with TFA treatment)	375.7	20.5	297.5	16.2
Scenario 3	1,482.8	80.9	1,404.5	76.6
Scenario 4	72.8	4.0	-5.4	-0.3

3.4. Ecosystem service costs

3.4.1. Potential pathways from PFAS exposure to ecosystem service impacts

The scientific evidence is clear that some PFAS have the potential to harm aquatic and terrestrial animals and plants due to their (eco)toxicological properties, their persistence, their ability to bioaccumulate in organisms and biomagnify in food webs, and their additive (and sometimes synergistic) effects.¹⁰⁴ Adverse effects have been observed in fish, crustaceans, amphibians, terrestrial invertebrates, birds, mammals,

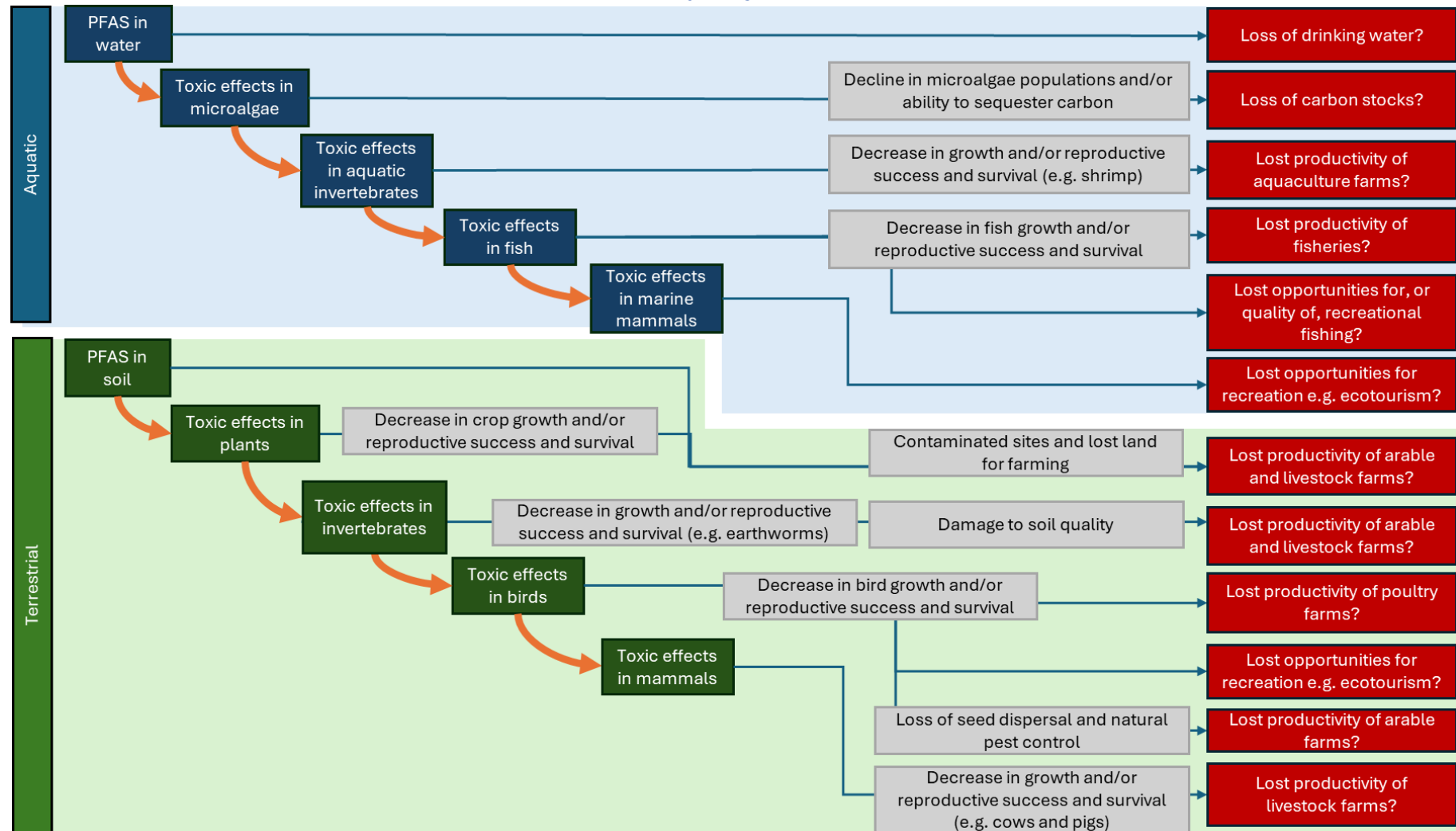
¹⁰³ Forever Pollution Project (2025): [Unaffordable - The absurd cost of 'PFAS as usual'](#).

¹⁰⁴ Ankley et al. (2020) Assessing the Ecological Risks of Per- and Polyfluoroalkyl Substances: Current State-of-the Science and a Proposed Path Forward. Available at: <https://setac.onlinelibrary.wiley.com/doi/epdf/10.1002/etc.4869> ; Banyoi et al. (2022) The effects of exposure to environmentally relevant PFAS concentrations for aquatic organisms at different consumer trophic levels: Systematic review and meta-analyses. Available at: <https://www.sciencedirect.com/science/article/pii/S0269749122016360>

algae, and plants. These effects relate to reproduction, development, behaviour, neurology, lethality, the liver, and the immune system. If realised in the environment, these toxic effects in organisms could lead to ecosystem damage (e.g. through reduced survival, growth, and reproductive success of organisms), which could lead to societal costs through damage to associated ecosystem services.

Most studies on the effects of PFAS are based on traditional chemical risk assessment methods which look at the effects of substances on individual organisms under controlled conditions. These studies cannot be used to accurately predict ecosystem service losses and costs because of the differences between study conditions (e.g. in laboratories) and the real world (with many uncontrolled variables). However, through analysing the types of organisms that may be adversely affected by PFAS, and the role of those organisms in contributing to ecosystem services, the plausibility of potential ecosystem service impacts of PFAS can be assessed. The figure below considers the various types of biological organisms for which there is evidence of adverse effects of PFAS, and links them to some key ecosystem services, to demonstrate possible ecosystem service impacts. The figure focuses on market impacts due to focus of this project on monetised impacts.

Figure 5 – Example pathways by which PFAS could potentially impact ecosystem services, noting that exact impacts are currently unknown



This diagram visualises how PFAS exposure in water and soil could potentially lead to some ecosystem service effects (non-exhaustive). Exposure to different types of organisms, e.g. from algae to invertebrates, fish, birds, and mammals, could lead to different types of effects.

To confirm whether these ecosystem service impacts are taking place, and to discern the scale of these impacts, more evidence is needed (e.g. from field studies or modern/advanced risk assessment methods¹⁰⁵).

Four qualitative case studies are included below to explore the potential societal impacts of PFAS in terms of ecosystem services. The approach does not fully overcome the lack of quantitative evidence on the impacts of PFAS, but it does build a weight of evidence that suggests impacts from PFAS may be occurring. As noted above, PFAS could influence all types of ecosystem services (due to their possible effects on primary producers which support all ecosystems), therefore the section below only paints a small part of the overall picture. Elaborated versions of the case studies are presented in the Task 4 report (Annex D, Section 4.2).

It is important to note that effects of PFAS (described in the case studies below) have been modelled and observed at a range of concentrations, depending on the PFAS substance studied, the type of biological organism exposed, the type of effect studied, and the duration of exposure to PFAS before effects are measured. These concentrations range from less than 10 ng/L to thousands of mg/L. The specificity of each data point and number of variables means that the overall state of knowledge on ecosystem impacts (and ecosystem service impacts) is far from complete. Moreover, even where environmental concentrations of PFAS are below the concentrations where effects have been observed in studies, there is a strong possibility that impacts may still be occurring. This is because (at least some) PFAS bioaccumulate in organisms, biomagnify in food webs, and can have chronic effects after prolonged exposure (over an organism's lifetime and multiple generations¹⁰⁶, which is longer than typically studied in (eco)toxicological studies¹⁰⁷). The effects of PFAS may also be additive, or synergistic, meaning that concentrations of individual PFAS may be low enough to not elicit toxic effects on their own, but the combined combination of PFAS in the environment could lead to negative effects. In the absence of any evidence, it is best practice to assume that risks are additive/cumulative. Moreover, some studies may not have exposed organisms to PFAS at levels lower than the reported concentrations at which effects were observed.

¹⁰⁵ See e.g.: Forbes and Galic (2016). Next-generation ecological risk assessment: Predicting risk from molecular initiation to ecosystem service delivery, Available at: <https://doi.org/10.1016/j.envint.2016.03.002>.

Maltby et al. (2021). Assessing chemical risk within an ecosystem services framework: Implementation and added value. Available at: <https://doi.org/10.1016/j.scitotenv.2021.148631>.

¹⁰⁶ Haimbaugh et al. (2022) Multi- and Transgenerational Effects of Developmental Exposure to Environmental Levels of PFAS and PFAS Mixture in Zebrafish (*Danio rerio*). Available at: <https://pmc.ncbi.nlm.nih.gov/articles/PMC9228135/>

¹⁰⁷ "Chronic" toxicity studies, designed to assess toxicity due to long-term exposure, often only assess effects after 21 days of exposure.

3.4.2. Case study 1: Effects on algae and climate regulation

- In the face of the current climate crisis, climate regulation ecosystem services have a clear societal value. Carbon sequestration in the EU in 2021 has been valued at over EUR 11 billion.¹⁰⁸ A wide range of estimates are available of the social cost of carbon, e.g. from tens of EUR per tonne of CO₂ to hundreds of thousands of EUR per tonne of CO₂.^{109,110}
- Algae play a critical role in climate regulation, as they have a higher capacity for absorbing carbon than plants.¹¹¹ Phytoplankton absorb between 20 to 35% of global annual CO₂ emissions,¹¹² The ecosystem service of climate regulation provided by the marine ecosystem (including algae) has been valued at about EUR 200 /ha/year globally.¹¹³
- Algae tend to be highly sensitive to the effects of PFAS. Observed effects include changes in chlorophyll, changes in species abundance, reduced growth, disruption of photosynthesis, and decreased cell viability, among others.¹¹⁴ These effects could lead to reduced carbon capture and storage by algae.
- Some PFAS are toxic to algae at concentrations as low as 10 ng/L.¹¹⁵ This is lower than surface water concentrations in scenarios 1 and 2. In scenario 3 and 4 the concentrations are expected to fall below this level over the time horizon.¹¹⁶
- Harm to algae caused by PFAS could be leading to significant ecosystem service costs by affecting chlorophyll content and

¹⁰⁸ <https://ecosystem-accounts.jrc.ec.europa.eu/accounting-tables/global-climate-regulation-use-sequestration-2021-monetary>

¹⁰⁹ Tol (2023). Social cost of carbon estimates have increased over time. Available at: <https://www.nature.com/articles/s41558-023-01680-x>

¹¹⁰ Archer et al. (2020) The ultimate cost of carbon. Available at: <https://link.springer.com/article/10.1007/s10584-020-02785-4>

¹¹¹ Naselli-Flores and Padisak (2023) Ecosystem services provided by marine and freshwater phytoplankton. Available at: <https://link.springer.com/article/10.1007/s10750-022-04795-y>

¹¹² Khatiwala et al. (2009) Reconstruction of the history of anthropogenic CO₂ concentrations in the ocean. Available at: <https://www.nature.com/articles/nature08526>

¹¹³ Brander et al. (2024) Economic values for ecosystem services: A global synthesis and way forward. Available at: <https://www.sciencedirect.com/science/article/pii/S2212041624000123#s0045> . Converted from USD 2020 value to EUR 2025 value.

¹¹⁴ <https://cfpub.epa.gov/ecotox/search.cfm>

¹¹⁵ Banyoi et al. (2022). The effects of exposure to environmentally relevant PFAS concentrations for aquatic organisms at different consumer trophic levels: Systematic review and meta-analyses. Available at: <https://www.sciencedirect.com/science/article/pii/S0269749122016360>

¹¹⁶ Note that average concentrations of the sum of PFAS (the results of Task 3) cannot be directly compared to effect thresholds of individual PFAS to predict the impacts on ecosystem services. See the final paragraph in section 3.4.1 on uncertainties.

photosynthetic capacity and could be compromising society's ability to mitigate climate change.

Although this case study is limited in scope and detail, the possible social cost of carbon (EUR 1,150 per tonne), alongside the role of algae in removing carbon from the atmosphere (e.g. claims that a 4000 m³ pond can absorb about 2,200 tonnes of CO₂ /year), indicates that any effects of PFAS on algae could have a significant economic cost to society. The EU has over 100,000 surface water bodies,¹¹⁷ each with different types and levels of algae in them.

3.4.3. Case study 2: Effects on pollinators and food provisioning

- Pollinators are essential for EU food security and support 5 to 15 billion EUR of the EU's agricultural output.¹¹⁸
- Some evidence of adverse effects of PFAS on key pollinator species is available, indicating that environmentally relevant concentrations of PFAS could be causing mortality, reduced growth and development, reduced reproductive success, and behavioural changes in bees and wasps.^{119,120,121, 122}
- One study in Austria monitored and detected various PFAS in bees and pollen, indicating that European bees are exposed to PFAS.¹²³
- Effects of PFAS could be reducing crop pollination rates by affecting the numbers of pollinators and/or health of pollinators.

¹¹⁷ https://environment.ec.europa.eu/topics/water/surface-water_en

¹¹⁸ EEA (2025) Protecting and restoring Europe's wild pollinators and their habitats. Available at: <https://www.eea.europa.eu/en/analysis/publications/protecting-and-restoring-europes-wild-pollinators-and-their-habitats>

¹¹⁹ Sonter et al. (2021) Biological and behavioral responses of European honey bee (*Apis mellifera*) colonies to perfluorooctane sulfonate exposure. Available at: <https://doi.org/10.1002/ieam.4421>

¹²⁰ The primary study has not been identified, but is referenced in the US EPA Knowledgebase as Wilkins (2001) Perfluorooctanesulfonate, Potassium Salt (PFOS): An Acute Oral Toxicity Study with the Honey Bee.

¹²¹ <https://ec.europa.eu/food/plant/pesticides/eu-pesticides-database/start/screen/active-substances>

¹²² Harris and Etheridge (2001). Comparison of Baits Containing Fipronil and Sulfluramid for the Control of *Vespula* Wasps. Available at: <https://www.tandfonline.com/doi/abs/10.1080/03014223.2001.9518255>

¹²³ Müller et al. (2025) Pfas in the Buzz: Seasonal Biomonitoring of Honey Bees (*Apis Mellifera*) and Pollen. Available at: https://papers.ssrn.com/sol3/papers.cfm?abstract_id=5263775

- Pollinators are threatened globally and the causes are not fully understood.¹²⁴ Chemical pollution (beyond the use of agrochemicals) has received little attention in research on pollinator decline.¹²⁵
- More work is needed to understand whether, and the extent to which, PFAS are influencing pollinator decline. Given the societal value of crop pollination as an ecosystem service, any effects of PFAS on pollinators could represent a significant societal cost. It is predicted that if pollinator habitats in the EU were restored and the use of harmful chemicals reduced, the ecosystem service value of crop pollination could be doubled.¹²⁶

3.4.4. Case study 3: Effects on poultry, livestock, and food provisioning

- Annual poultry sales in the EU are worth 32 billion EUR and the livestock farming industry contributes around 168 billion EUR per year to the EU economy.^{127,128}
- There is evidence of toxicity of PFAS in chickens, including evidence of reduced survival and growth.^{129,130} Some evidence of PFAS toxicity to pigs (based on cellular / molecular effects) is available, but no studies on PFAS toxicity to cows was identified. At the same time, farmers have observed cattle death in regions of the US with high levels of PFAS contamination.¹³¹
- Toxic effects of PFAS in farmed animals could be causing reduced productivity (e.g. through death of animals or reduced size of animals),

¹²⁴ Lima et al. (2022) Editorial: The decline of wild bees: Causes and consequences. Available at: <https://doi.org/10.3389/fevo.2022.1027169>

¹²⁵ Lima et al. (2022) Editorial: The decline of wild bees: Causes and consequences. Available at: <https://doi.org/10.3389/fevo.2022.1027169>

¹²⁶ Eurostat (2021). Accounting for ecosystems and their services in the European Union. Available at: <https://ec.europa.eu/eurostat/en/web/products-statistical-reports/-/ks-ft-20-002>

¹²⁷ <https://avec-poultry.eu/what-we-do/working-groups/trade/#:~:text=Annual%20sales%20of%20poultry%20meat%20in%20Europe%20are, trading%20partner%20in%20the%20global%20poultry%20meat%20market.>

¹²⁸ https://animaltaskforce.eu/wp-content/uploads/2024/11/Facts-and-figures-sustainable-and-competitive-livestock-sector-in-EU_FINAL.pdf#:~:text=The%20livestock%20sector%20contributes%20substantially%20to%20the%20European, and%20creates%20employment%20for%20almost%2030%20million%20people.

¹²⁹ <https://cfpub.epa.gov/ecotox/search.cfm>

¹³⁰ Peden-Adams et al. (2009) Developmental toxicity in white leghorn chickens following in ovo exposure to perfluorooctane sulfonate (PFOS). Available at: <https://pubmed.ncbi.nlm.nih.gov/19071210/>

¹³¹ The Guardian (2024), Texas farmers claim company sold them PFAS-contaminated sludge that killed livestock. Available at: <https://www.theguardian.com/environment/2024/mar/01/texas-farmers-pfas-killed-livestock> ; Dinis-Oliveira (2024). A tribute to Robert Bilott and one of the major toxicological discoveries: "Dark Waters" and the poison truth behind the Teflon nightmare. Available at: <https://publicacoes.cespu.pt/index.php/sl/article/view/186>

resulting in economic losses. This cannot be predicted quantitatively in this study, but could be significant given the value of animal farming in the EU.

- Commission Regulation 2022/2388/EU sets maximum cumulative concentrations for PFAS in animal products.¹³² If PFAS exceed these concentrations, animal produce should be discarded, resulting in a loss of sales. Some case studies indicate that animal produce has been discarded in Belgium in order to protect human health,^{133,134} but evidence to facilitate a broader assessment of these costs has not been identified.
- It is currently unclear what proportion of livestock and poultry is contaminated with PFAS at a level that causes toxic effects on survival, reproduction, and development, or which causes exceedance of the maximum levels of PFAS set out in Regulation 2022/2388/EU. The societal cost could be significant given the multi-billion Euro market of the animal farming industry in the EU.

3.4.5. Case study 4: Effects on aquaculture and food provisioning

- Aquaculture farming in the EU generated 4.8 billion EUR in 2023.¹³⁵ In 2022, 30 billion EUR of seafood was imported and 8.1 billion EUR was exported.¹³⁶
- There is a large body of evidence of PFAS toxicity to fish and crustaceans, including those which constitute a large portion of seafood produced and consumed in the EU (trout, sea bream, cod, and salmon).¹³⁷ PFAS can limit the growth, development, and survival of some aquatic species, which could be causing economic losses through reduced productivity of aquaculture farms.
- Commission Regulation 2022/2388/EU sets maximum cumulative concentrations for PFAS in fish and crustaceans. If PFAS exceed these concentrations, produce should be discarded, resulting in a loss of sales.

¹³² Commission Regulation 2022/2388/EU on maximum levels of PFAS in certain foodstuffs.

Available at: <https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32022R2388>

¹³³ RTBF Actus (2021) Flanders shaken by an environmental scandal that concerns us all.

Available at: <https://www.rtf.be/article/la-flandre-secouee-par-un-scandale-environnemental-qui-nous-concerne-tous-10781726>

¹³⁴ La Libre (2024) PFAS pollution: Meat production at Stabroek farm restricted after PFAS discovery. Available at: <https://www.lalibre.be/planete/sante/2024/05/02/pollution-aux-pfas-la-production-de-viande-dune-ferme-de-stabroek-restreinte-apres-la-decouverte-de-pfas-2RGJKA4KFREWZETY2LGPDYZWCE/>

¹³⁵ https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Aquaculture_statistics#Highlights

¹³⁶ DG MARE, EUMOFA (2024) The EU fish market. Available at: <https://op.europa.eu/en/publication-detail/-/publication/22f27511-b382-11ef-acb1-01aa75ed71a1>

¹³⁷ <https://cfpub.epa.gov/ecotox/search.cfm>

Monitoring studies indicate that these limits are exceeded in some fish in the EU.¹³⁸

- Overall, ecosystem service losses through damages to fish and aquaculture stocks could be having a significant cost to society through impacts on the multi-billion Euro fishing industry.

3.4.6. Considerations of future costs

Future decisions could change the use, emissions, remediation / clean-up, and environmental exposure patterns of PFAS (explored in Task 3), which could have consequences for the future ecosystem service costs of PFAS. For example:

- In scenarios 1 and 2, where environmental exposure is expected to increase, the costs of PFAS pollution, in terms of ecosystem services, are also expected to increase over time.
- In scenarios 3 and 4, ecosystem service losses over time are not expected to be as severe. Costs are expected to continue, and potentially increase, for some time, but in the long-term, costs may gradually decrease as PFAS exposure decreases. It is not possible within the scope of this study to predict specific magnitudes or timescales for these trends because of the limited understanding of the ecosystem service costs.

The potential increase in costs, even with decreasing environmental exposure, is noted because bioaccumulation and biomagnification may lead to continued increasing internal exposure and effects in organisms. Similar problems have been observed with other persistent organic pollutants banned decades ago which are still present in the environment, e.g. polychlorinated biphenyls (PCBs) in whales.¹³⁹ Effects may also be prolonged for organisms with longer life spans, e.g. where exposure to a foetus can lead to effects through the foetus' lifespan, and potentially effects on the eventual offspring of the foetus.¹⁴⁰ Of the

¹³⁸ Rüdél et al. (2022) Tissue concentrations of per- and polyfluoroalkyl substances (PFAS) in German freshwater fish: Derivation of fillet-to-whole fish conversion factors and assessment of potential risks. Available at: <https://doi.org/10.1016/j.chemosphere.2021.133483> ; Langberg et al. (2024) Human exposure to per- and polyfluoroalkyl substances (PFAS) via the consumption of fish leads to exceedance of safety thresholds. Available at: <https://doi.org/10.1016/j.envint.2024.108844> ; Teunen et al. (2021) PFAS accumulation in indigenous and translocated aquatic organisms from Belgium, with translation to human and ecological health risk. Available at: <https://link.springer.com/article/10.1186/s12302-021-00477-z>

¹³⁹ Megson et al. (2022) Polychlorinated biphenyl (PCB) concentrations and profiles in marine mammals from the North Atlantic Ocean. Available at: <https://www.sciencedirect.com/science/article/pii/S004565352103111>

¹⁴⁰ Haimburgh et al. (2022) Multi- and Transgenerational Effects of Developmental Exposure to Environmental Levels of PFAS and PFAS Mixture in Zebrafish (*Danio rerio*). Available at: <https://pmc.ncbi.nlm.nih.gov/articles/PMC9228135/>

ecosystem services mentioned in this report, this could be most relevant to food provisioning related to livestock farming.

Climate change may also influence the future costs of PFAS to society (in all scenarios). Climate change can change the sensitivity of organisms to the toxic effects of PFAS.¹⁴¹ This could lead to increased or decreased toxicity to different species, although more research is needed to better understand the expected changes in toxicity and impacts. Melting permafrost (as a result of climate change) can also release PFAS, enabling it to mobilise in the environment, potentially increasing the societal costs of PFAS.¹⁴² Climate change may also change the societal value of ecosystem services, e.g. climate regulation and food provisioning may become more valuable, which could increase the costs of PFAS pollution in terms of losses to these services.

¹⁴¹ Chung et al. (2024) Effects of Temperature and Salinity on Perfluorooctane Sulfonate (PFOS) Toxicity in Larval Estuarine Organisms. Available at: <https://pmc.ncbi.nlm.nih.gov/articles/PMC11053673/> ; Alum (2025) The role of toxicology in climate change: Understanding the risks of novel environmental toxins. Available at: <https://www.tandfonline.com/doi/full/10.1080/27658511.2025.2467485#abstract>

¹⁴² Mahmoudnia et al. (2022) Change in global PFAS cycling as a response of permafrost degradation to climate change. Available at: <https://www.sciencedirect.com/science/article/pii/S2772416621000383>

4. Conclusions

Three main types of societal costs have been identified and assessed in this study: (i) costs associated with the human health impacts of PFAS pollution from 4 already regulated PFAS (PFOA, PFOS, PFHxS and PFNA) for which scientific literature on health impacts is sufficiently developed, (ii) costs associated with the remediation and treatment of soil and water to remove PFAS pollution, and (iii) potential pathways for costs associated with the losses of ecosystem services due to PFAS pollution (simply referred to as 'ecosystem service costs' in the following). An overview of the results across all three cost types for each scenario is shown in [Table 46](#), which presents discounted annual costs in 2024, 2030, 2040 and 2050, as well as the present value over the whole assessment period. The ecosystem service costs could not be quantified or monetised, but the case studies in this report have shown that PFAS may affect ecosystem services contributing billions of Euros to the EEA economy, and [Table 46](#) summarises the likely relative trend of ecosystem service costs across scenarios qualitatively.

Key conclusions are outlined below for each scenario.

4.1. Scenario 1 (Business as usual)

Although limited to the impacts of 4 types of PFAS, only, health costs dominate the quantified costs in this scenario. The exposure modelling in Task 3 predicted an increase in emissions of PFAS overall, while PFOA, PFOS and PFHxS emissions will decline under this scenario¹⁴³. Human health costs from PFOA, PFOS, PFHxS and PFNA pollution are estimated at €39.5 [0.005-600.5] billion/year in 2024, reaching €29.5 [0.004-426.0] billion in 2050¹⁴⁴, due to the estimated decline in blood serum concentrations of legacy PFAS (PFOA, PFOS, PFHxS). However, the increasing blood serum levels of 'other PFAS' types that are not yet sufficiently studied in the scientific literature and could not be quantified, are likely to result in an increase in the combined disease burden from all PFAS pollution between 2025-2050. In more detail:

¹⁴³ As discussed in Section 2.4.2.3, concentrations for PFOA, PFOS, PFHxS and PFNA are projected based on past time-series data. Despite a 2023 REACH restriction, PFNA blood serum levels continue to rise through 2024, likely due to ongoing exposure from existing stockpiles and PFNA's slow elimination rate.

¹⁴⁴ As a reminder: Square brackets indicate the potential range of values, taking into account the estimates from the sensitivity analysis. For example, "€39.5 [0.005-600.5] billion" indicates a medium estimate of €39.5 billion, a low sensitivity estimate of €0.005 billion, and a high sensitivity estimate of €600.5 billion.

- Relatively high proportions of disease burden are attributable to PFOA, PFOS, PFHxS and PFNA exposure impacts through osteoporosis, high blood pressure, and CKD.
- Non-market disease burden accounts for the majority of the estimated human health costs, followed by productivity costs and healthcare costs.
- The 'background' cohort and/or the population group 'adults (20+ years) general population' accounts for the majority of human health costs from PFOA, PFOS, PFHxS and PFNA exposure.
- Human health costs per person, from PFOA, PFOS, PFHxS and PFNA exposure, are especially high for 'newborns (0 years)', 'children (1-4 years)', 'people (15+ years) residing near contaminated sites', and 'exposed workers'.

Remediation costs and miscellaneous costs of PFAS pollution (all PFAS) add another €3.8[0.002-24.2] billion/year in 2024. The exposure modelling in Task 3 predicted an increase in the number of contaminated sites that require remediation, leading to an increase in the estimated remediation costs to €4.7 [0.003-29.9] billion/year in 2050. It is assumed that no significant drinking water or wastewater treatment is occurring specifically to remove PFAS in scenario 1.

Ecosystem service costs could not be quantified, but they could be significant and would be expected to increase in this scenario, at least partially offsetting the decrease in health costs.

The total present value of quantifiable costs over the assessment period is estimated at around €440 billion in scenario 1 (with human health costs limited to PFOA, PFOS, PFHxS and PFNA only).

4.2. Scenario 2 (Drinking Water Directive)

Estimated health costs are comparable to scenario 1, despite the reduction in PFAS concentrations in drinking water. This is because drinking water only accounts for a small fraction of human exposure, and therefore the exposure modelling from Task 3 predicts virtually identical blood serum concentrations of PFAS in scenarios 1 and 2. Human health costs from PFOA, PFOS, PFHxS and PFNA pollution are estimated to decline from €39.5 [0.005-600.5] billion/year in 2024 to €29.5 [0.004-426.0] billion in 2050, due to the estimated decline in blood serum concentrations of legacy PFAS (PFOA, PFOS, PFHxS). Similar to scenario 1, the increasing blood serum levels of 'other PFAS' types that are not yet sufficiently studied in the scientific literature and could not be quantified, are likely to result in an increase in the combined disease burden from all PFAS pollution between 2025-2050.

Costs for soil remediation and removal of PFAAs from drinking water are expected to be relatively small compared to the health costs, contributing €3.8 [0.002-24.2] billion/year in 2024 and increasing to €6.2 [0.3-153.4] billion/year in 2050. This is based on the predictions from the Task 3 exposure modelling that the number of contaminated sites requiring soil remediation increase (equivalent to scenario 1), and that the volumes of drinking water requiring additional treatment due to DWD threshold exceedances increase.

Costs to remove TFA from drinking water have been calculated separately (due to more severe uncertainties associated with TFA). The inclusion of TFA would increase the drinking water treatment costs dramatically. Assuming that Member States apply the Total PFAS threshold of 500 ng/l, additional drinking water treatment costs of around €14-15 billion would be estimated to be incurred in the EEA per year. These much higher costs (compared to PFAAs) reflect that TFA concentrations are already widely observed to exceed the proposed threshold, as well as the assumption that more costly technologies are required to remove TFA.

Ecosystem service costs would be expected to be comparable to scenario 1, since drinking water treatment does not significantly affect PFAS pollution in the environment.

The present value of quantifiable costs over the assessment period is estimated at around €450 billion in scenario 2 (with human health costs limited to PFOA, PFOS, PFHxS and PFNA only), which is slightly higher than in scenario 1. When considering drinking water treatment to remove TFA, the present value of scenario 2 could even be over €200 billion higher than in scenario 1.

4.3. Scenario 3 (Environmental Quality Standards)

Under this scenario, estimated remediation/treatment costs dominate the total quantifiable costs of PFAS pollution. This is largely because of the assumption that additional treatment to remove PFAS will be required for all wastewater in the EEA to achieve compliance with the EQS. Costs for soil remediation and wastewater treatment are estimated to decrease slowly from around €80.2 [21.6-712.9] billion/year in 2024 to €75.4 [19.9-666.9] billion/year in 2050. The decrease reflects a decline in the EEA population, which is assumed to lead to an equivalent decline in the amount of wastewater generated.

The resulting reductions in PFAS concentrations in the environment (and therefore also food and drinking water) has been estimated to result in a sharp reduction in blood serum concentrations of PFAS (overall, and specifically for PFOA, PFOS, PFHxS and PFNA which account for the quantifiable health costs as discussed above) over time, according to Task 3 exposure modelling.

As a result, quantifiable human health costs from PFOA, PFOS, PFHxS and PFNA pollution are estimated to decline from €39.5 [0.005-600.5] billion/year in 2024 to €12.0 [0.001-373.5] billion in 2030. Subsequently, zero health costs are estimated in the medium and low-sensitivity scenarios for 2040 and 2050 given the negligible levels of PFAS in human blood serum¹⁴⁵, although some health impacts are estimated in the high-sensitivity scenario with equivalent monetary costs of €3.5 billion in 2040 and €3 billion in 2050. In addition, blood serum levels of ‘other PFAS’ types that are not yet sufficiently studied in the scientific literature and could not be quantified are likely to result in additional disease burden between 2025-2050. In more detail:

- Relatively high proportions of disease burden are attributable to PFOA, PFOS, PFHxS and PFNA exposure impacts through osteoporosis, high blood pressure, and adult obesity. In 2040 and 2050, these endpoints/health risks account for the entirety of the costs to human health in the high-sensitivity scenario.
- The ‘background’ cohort and/or the population group ‘adults (20+ years) general population’ accounts for the majority of human health costs from PFOA, PFOS, PFHxS and PFNA exposure.
- In 2030, human health costs per person from PFOA, PFOS, PFHxS and PFNA exposure are especially high for ‘newborns (0 years)’, ‘children (1-4 years)’, ‘people (15+ years) residing near contaminated sites’, and ‘exposed workers’. However, from 2040 onwards, the costs are borne entirely by adults in the general population, people (15+ years) residing near contaminated sites, and exposed workers as these groups are affected by osteoporosis, high blood pressure and adult obesity.

The present value of quantifiable costs over the assessment period is estimated at around €1.7 trillion (with human health costs limited to PFOA, PFOS, PFHxS and PFNA only), which is about €1.3 trillion higher than estimates under scenarios 1 and 2, due to the dominant wastewater treatment costs. However, ecosystem service costs, which could not be quantified, would be expected to gradually decrease in this scenario and to be lower than in scenarios 1 and 2, at least partly offsetting the wastewater treatment costs.

¹⁴⁵ As discussed in Sections 2.4 and 3.1, this reflects the assumption of a direct relationship between falling emissions and exposure, as well as half-lives of PFAS in blood serum based on biomonitoring data. Note that in reality, the persistence of PFAS in the environment could lead to continued human exposure even when emissions are eliminated, which has not been considered in the exposure modeling.

4.4. Scenario 4 (Total stop of production and uses of PFAS)

Health costs dominate the quantified costs of PFAS pollution in this scenario. Costs from human exposure to PFOA, PFOS, PFHxS and PFNA are estimated to fall sharply from €39.5 [0.005-600.5] billion/year in 2024 to €0.5 [0-21.5] billion/year in 2040. This is a less steep decline than estimated under scenario 3 due to the assumption in the Task 3 exposure modelling that stockpiles of articles in consumer uses would continue to be used until they reach their end of life, leading to a slightly slower decline in predicted blood serum concentrations. In 2050, the steep decline in exposure towards zero levels of PFAS in human blood translates to no monetary costs. However, the blood serum levels of 'other PFAS' types that are not yet sufficiently studied in the scientific literature (and thus not quantified) are likely to result in additional disease burden between 2025-2040. In more detail:

- Relatively high proportions of disease burden are attributable to PFOA, PFOS, PFHxS and PFNA exposure impacts through high blood pressure, osteoporosis, female infertility, and adult obesity. In 2040, disease burden is attributable to osteoporosis in the medium-sensitivity scenario, or chronic kidney disease, high blood pressure, high LDL cholesterol, osteoporosis and female infertility in the high-sensitivity scenario.
- The 'background' cohort and/or the population group 'adults (20+ years) general population' accounts for the majority of human health costs from PFOA, PFOS, PFHxS and PFNA exposure.
- In 2030, human health costs per person from PFOA, PFOS, PFHxS and PFNA exposure are especially high for 'newborns (0 years)', 'children (1-4 years)', 'people (15+ years) residing near contaminated sites', and 'exposed workers'. However, from 2040 onwards, the costs are borne entirely by adults in the general population, people (15+ years) residing near contaminated sites, and exposed workers as these groups are affected by CKD, high blood pressure, high LDL cholesterol, osteoporosis, and other relevant endpoints or impact pathways.

Similarly to scenario 1, the remediation costs would still be relatively small compared to the health costs (around €3.8 [0.002-24.2] billion/year throughout the assessment period) and no significant drinking water or wastewater treatment specifically to remove PFAS has been assumed.

Similarly to scenario 3, ecosystem service costs, would be expected to gradually decrease in this scenario and to be lower than in scenarios 1 and 2.

In conclusion, out of the four assessed scenarios, scenario 4 would be expected to be the scenario associated with the lowest societal costs of PFAS pollution

by far. **The present value of quantifiable costs over the assessment period is estimated at around €330 billion in scenario 4 (with human health costs limited to PFOA, PFOS, PFHxS and PFNA only), which is about €110 billion lower than the present value for scenario 1.**

4.5. Scenario comparison

The table below presents a high-level comparison of the estimated costs of PFAS pollution.

Table 46 – Comparison of estimated health costs, remediation/treatment costs and ecosystem service costs of PFAS pollution in the EEA by scenario, undiscounted costs per year and present values over the whole assessment period (medium estimate and [low-high] sensitivities, in 2024 euros)

Scenario	Health costs from human exposure to PFOA, PFOS, PFHxS and PFNA	Soil remediation / water treatment costs	Potential costs associated with the losses of ecosystem services
Scenario 1: Business as usual	Undiscounted annual values: 2024: €39.5 [0.005-600.5] bn 2030: €29.5 [0.005-529.5] bn 2040: €27.0 [0.004-456.5] bn 2050: €29.5 [0.004-426.0] bn Present value over assessment period: €360 [0.052-5,750] bn	Undiscounted annual values: 2024: €3.8 [0.002-24.2] bn 2030: €3.9 [0.002-25.1] bn 2040: €4.3 [0.003-27.0] bn 2050: €4.7 [0.003-29.9] bn Present value over assessment period: €78.3 bn	↗ Potentially significant and increasing impact (not quantifiable) on ecosystem services that contribute € billions to the EEA economy.
Scenario 2: Drinking Water Directive (DWD)	Undiscounted annual values: 2024: €39.5 [0.005-600.5] bn 2030: €29.5 [0.005-529.5] bn 2040: €27.0 [0.004-456.5] bn 2050: €29.5 [0.004-426.0] bn Present value over assessment period: €360 [0.051-5,750] bn (Comparable to Scenario 1, since drinking water only accounts for a small fraction of human exposure)	Undiscounted annual values: 2024: €3.8 [0.002-24.2] bn (€20.0 [2.2-817.3] bn with TFA) 2030: €4.2 [0.07-47.6] bn (€19.8 [2.2-804.1] bn with TFA) 2040: €4.5 [0.07-50.6] bn (€19.7 [2.1-782.9] bn with TFA) 2050: €6.2 [0.3-153.4] bn (€19.7 [2.1-763.5] bn with TFA) Present value over assessment period: €85.8 bn (€297.5 bn with TFA)	↗ Comparable to scenario 1.

Scenario	Health costs from human exposure to PFOA, PFOS, PFHxS and PFNA	Soil remediation / water treatment costs	Potential costs associated with the losses of ecosystem services
Scenario 3: Environmental Quality Standards (EQS)	Undiscounted annual values: 2024: €39.5 [0.005-600.5] bn 2030: €12.0 [0.001-373.5] bn 2040: €0.0 [0.0-3.5] bn 2050: €0.0 [0.0-3.2] bn Present value over assessment period: €240 [0.03-4,350] bn	Undiscounted annual values: 2024: €80.2 [21.6-712.9] bn 2030: €79.0 [21.2-701.5] bn 2040: €77.1 [20.5-683.4] bn 2050: €75.4 [19.9-666.9] bn Present value over assessment period: €1,480 bn	 Potentially significant impact (not quantifiable) on ecosystem services will continue for some time due to persistence, bioaccumulation and biomagnification of PFAS. Gradual decrease of impacts (not quantifiable) in the long term due to eventual degradation, dispersion to lower concentrations, and remediation/treatment.
Scenario 4: Total stop of production and uses of PFAS	Undiscounted annual values: 2024: €39.5 [0.005-600.5] bn 2030: €17.0 [0.002-412.5] bn 2040: €0.5 [0.0-21.5] bn 2050: €0.0 bn Present value over assessment period: €260 [0.033-4,500] bn	Undiscounted annual values: 2024: €3.8 [0.002-24.2] bn 2030: €3.8 [0.002-24.4] bn 2040: €3.8 [0.002-24.4] bn 2050: €3.8 [0.002-24.4] bn Present value over assessment period: €72.8 bn	 Comparable to scenario 3.

Note: The sensitivities for human health costs and remediation/treatment costs are based on the sensitivity scenarios defined in Section 2.5 and Annex D (Sections 3.1.7 and 5.1.4). For example, not all endpoints are included in the low and medium estimates for health costs. Please refer to Annex D Section 3.1.7 for the endpoints which are included in the medium, low and high sensitivities.

In summary, scenario 4 is expected to have the lowest societal costs of PFAS pollution, out of the four assessed scenarios. This is primarily because the stop of production and use of PFAS would reduce emissions, leading to a gradual decline in health costs (with a lag due to the persistence of PFAS in human blood serum), even when assessing the health costs of only 4 PFAS. Under this scenario, soil remediation costs would no longer increase either (assumed to remain constant over the assessment period due to the persistence of PFAS in soil) and no additional water treatment costs are expected. Ecosystem service costs (not quantified) would also fall gradually in scenario 4.

In the medium-sensitivity scenario, the highest quantifiable costs are estimated for scenario 3 due very high wastewater treatment costs that are expected to be required to comply with EQS thresholds. However, the scenario does lead to gradually declining human health costs (with a lag due to the persistence of PFAS in human blood serum), and gradually declining ecosystem service costs (not quantified).

Scenarios 1 and 2 are expected to lead to relatively similar societal costs, in between scenarios 4 and 3. In both scenarios 1 and 2, costs for remediation/treatment and ecosystem service losses are expected to increase over the assessment period due to increasing PFAS emissions, while human health costs are estimated to fall slightly between 2024 and 2050 due to the estimated decline in blood serum concentrations of legacy PFAS (PFOA, PFOS, PFHxS).

4.6. Gaps/limitations and areas for further work

Note that these conclusions should be interpreted with care, considering the uncertainties and limitations noted throughout this report, and summarised in Section 2.6. In particular, we would like to highlight the following gaps as areas for work to further improve our understanding of the societal costs of PFAS pollution:

- Additional evidence of PFAS levels in blood serum for specific populations and additional PFAS substances, as well as projections of these concentrations into the future, to refine the exposure estimated in the present study.
- Stronger evidence on the links between PFAS exposure and health risks for a wider range of PFAS substances and end-points, as well as mixture/cumulative effects, to potentially complement the health costs that could be quantified in the present study.
- Additional evidence on the number of contaminated sites and especially on the extent of soil remediation and water treatment that would be

required at each site, to refine the remediation/treatment costs estimated in the present study.

- Evidence on the effects of PFAS pollution on ecosystems, and consequently ecosystem services, under real-world conditions, to allow for the quantification of potential ecosystem service losses.

It should also be noted that the present study uses June 2024 as the regulatory position for the business as usual scenario, and does not consider the REACH restrictions on PFHxA and on all PFAS used in fire-fighting foams. The assessment is also based on projected emissions taken from the universal PFAS restriction Background Document published in 2023. The updated version of the Background Document published in August 2025 contained lower absolute values of projected PFAS emissions, but with a sharper increase over time. The combination of these two limitations (emissions without latest restrictions and data from 2023 version of the universal PFAS restriction proposal Background Document) could to some extent mitigate each other and are considered anyhow within the acceptable range of uncertainty of the study.

Annex A – Task 1 report (initial data gathering)

Contents

1. Introduction	2
1.1. This report	2
1.2. Project context.....	2
2. Method overview	2
2.1. Literature review	2
2.2. Interviews.....	3
2.3. PFAS definitions and scope for this study	4
2.4. Limitations.....	9
3. Findings	9
3.1. Human health costs (Q1)	9
3.1.1. Q1.1 To what extent are humans exposed to PFAS in the EU?	10
3.1.2. Q1.2 What PFAS exposure is associated with human health risks?	21
3.1.3. Q1.3 What are the observed risk relationships and/or predicted human health impacts from those risks?	36
3.1.4. Q1.4 What are the costs associated with the human health impacts?	51
3.1.5. Q1.5 What are the geographical and temporal trends in human health costs?	57
3.2. Environmental costs (Q2).....	61
3.2.1. Q2.1 To what extent are environmental compartments (soil, water, air, and biota) contaminated with PFAS in the EU?	61
3.2.2. Q2.2 What are the environmental effects on aquatic and terrestrial species and populations?.....	72
3.2.3. Q2.3 What are the ecosystem-level effects? / Q2.4 What are the effects on biodiversity?..	79
3.2.4. Q2.5 What are the monetised ecosystem service costs associated with impacts on species, ecosystems and biodiversity?	81
3.2.5. Q2.6 What are the environmental clean-up costs (soil and water remediation/treatment costs) and litigation costs?.....	84
3.2.6. Q2.7 What are the geographical and temporal trends in environmental costs?	86
3.3. Overall societal costs from PFAS (Q3).....	87
3.3.1. Q3.1 What are the methods to calculate societal costs from PFAS pollution?	87
3.3.2. Q3.2 What are the direct and indirect, market and non-market, one-off and recurring costs of PFAS pollution?	89
3.4. Gaps and uncertainties.....	93
3.5. Conclusions and next steps.....	93
Appendices to Annex A.....	95
A. Literature review screening and analysis Excel file	95
B. Additional tables of evidence against research question 2	117

1. Introduction

1.1. This report

WSP and Ricardo are supporting DG ENV with a **study on the cost of PFAS pollution for our society**¹ under framework contract ENV.01/FRA/2023/0006 *Economic analysis of environmental policies and analytical support in the context of Better Regulation* led by Trinomics B.V.

This is the **'Task 1 Report'**, which provides an interim project deliverable summarizing the outputs of the literature review and interviews conducted to date (see also description of Task 1 in the project context below).

1.2. Project context

The objective of this study is to complement and update the existing sources of information (and in particular the 2019 Nordic Council study²) on the overall external costs of per- and polyfluoroalkyl substances (PFAS) pollution in the EU and in the European Economic Area (EEA). More specifically, the objective of this contract is to present information on all components of the societal costs of PFAS pollution, expressed in monetary terms and based on an up-to-date list of impacts of PFAS on the environment and human health. This assessment will describe not only the cost of current pollution but also the future costs under a limited number of prospective scenarios representing hypothetical future developments, hence showing the current and future costs of inaction compared to hypothetical levels of action.

The project is organised in the following tasks:

- Task 1: Literature review of existing studies on the costs of PFAS pollution and identification of possible knowledge gaps
- Task 2: Development of a methodology to update and expand the existing knowledge on societal costs of current and future PFAS pollution in the EU
- Task 3: Development of 4 prospective scenarios representing hypothetical PFAS future pollution levels in EU
- Task 4: Assessment of the societal costs of current and future PFAS pollution (up to 2050, under hypothetical future scenarios)

2. Method overview

2.1. Literature review

A targeted literature review has been conducted against three high-level research questions on 1) the human health costs of PFAS, 2) the environmental costs of PFAS, and 3) the overall societal cost of PFAS, comprising 14 sub-questions (shown as sub-headings in Section 3). The following steps were followed:

- Step 1 – A list of 82 relevant literature sources were reviewed in-depth, with a focus on recent publications after 2019, including meta-analyses, secondary sources provided by the

¹ Specific Contract No 090202/2024/924706/ENV.B2

² Goldenman et al. (2019). *The cost of inaction: A socioeconomic analysis of environmental and health impacts linked to exposure to PFAS*. Available at: [THE COST OF INACTION](#)

European Commission during project inception and/or the outputs of an initial review of the literature.

- Step 2 – These literature sources were prioritised for information extraction based on an evaluation of geographic and thematic relevance, robustness and limitations, and gaps were identified to help further targeting any additional searches.
- Step 3 – Additional targeted searches were undertaken to identify relevant literature that could address the gaps identified in the evidence base answering each research question. Searches used specific terms and strings (combinations of key words) applied to common search engines (Google, Google Scholar). Sources deemed potentially relevant based on their titles and abstracts were prioritised and reviewed in-depth for information extraction based on a similar evaluation conducted for the 82 ‘known’ sources in Step 1.
- Step 4 – All the information extracted was triangulated against each research question and sub-question and findings were developed.

Searches and evaluations are documented in an MS Excel document, which has been added to Appendix A to Annex A. The findings and information extracted from this literature review are summarised in Section 3, and sources are documented in the footnotes.

2.2. Interviews

Eight semi-structured interviews were conducted to validate the findings from the literature review and address any gaps. Stakeholders contacted for interviews were agreed with the Commission but it was also pointed that more should be interviewed in a next stage. These stakeholders comprised experts and authors of key sources, and representatives of relevant research and Non-Governmental Organisations. Experts from the following organisations and projects were interviewed as part of this Task 1:

- Dutch National Institute for Public Health and the Environment (RIVM)
- European Environmental Bureau (EEB)
- International Chemical Secretariat (ChemSec)
- German UBA
- VITO
- Organisation for Economic Co-operation and Development (OECD)
- US Environmental Protection Agency
- Global PFAS Science Panel
- Forever Pollution Project
- ETH Zurich

For each research question, the team drafted questions for stakeholders to provide input on key information sources and gaps. Each stakeholder was provided with a tailored interview guide before the interview, covering the research questions most relevant to their expertise³.

The outputs of these interviews are documented in Section 3. Further interviews are foreseen to support the development of the methodology in Task 2, and/or gather further data to support the execution of the methodology in Task 4.

³ An overview of all research questions was provided to all stakeholders, so that every stakeholder would have the opportunity to provide input to every research question, if they felt they had relevant input to provide.

2.3. PFAS definitions and scope for this study

Per- and poly-fluoroalkyl substances (PFAS) are a large class of synthetic chemicals with diverse structures and properties, broadly defined as substances that contain a carbon-fluorine bond, usually -CF₂- or -CF₃- constituents⁴. The number of substances within this group remains unknown but estimates have increased over the years. In 2015, a KEMI study⁵ reported more than 3,000 PFAS were on the global market for commercial use. An OECD Study⁶ searched for perfluorinated compounds and found 4,730 PFAS in 2018. These earlier estimations were based on the previous OECD definition, which was narrower (excluding fluoropolymers, F-gases and many other structures). Most recently, the 2023 REACH restriction proposal of PFAS suggests there might be as many as 10,000 chemicals in this group⁷ (which includes fluoropolymers and fluorinated gases).

These substances can be categorised in several ways, including by chemical structure and functional groups, carbon chain length, regulatory status, and others; which we have considered to determine the chemical scope, in discussions with the European Commission.

PFAS by chemical structure and functional groups

The study has structured our review of substances into three major groups, comprising perfluoroalkyl acids, polymeric PFAS (including fluoropolymers) and fluorinated greenhouse gases. It is acknowledged that this does not necessarily provide completeness, but it captures a wide range of diverse and relevant PFAS for this study. In more detail^{8,9}:

- **Per- or Poly- fluoroalkyl Acids (PFAAs) and precursors to PFAAs** are a main subgroup of PFAS, known for their persistence, bioaccumulation, and potential toxicity. PFAAs are typically classified into per- or poly- fluorocarboxylic acids (PFCAs) and per- or poly- fluorosulfonic acids (PFSAs). Within this subgroup: perfluoroalkyl, or fully fluorinated, substances containing only carbon-fluorine bonds, tend to be chemically stable, persistent and resistant to degradation; whereas polyfluoroalkyl, or partially fluorinated substances, contain at least one non-fluorinated carbon, which can make them slightly more degradable than perfluoroalkyl substances.
- **Polymeric PFAS** are polymers with fluorinated compounds and include fluoropolymers, side-chain fluorinated polymers and polymeric perfluoropolyethers. Fluoropolymers are polymers containing repeated fluorinated monomer units. Fluoropolymers have fluorine atoms directly attached to their carbon-only backbone. They can be also fully or partially fluorinated, linear or branched. There are two distinct sub-types of fluoropolymers: fluoroplastics and fluoroelastomers, which differ according to their elasticity properties. Fluoropolymers are the most widely used polymeric PFAS. Side-chain fluorinated polymers have a non-fluorinated polymer backbone with fluorinated side chains, and can degrade into PFAAs. Polymeric perfluoropolyethers have a carbon and oxygen polymer backbone with fluorine atoms attached to the carbon atoms.

⁴ *Per- and polyfluoroalkyl substances (PFAS) - ECHA*

⁵ Swedish Chemicals Agency (2015). Occurrence and use of highly fluorinated substances and alternatives: Report from a government assignment. <https://www.kemi.se/en/publications/reports/2015/report-7-15-occurrence-and-use-of-highly-fluorinated-substances-and-alternatives>

⁶ OECD (2018). Toward a new comprehensive global database of per and polyfluoroalkyl substances (PFASs): summary report on updating the OECD 2007 list of per and polyfluoroalkyl substances (PFASs). [https://one.oecd.org/document/ENV/JM/MONO\(2018\)7/en/pdf](https://one.oecd.org/document/ENV/JM/MONO(2018)7/en/pdf)

⁷ ECHA (2023). ECHA publishes PFAS restriction proposal. <https://echa.europa.eu/-/echa-publishes-pfas-restriction-proposal>

⁸ OECD (2021). Reconciling Terminology of the Universe of Per- and Polyfluoroalkyl Substances: Recommendations and Practical Guidance, OECD Series on Risk Management of Chemicals, OECD Publishing, Paris, <https://doi.org/10.1787/e458e796-en>.

⁹ Environment Agency (2021). Poly- and perfluoroalkyl substances (PFAS): sources, pathways and environmental data. Available at: https://assets.publishing.service.gov.uk/media/611e31fbd3bf7f63b19cea2d/Poly_-and_perfluoroalkyl_substances_-_sources_pathways_and_environmental_data_-_report.pdf

- **Fluorinated gases**, or F-gases, comprise hydrofluorocarbons (HFCs, equating to approximately 90% of all F-gases), perfluorocarbons, sulfur hexafluoride (SF₆) and nitrogen trifluoride (NF₃).¹⁰ Further information on lists of substances in each F-gas group can be found in the Annexes of Regulation (EU) 2024/573 on fluorinated greenhouse gases.¹¹

PFAS by chain length

PFAS, especially the PFAAs or acids, can also be classified based on the length of their carbon chain. There does not appear to be a single (or regulatory) definition of what constitutes long versus short chain PFAS. This report adopts an approach based on a review of several reports^{12,13}, as follows:

- **Ultra short chain**, refers to carbon chain lengths <4 (e.g., trifluoroacetic acid, TFA)
- **Short chain**, refers to carbon chain lengths of ≤6 (PFCAs) or ≤5 (PFSAAs) (e.g., perfluorohexanoic acid, PFHxA)
- **Long chain**, refers to carbon chain lengths ≥7 (PFCAs) or ≥6 (PFSAAs) (e.g., perfluorooctanoic acid, PFOA).

PFAS by regulatory status

The literature and policy discussions also refer to 'legacy' and 'non-legacy' PFAS.

- 'Legacy' PFAS are those that have been regulated and/or phased out of production yet are regularly still detected in human and environmental monitoring campaigns due to their persistence.¹⁴
- Non-legacy PFAS, or emerging PFAS, refers to the broader remit of substances that have not been phased out, or have been used as replacements for legacy PFAS.

There is no universally defined list of the chemicals that constitute 'legacy'. For the purpose of this report and owing to the breadth of data available in the literature, four PFAAs are referred to as legacy substances throughout: PFOA (perfluorooctanoic acid), PFOS (perfluorooctanesulfonic acid), PFNA (perfluorononanoic acid), and PFHxS (perfluorohexanesulfonic acid). All other PFAS are considered as 'non-legacy'.

Please note that according to the grouping of PFAS by chain length, all legacy PFAS also are categorised as 'long-chain' PFAAs.

Scope for this Study

This study cannot cover the available evidence across all of these substances completely. As noted above, the study has focussed on a selection of PFAS across three main subgroups: PFAA and precursors of PFAAs, polymeric PFAS (especially fluoropolymers) and F-gases, including some of the 'most common' substances (i.e., PFOA, PFOS, PFHxS, TFA and the fluoropolymers PTFE, PVDF), as iterated and agreed with the European Commission.

¹⁰ DG CLIMA. FAQ - Fluorinated Greenhouse Gases - Climate Action. Available at: https://climate.ec.europa.eu/eu-action/fluorinated-greenhouse-gases/faq_en

¹¹ Regulation (EU) 2024/573 of the European Parliament and of the Council of 7 February 2024 on fluorinated greenhouse gases, amending Directive (EU) 2019/1937 and repealing Regulation (EU) No 517/2014. Available at: https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=OJ:L_202400573

¹² ITRC (X). Naming conventions for per- and polyfluoroalkyl substances. Available at: https://pfas-dev.itrcweb.org/wp-content/uploads/2020/10/naming_conventions_508_2020Aug_Final.pdf

¹³ Brase RA, Mullin EJ, Spink DC (2021). Legacy and Emerging Per- and Polyfluoroalkyl Substances: Analytical Techniques, Environmental Fate, and Health Effects. *Int J Mol Sci.* 2021 Jan 20;22(3):995. doi: 10.3390/ijms22030995. PMID: 33498193; PMCID: PMC7863963. Available at: <https://pmc.ncbi.nlm.nih.gov/articles/PMC7863963/>

¹⁴ Brase RA, Mullin EJ, Spink DC (2021).

The Table below lists a selection of per- and poly-fluoroalkyl substances most found in the literature review on human exposure, health risks, risk-relationships, costs and trends of PFAS pollution in the EU, which were subsequently included in the final scope of the investigation against research question 1 (human health costs).

Table 2-1: PFAS in scope of the investigation of human health costs of PFAS pollution as part of this study

Type	Substance acronym	Substance	Number of carbons	Chain length	Legacy
PFAAs	TFA	Trifluoroacetic acid	2	Ultra short	No
	PFBS	Perfluorobutanesulfonic acid	4	Short	No
	PFPeA	Perfluoropentanoic acid	5	Short	No
	PFHxA	Perfluorohexanoic acid	6	Short	No
	PFHxS	Perfluorohexanesulfonic acid	6	Short	Yes
	PFHpA	Perfluoroheptanoic acid	7	Long	No
	PFHpS	Perfluoroheptanesulfonic acid	7	Long	No
	PFOA	Perfluorooctanoic acid	8	Long	Yes
	PFOS	Perfluorooctanesulfonic acid	8	Long	Yes
	PFNA	Perfluorononanoic acid	9	Long	Yes
	PFDA	Perfluorodecanoic acid	10	Long	No
	PFDS	Decane-1-sulfonic acid	10	Long	No
	PFUnDA	Perfluoroundecanoic acid	11	Long	No
	PFDoDA	Perfluorododecanoic acid	12	Long	No
	PFTTrDA	Perfluorotridecanoic acid	13	Long	No
	PFTeDA	Perfluorotetradecanoic acid	14	Long	No
Precursors to PFAA	PFHxPA	Perfluorohexylphosphonate	6	Long	No
	FOSA	Perfluorooctanesulfonamide	8	Long	No
	6:2 DiPAP	6:2 Polyfluoroalkylphosphate diester	8	Long	No

Type	Substance acronym	Substance	Number of carbons	Chain length	Legacy
F-gases	SF6	Sulfur hexafluoride	N/A	N/A	No
	HFC143a	1,1,1-Trifluoroethane	2	Ultra short	No
	HFC 134a	1,1,1,2-Tetrafluoroethane	2	Ultra short	No
	HFC245fa	1,1,1,3,3-Pentafluoropropane	3	Ultra short	No
	HFC152a	1,1-Difluoroethane	2	Ultra short	No
	HFC125a	Pentafluoroethane	2	Ultra short	No
	Halothane	2-Bromo-2-chloro-1,1,1-trifluoroethane	2	Ultra short	No
	HCFC123	1,1-Dichloro-2,2,2-trifluoroethane	2	Ultra short	No
	HCFC124	1-Chloro-1,2,2,2-tetrafluoroethane	2	Ultra short	No
	Desflurane	1,2,2,2-Tetrafluoroethyl difluoromethyl ether	2	Ultra short	No
	Isoflurane	2-Chloro-2-(difluoromethoxy)-1,1,1-trifluoro-ethane	2	Ultra short	No
	Sevoflurane	1,1,1,3,3,3-Hexafluoro-2-(fluoromethoxy)propane	3	Ultra short	No
Fluoro-polymers	PTFE	Polytetrafluoroethylene	N/A	N/A	No
	PVDF	Polyvinylidene fluoride	N/A	N/A	No

The investigation of the presence of PFAS across environmental compartments and their environmental effects has primarily focussed on whatever information is available, which does not cover all and could cover different substances to those listed on the table above. While data on many species in the group of PFAAs and precursors to PFAAs was found, our research also found a distinct lack of information on environmental presence and effects of fluoropolymers and F-gases, despite having conducted targeted searches to address this data gap.

Please note that any read-across methods that can be considered in this Study predict or model properties of data-poor PFAS by comparing this to structurally similar and well-studied substances will be explored as part of the study's methodology specification stage (Task 2). Reasonable groupings could include or consider chemical and functional groups, molecular size, environmental behaviour, degradability, and/or uses.

2.4. Limitations

The research questions targeted in this study cover highly complex and emerging areas, with hundreds of relevant new articles published each year, as discussed further in Section 3. This means that a large volume of studies has been generated, and thus it is difficult to review comprehensively all the literature in a short timeframe. This further recognises that within the literature the results can present conflicting findings or variable levels of confidence in their results, and thus must be reviewed thoroughly.

The approach employed in this study has thus been to try and identify review papers and meta-analyses that digest a wider body of literature, as well as the latest most robust sources of information, so to gain an overview of the availability and robustness of the evidence against each of the research questions.

As a result, the findings from this task form a robust evidence base for the development of a methodology (Task 2) to update and expand the existing knowledge on societal costs of current and future PFAS pollution in the EU. During the development of the methodology, additional data needs may emerge, which we will seek to address with targeted searches and research, where possible.

3. Findings

3.1. Human health costs (Q1)

This section sets out the literature review findings against each of the five research questions exploring the human health costs of PFAS pollution.

Please note that the questions and the literature underpinning the answers are highly technical. As a result, the answers are typically structured in two parts: a first part presenting an overview of the concepts and findings, usually coupled with a mapping of the evidence and associated levels of confidence; followed by a second part which extracts key technical evidence that is relevant for the next steps of this study. The latter includes data concerning blood serum levels of PFAS across European populations, quantitative exposure-risk relationships, quantitative health impacts and monetary values of said impacts as present in the literature identified during this review.

3.1.1. Q1.1 To what extent are humans exposed to PFAS in the EU?

Firstly, human exposure refers to “*the amount of, and frequency with which, a substance comes into contact with a person*”.¹⁵ Humans can be exposed to PFAS through various routes and media, which are considered below by population group.

For the **general population**, including adults, teenagers, children, infants, newborns, and pregnant women, the primary routes of PFAS exposure are the ingestion of food products (particularly fish and meat) and drinking of contaminated water. Consumer products containing PFAS, such as waterproof clothing, carpets and some personal care products, can also result in exposures to PFAS through the ingestion of dusts and residues.¹⁶ Newborns and infants can also be exposed through several routes including transfer through the blood/brain barrier, through the placenta, *via* breastfeeding¹⁷, and/or the consumption of powdered milk formula mixed with PFAS-contaminated water. Furthermore, due to their heightened mouthing behaviours, babies and young children may ingest PFAS from PFAS-containing products that they have put in their mouths.¹⁸

For **workers** in industries producing PFAS or PFAS-containing goods, other routes of exposure (compared to the general population) such as contaminated air and/or dermal contact can result in higher levels of exposure and for longer durations. For example, the Australian ‘Expert Health Panel for PFAS’ noted that PFAS blood serum levels can be up to 1000 times greater in occupationally exposed populations (compared to the general population).¹⁹ Firefighters, as an occupational subgroup, may also be exposed to higher levels of PFAS due to their presence in some firefighting foams (aqueous film-forming foams, AFFF) and the way that fire-fighting foam is used (wide and dispersive) making exposure control more challenging than in industrial settings.²⁰

People living near contaminated sites, such as those following industrial spills, have also been shown to have PFAS levels up to a hundred times higher than those living in non-contaminated areas.²¹

Overall, there are a range of exposure sources of PFAS, such as PFAS manufacture, industrial activities, PFAS-containing products, wastewater, and others, which result in PFAS presence in food, water, air, dust and other media, leading to human exposure through inhalation, ingestion and/or dermal contact. These high-level pathways that result in human exposure to PFAS have also been summarised in Figure 3-1 below.²²

¹⁵ American Chemistry Council (2022). What is a chemical exposure? Available at: [What is a Chemical Exposure? - Chemical Safety Facts](#)

¹⁶ ATSDR (2024). How to prevent PFAS exposure. Available at: [How to Prevent PFAS Exposure | PFAS and Your Health | ATSDR](#)

¹⁷ Xie et al., (2024). Per- and polyfluoroalkyl substances (PFAS) exposure in plasma and their blood–brain barrier transmission efficiency–A pilot study, Environment International, 187, 108719. Available at: <https://doi.org/10.1016/j.envint.2024.108719>

¹⁸ ATSDR (2024). How to prevent PFAS exposure. Available at: [How to Prevent PFAS Exposure | PFAS and Your Health | ATSDR](#)

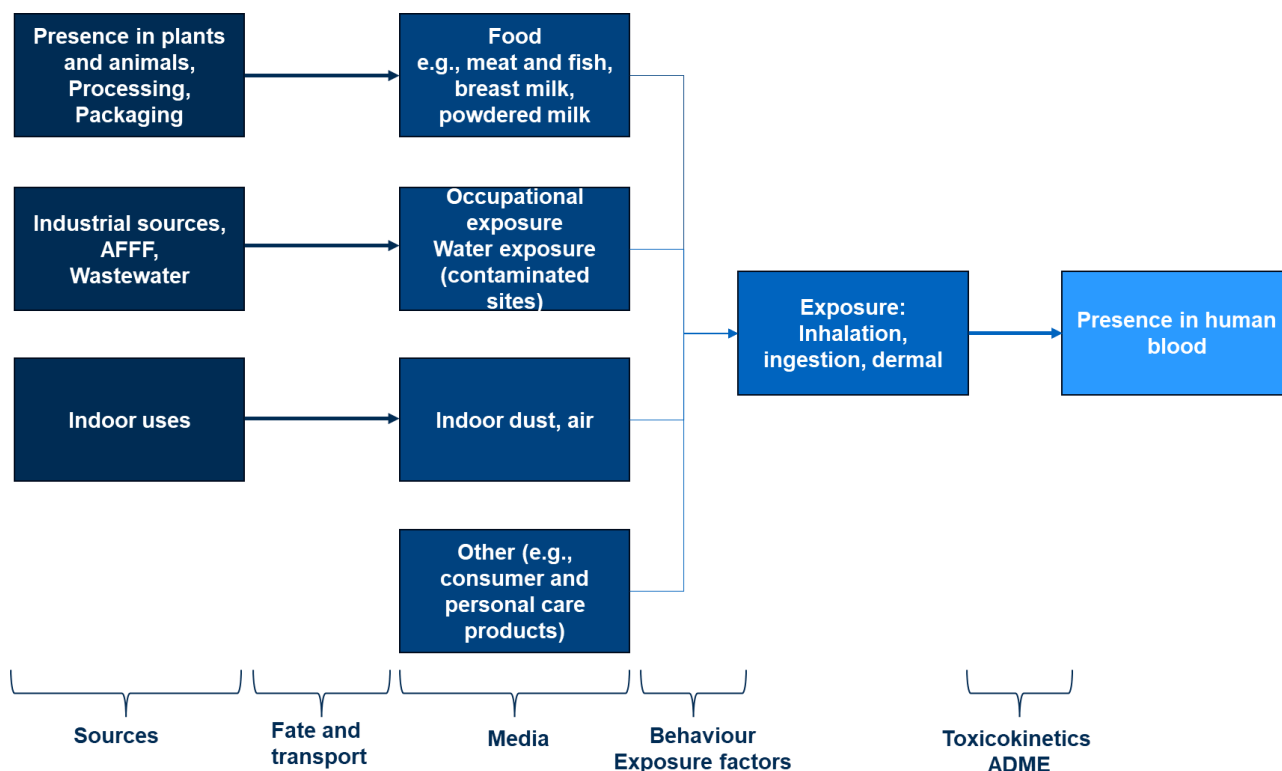
¹⁹ Australia Government Department of Health (2018). Expert Health Panel for Per- and Poly-Fluoroalkyl Substances (PFAS). Available at: [Expert Health Panel on PFAS | Australian Government Department of Health and Aged Care](#)

²⁰ U.S. Environmental Protection Agency (2024). Our Current Understanding of the Human Health and Environmental Risks of PFAS. Available at: [Our Current Understanding of the Human Health and Environmental Risks of PFAS | US EPA](#)

²¹ Zahm et al. (2024). Carcinogenicity of perfluorooctanoic acid and perfluorooctanesulfonic acid, The Lancet Oncology, 25, 16. Available at: [https://www.thelancet.com/journals/lanonc/article/PIIS1470-2045\(23\)00622-8/fulltext](https://www.thelancet.com/journals/lanonc/article/PIIS1470-2045(23)00622-8/fulltext)

²² De Silva et al. (2020). PFAS Exposure Pathways for Humans and Wildlife: A Synthesis of Current Knowledge and Key Gaps in Understanding, Environmental Toxicology and Chemistry, 40, 631. Available at: <https://doi.org/10.1002/etc.4935>

Figure 3-1: Summary of PFAS exposure pathways in humans



Source: Reproduced from De Silva et al. (2020).²³

The literature review has identified that **human biomonitoring data documenting human exposure to PFAS** and other chemicals in the European Union and European Economic Area are available, by population group, with a particular emphasis on four legacy PFAS, that is, PFOA, PFOS, PFNA, PFHxS. This is especially thanks to the European Human Biomonitoring Initiative (HBM4EU). Based on the availability of literature data, the exposure levels presented in this section relate to PFAAs. Additional information was sought relating to other PFAS groups, such as F-gases and fluoropolymers. These are considered separately to the PFAAs.

PFAAs and PFAA Precursors

HBM4EU was funded under the Horizon 2020 programme and involved 30 countries, the European Environment Agency and the European Commission,²⁴ with the aim to document and assess human exposure to chemicals in Europe.²⁵ In particular, PFAS was selected as a priority substance group and, thus, blood serum levels were monitored.²⁶ The initiative took place between 2017 – 2022 but also included data developed outside of these timeframes (e.g., from 2014 onwards). The programme

²³ De Silva et al. (2020). *PFAS Exposure Pathways for Humans and Wildlife: A Synthesis of Current Knowledge and Key Gaps in Understanding*, Environmental Toxicology and Chemistry, 40, 631. Available at: <https://doi.org/10.1002/etc.4935>

²⁴ Vicente et al., (2023). *HBM4EU results support the Chemicals' Strategy for Sustainability and the Zero-Pollution Action Plan*, International Journal of Hygiene and Environmental Health, 248, 114111. Available at: <https://doi.org/10.1016/j.ijheh.2023.114111>

²⁵ UBA (2023). *HBM4EU: European Human Biomonitoring Initiative*. Available at: [HBM4EU: European Human Biomonitoring Initiative | Umweltbundesamt](https://hbm4eu.eu/)

²⁶ Uh et al., (2023). *PFAS: what can we learn from the European Human Biomonitoring Initiative HBM4EU*, International Journal of Hygiene and Environmental Health, 250, 114168. Available at: <https://doi.org/10.1016/j.ijheh.2023.114168>

produced 'aligned and harmonized' biomonitoring studies of PFAS, with additional cohort studies investigated such as mother-child exposure and occupational exposure.²⁷

Regarding PFAS, HBM4EU produced internal exposure reference levels for 12 PFAS across nearly 2,000 teenagers in nine countries.²⁸ The results from this initiative, and any associated publications, offer a key source of evidence. Additional data were also obtained, upon request, from the HBM4EU dashboard *via* Vito, stratified by a) substance, b) age, c) population group, and d) location.

The Table below presents an **overview of the evidence available by population group and substance**. For example, this shows there is evidence of blood serum levels of PFAAs and PFAA precursors for adults in the general population, including for non-legacy substances. The evidence is more limited for other specific population groups.

Table 3-1: Overview of exposure evidence identified or available, by population group and PFAS

Population group	Evidence of blood serum levels of PFAS in the EU-27	Main sources of evidence
Adults – Workers	✓ PFOS, PFOA, PFNA, PFHxS ✓ PFPeA, PFHxA, PFHpA, PFDA, PFUnDA, PFDoDA, PFBS, PFHpS	Uhl et al (2023)*, Rihackova et al (2023), Palesova et al (2023), Andersen et al (2024), Goen et al (2023)
Adults – general population (20 - 65+ years)	✓ PFOA, PFOS, PFNA, PFHxS ✓ PFDA, PFUnDA, PFDoDA, PFTrDA, PFBS, PFHpS, PFDS, PFHxPA, PFOSA, 6:2diPAP	Poothong et al (2020), ETC HE Report (2023), Brede et al (2010), HBM4EU platform data*
Teenagers (13-19 years)	✓ PFOA, PFOS, PFNA, PFHxS	Richterova et al (2023)*, Uhl et al (2023)*, HBM EU platform data*
Children (0-12 years)	✓ PFOA, PFOS, PFNA, PFHxS	DeLuca et al (2022), Balk et al (2019), Papadopoulou et al (2021), Fabelova et al (2023)*
Pregnant women	✓ PFOA, PFOS, PFNA, PFHxS	Fabelova et al (2023)*, ETC HE Report (2023), HBM EU data platform
People living near industrial sites	✓ PFOA, PFOS, PFNA, PFHxS ✓ PFPeA, PFHxA, PFHpA, PFDA, PFUnDA, PFDoDA, PFBS	Brede et al (2010), Pitter et al (2020), Gebbink et al (2020)

* - indicates a publication using HBM4EU data.

The rest of this section collates the results of several human biomonitoring studies conducted in the EU, disaggregated by substance and population group, published between 2019-2024, inclusive of data from the HBM4EU platform. These are summarised in terms of **blood serum level concentrations of individual PFAS (µg/L), presented as an average of median, lower and upper bound from all studies identified**. This is followed by a more in-depth exploration of the evidence concerning specific drivers of exposure across population groups, such as food and water.

²⁷ Uhl et al., (2023). *PFASs: What can we learn from the European Human Biomonitoring Initiative HBM4EU*, International Journal of Hygiene and Environmental Health, 250, 114168. Available at: <https://doi.org/10.1016/j.ijheh.2023.114168>

²⁸ Uhl et al., (2023). *PFASs: What can we learn from the European Human Biomonitoring Initiative HBM4EU*, International Journal of Hygiene and Environmental Health, 250, 114168. Available at: <https://doi.org/10.1016/j.ijheh.2023.114168>

Table 3-2 presents an average of the median, lower and upper levels of PFAS, focussing on PFAAs and PFAA precursors, in blood serum identified in several sources of literature, disaggregated by PFAS type and population group. PFOS is found across all population groups typically in relatively higher blood serum concentrations compared to other PFAS, though there are exceptions. For example, PFOA levels in people living near contaminated sites are higher than PFOS, attributable to specific contamination of the relevant areas.²⁹ Higher blood serum levels of PFOS and PFOA are associated with their widespread industrial and commercial use.³⁰

As is consistent with previous studies, occupational workers and people living near contaminated sites typically have higher levels of PFAS in their blood compared to the general population (all ages and sub-groups). For example, PFOA levels for people living near industrial sites range from 1.45 – 396.48 µg/L (median 19.46 µg/L), compared to levels of 0.40 – 12.01 µg/L (median 1.81 µg/L) in the general population (adults).

The results show that the other legacy PFAS, such as PFNA and PFHxS, are prevalent in similar concentrations across the general population groups (median values are comparable across most population and groups), with the exception of PFHxS concentrations in people living near industrial sites – these values are slightly higher when compared to other population groups, including workers.

Levels of PFAS in general population sub-groups vary. For example, median levels of PFOA, PFOS, PFHxS and PFNA are higher in children (0-12 years) compared to teenagers, possibly attributable to maternal transfer and increased ingestion from consumer products. Adults in the general population typically have higher levels compared to teenagers, children and infants, however pregnant women have higher median PFAS levels for all four legacy PFAS.

²⁹ Brede et al., (2010). Two-year follow-up biomonitoring pilot study of residents' and controls' PFC plasma levels after PFOA reduction in public water system in Arnsberg, Germany, *International Journal of Hygiene and Environmental Health*, 213, 217. Available at: <https://doi.org/10.1016/j.ijheh.2010.03.007>

³⁰ U.S. Environmental Protection Agency (2024). *Our Current Understanding of the Human Health and Environmental Risks of PFAS*. Available at: [Our Current Understanding of the Human Health and Environmental Risks of PFAS | US EPA](#)

Table 3-2: Blood serum levels of PFAAs and PFAA precursors($\mu\text{g/L}$), disaggregated by population group, as an average over the time period 2019-2024

Substance 'group'	Adults – Workers (20-65+)	Adults – general population (20- 65+)	Teenagers – general pop. (13- 19)	Children – general pop. (0-12)	Pregnant women – general pop.	People living near industrial sites
PFOA	2.37 [0.4 - 3.35]	1.81 [0.4 - 12.01]	0.75 [0.2 - 1.29]	2.1 [0 - 14]	2.04 [0.45 - 9.28]	19.46 [1.45 - 396.48]
PFOS	17.43 [0.95 - 831.33]	5.04 [1.27 - 22.78]	1.76 [0.5 - 2.82]	1.64 [0 - 17]	10.54 [2.54 - 34.26]	5.65 [1.65 - 54.35]
PFNA	0.43 [0.18 - 1.55]	0.77 [0.22 - 2.08]	0.33 [0.08 - 0.82]	0.35 [0 - 1.14]	0.56 [0.17 - 1.71]	0.5 [0.5 - 39.7]
PFHxS	0.75 [0.2 - 21.23]	0.68 [0.16 - 2.09]	0.37 [0.12 - 1.07]	0.83 [0 - 16]	0.47 [0.04 - 1.11]	1.91 [0.5 - 36.98]
PFPeA	0.4 [0.4 - 0.5]	-	0.04 [0 - 0.18]	-	-	0.5 [0.5 - 0.5]
PFHxA	0.3 [0.3 - 0.71]	-	0.07 [0.03 - 0.13]	-	-	0.5 [0.5 - 7.1]
PFHpA	0.2 [0.2 - 1.89]	-	0.02 [0 - 0.11]	-	-	0.5 [0.5 - 15.1]
PFDA	0.2 [0.17 - 0.63]	0.3 [0.09 - 0.89]	0.09 [0.01 - 0.35]	-	0.26 [0.15 - 0.5]	0.5 [0.5 - 8.3]
PFUnDA	0.15 [0.15 - 0.16]	0.21 [0.03 - 0.94]	0.02 [0 - 0.22]	-	-	0.5 [0.5 - 6]
PFDoDA	0.2 [0.2 - 0.2]	0.04 [0 - 0.14]	-	-	-	0.5 [0.5 - 4.5]
PFTTrDA	-	0.05 [0 - 0.24]	-	-	-	-
PFBS	0.1 [0.1 - 9.01]	0.02 [0 - 0.11]	-	-	-	0.5 [0.5 - 8.9]
PFHpS	0.23 [0.2 - 28.55]	0.2 [0.06 - 0.63]	0.02 [0 - 0.19]	-	-	-
PFDS	-	0.06 [0 - 0.18]	-	-	-	-
PFHxPA	-	0.18 [0 - 0.43]	-	-	-	-
PFOSA	-	0.03 [0 - 0.05]	-	-	-	-
6:2diPAP	-	0.01 [0 - 0.14]	-	-	-	-

Source: Ricardo analysis drawing on a range of published sources, including HMB4EU and others.

The following sections explore, in more depth, the **key drivers of exposure across different population groups**, primarily in relation to PFAAs and PFAA precursors. Considerations for F-gases and fluoropolymers are provided in subsequent and separate subsections.

Worker exposures

There are several occupations that are more highly exposed to PFAS. For example, in the Nordic Council of Ministers study³¹, occupational workers at chemical production plants (83,627-273,000 people) were considered to have the highest levels of PFAS exposure (particularly PFOS and PFOA) based on findings from previous epidemiological studies such as the C8 Health Project³² or the 3M study.³³ A recent meta-analysis reported median blood serum levels in occupational workers (not exclusive to Europe) for PFOA (113-5,200 µg/L, maximum level 92,030 µg/L), whilst the geometric mean for PFOS serum levels was 941 µg/L (maximum concentration 10,600 µg/L).³⁴

Firefighters are also considered highly exposed to PFAS due to its presence in aqueous film-forming foams. A 2023 Czech study identified that 10.9% and 7.6% of firefighters had PFOS and PFOA blood serum levels, respectively, exceeding threshold levels of 5 µg/L (PFOS) or 2 µg/L (PFOA) as determined in the Study³⁵. The incidence of exceedance for both substances simultaneously was 3.5%. Overall, PFAS levels were found to be linked to age, service length, population size and whether they donated blood (as a route for eliminating PFAS).

Occupational uses of PFOS are still permitted until September 2025 for electroplating, specifically for "*mist suppressants for non-decorative hard Cr(VI) plating in closed loop systems*".³⁶ As part of the HBM4EU initiative, a sub-study on workers known to be exposed to chromates was carried out including workers from Belgium, Finland, France and Italy. The median and maximum levels of PFOS identified in this population were 4.83 and 789 µg/L (chrome plating workers), and 4.97 and 1,513 µg/L for welders, compared to control values of 3.65 and 13.9 µg/L.³⁷

Studies have also identified relatively highly exposed workers in other professions. A historical study examining PFAS blood serum levels from greenhouse workers conducted between 1996-2001 (published in 2024) identified PFOS and PFOA levels 30-50% higher in female workers compared to the general population, once corrected for age and parity (PFOA: 5.69 vs 43 µg/L, PFOS: 42.49 vs 25.88 µg/L). Several PFOS precursors (e.g., N-MeFOSAA, N-EtFOSAA) were also found in higher levels in exposed greenhouse workers following the application of pesticides.³⁸

The recent literature examined in this study aligns with the conclusions of previous studies, such as the 2019 Nordic Council of Ministers study. Occupational workers, especially those working in particular chemical industries, have higher blood serum levels of several PFAS (particularly legacy PFAS such as PFOS and PFOA) compared to the general population. The risks associated with these

³¹ Goldenman et al. (2019). *The cost of inaction: A socioeconomic analysis of environmental and health impacts linked to exposure to PFAS*. Available at: [THE COST OF INACTION](#)

³² Frisbee et al., (2009). *The C8 Health Project: Design, Methods, and Participants*, Environmental Health Perspectives, 117, 1873. Available at: <https://doi.org/10.1289/ehp.0800379>

³³ Andres et al., (2024). *An investigation of 3M Cordova, IL production worker's per- and polyfluoroalkyl substances biomonitoring results and mortality experience*, International Journal of Hygiene and Environmental Health, 256, 114321. Available at: <https://doi.org/10.1016/j.ijheh.2024.114321>

³⁴ Steenland et al., (2021). *PFAS and cancer, a scoping review of the epidemiologic evidence*, Environmental Research, 194, 110690. Available at: <https://doi.org/10.1016/j.envres.2020.110690>

³⁵ Rihackova et al (2023). *The exposure of Czech firefighters to perfluoroalkyl substances and polycyclic aromatic hydrocarbons: CELSPAC – FIREexpo case-control human biomonitoring study*, Science of the Total Environment, 881, 163298. Available at: <https://doi.org/10.1016/j.scitotenv.2023.163298>

³⁶ Göen et al., (2024). *HBM4EU chromates study – PFAS exposure in electroplaters and bystander*, Chemosphere, 346, 140613. Available at: <https://doi.org/10.1016/j.chemosphere.2023.140613>

³⁷ Göen et al., (2024). *HBM4EU chromates study – PFAS exposure in electroplaters and bystander*, Chemosphere, 346, 140613. Available at: <https://doi.org/10.1016/j.chemosphere.2023.140613>

³⁸ Andersen et al., (2024). *Higher serum concentrations of PFAS among pesticide exposed female greenhouse workers*, International Journal of Hygiene and Environmental Health, 255, 114292. Available at: <https://doi.org/10.1016/j.ijheh.2023.114292>

elevated exposures are further explored in Q1.2, whilst the remainder of this section examines PFAS exposure pathways in the general population.

General population

'General population' refers to **adults, teenagers, children and infants** that may be exposed to PFAS through their daily activities. There are four routes of PFAS exposure for these populations: dietary intake, drinking water, and, to a lesser extent, indoor exposures to dust and air, and consumer exposures. Dietary intake is considered the most prevalent pathway of exposure.³⁹

Dietary intake

In 2022, Pasecnaja *et al.* examined the presence of PFAS in food sold on the European market for the following categories: fish and seafood, meat and meat products, dairy products, cereals and cereal-based products, fruits and vegetables, eggs, and fats and oils. Samples were taken from several countries across Europe (Belgium, Czechia, France, Greece, Italy, Norway, Spain, Sweden). The study found that dietary intake of different foods was a major contributor of exposure to legacy PFAS (PFOA, PFOS, PFNA and PFHxS). Seafood, meat and eggs were major sources of PFOS, whilst meat products (in particular offal) and fish contributed to PFOA exposure. High concentrations of PFAS in sampled products was linked to increased dietary intake of PFAS, with Norway shown to have the highest dietary intake for the combined sum of PFOS, PFOA, PFNA and PFHxS (60 ng kg body weight per day ($\text{bw}^{-1} \text{ day}^{-1}$)), followed by Belgium (30 ng kg $\text{bw}^{-1} \text{ day}^{-1}$) and Greece (13 ng kg $\text{bw}^{-1} \text{ day}^{-1}$).⁴⁰

The HBM4EU Initiative explored dietary links further. The results aligned with those of Pasecnaja *et al.* (2022), noting that dietary intake of fish, eggs and offal (as well as drinking water, covered in the following subsection) contributed to increased blood serum levels of PFAS. Higher consumption of fish and seafood (at least twice per week) was associated with statistically significantly increased blood serum levels of PFOS (21%) and PFNA (20%), whilst the consumption of eggs (at least twice per week) led to increases in blood serum content of PFNA (14%) and PFOS (11%). Consumption of offal translated to a 14% increase in PFAS levels in blood serum, whilst locally sourced food (e.g., caught from the ocean, grown on nearby land) equated to a 40% increase in PFAS blood serum levels.⁴¹ The sampling conducted in the HBM4EU initiative and in the Pasecnaja *et al.* (2022) study covered a wide range of European countries and thus the findings are considered representative of the geographic scope of this literature review.

Drinking water

Drinking water can also be a major source of PFAS exposure. In the EU, the European Food Safety Authority (EFSA) set a tolerable weekly intake (TWI) of 4.4 ng/kg for dietary intakes of the combined sum of PFOS, PFOA, PFNA and PFHxS.⁴² A meta-analysis conducted in 2019 by Domingo *et al.* reviewed PFAS levels in drinking water (PFOS and PFOA) in several European countries: France, Germany, Italy, Sweden, and Spain.⁴³ The results generally found that consumption of tap water by the general population does not lead to health risks. However, the study only focuses on levels of PFOS and PFOA, with variations noted between different countries.

³⁹ Domingo *et al.*, (2019). Human exposure to per- and polyfluoroalkyl substances (PFAS) through drinking water: A review of the recent scientific literature, *Environmental Research*, 177, 108648. Available at: <https://doi.org/10.1016/j.envres.2019.108648>

⁴⁰ Pasecnaja *et al.*, (2022). Occurrence of selected per- and polyfluorinated alkyl substances (PFASs) in food available on the European market - A review on levels and human exposure assessment, *Chemosphere*, 287, 132378. Available at: <https://doi.org/10.1016/j.chemosphere.2021.132378>

⁴¹ Richterova *et al.*, (2023). PFAS levels and determinants of variability in exposure in European teenagers – Results from the HBM4EU aligned studies (2014–2021), *International Journal of Hygiene and Environmental Health*, 247, 114057. Available at: <https://doi.org/10.1016/j.ijheh.2022.114057>

⁴² Uhl *et al.*, (2023). PFASs: What can we learn from the European Human Biomonitoring Initiative HBM4EU, *International Journal of Hygiene and Environmental Health*, 250, 114168. Available at: <https://doi.org/10.1016/j.ijheh.2023.114168>

⁴³ Domingo *et al.*, (2019). Human exposure to per- and polyfluoroalkyl substances (PFAS) through drinking water: A review of the recent scientific literature, *Environmental Research*, 177, 108648. Available at: <https://doi.org/10.1016/j.envres.2019.108648>

In contaminated areas, such as those near industrial sites, drinking water is often the primary source of PFAS exposure.⁴⁴ This phenomenon is evidenced in the biomonitoring studies conducted by Brede *et al.* (2010) where residents who were supplied water contaminated with PFOA had blood serum concentrations 4.5-8.3 times higher than (non-exposed) reference groups. One year after the introduction of clean up measures, PFOA blood serum levels had reduced by 10-20%. After two years, PFOA levels had decreased by 39% in women and children and by 26% in men.⁴⁵

House dust and indoor air

House dust and indoor air also contribute to PFAS exposure in humans, although to a lesser extent than dietary intake and drinking water. A study examining multiple pathways of human exposure to PFAS and blood serum levels in Oslo (61 participants, 2020) found that indirect exposures such as through dust and air contributed minimally to total exposure, though noted that these exposures can accumulate and increase over time. Higher blood serum levels of different PFAS across members of a household were correlated with increased intake of house dust, which can be especially the case for household members that spend relatively more time on the floor, such as babies and toddlers. For exposure *via* indoor air, positive associations were identified for intake of 10:2FTOH and blood serum levels of PFUnDA, and similarly between 8:2FTOH and PFNA.⁴⁶ The findings of this study are limited based on geographical and sample size constraints, but the conclusion that house dust and indoor air contribute to total exposures secondary to dietary intake and drinking water is aligned with the wider consensus on how humans are exposed to PFAS.

Consumer goods

The general population are also exposed to PFAS *via* consumer products such as waterproof clothing, carpets and some personal care products.⁴⁷ Humans can be exposed to consumer product based PFAS through indoor air and dusts in the same processes detailed above, but additionally through dermal exposure and/or ingestion, depending on the product. Some PFAS have been identified in food contact materials which may lead to their transfer to food items. Conversely, young children can be exposed to higher levels of PFAS through the consumer pathway as they are more likely to put toys and other items in their mouth (e.g., pica behaviour).⁴⁸

In Europe, high levels of PFAS have been identified in products such as ski waxes (PFOA, up to 2,000 µg/m²), leather (PFBA, up to 200 µg/kg and PFBS up to 120 µg/kg), outdoor textiles (PFOA, up to 19 µg/m²), some baking papers (up to 15 µg/m²), and others.⁴⁹

Pregnant women and newborns

As part of the HBM4EU study on PFAS, Fábelová *et al.* (2023) examined the relationship between PFAS exposures and blood serum levels in pregnant women and newborns (measured *via* cord blood). The study found high detection rates of PFOA, PFOS, PFNA and PFHxS.

Maternal serum concentrations were highest for PFOS, followed by PFOA, PFHxS and PFNA. Higher concentrations of PFAS were associated with higher maternal age, primipara birth and lower educational level, which applies to PFAS levels in both maternal and cord blood. These results are aligned with the current scientific understanding that pregnancy is a route of PFAS elimination from the human body. Other drivers of exposure are aligned with those observed for the general

⁴⁴ De Silva *et al.* (2020). *PFAS Exposure Pathways for Humans and Wildlife: A Synthesis of Current Knowledge and Key Gaps in Understanding*, Environmental Toxicology and Chemistry, 40, 631. Available at: <https://doi.org/10.1002/etc.4935>

⁴⁵ Brede *et al.*, (2010). *Two-year follow-up biomonitoring pilot study of residents' and controls' PFC plasma levels after PFOA reduction in public water system in Arnsberg, Germany*, International Journal of Hygiene and Environmental Health, 213, 217. Available at: <https://doi.org/10.1016/j.ijheh.2010.03.007>

⁴⁶ Poonthong *et al.*, (2020). *Multiple pathways of human exposure to poly- and perfluoroalkyl substances (PFASs): From external exposure to human blood*, Environment International, 134, 105244. Available at: <https://doi.org/10.1016/j.envint.2019.105244>

⁴⁷ ATSDR (2024). *How to prevent PFAS exposure*. Available at: [How to Prevent PFAS Exposure | PFAS and Your Health | ATSDR](https://www.atsdr.cdc.gov/Prevention/How-to-Prevent-PFAS-Exposure/PFAS-and-Your-Health/ATSDR)

⁴⁸ ATSDR (2024). *How to prevent PFAS exposure*. Available at: [How to Prevent PFAS Exposure | PFAS and Your Health | ATSDR](https://www.atsdr.cdc.gov/Prevention/How-to-Prevent-PFAS-Exposure/PFAS-and-Your-Health/ATSDR)

⁴⁹ Kotthoff *et al.*, (2015). *Perfluoroalkyl and polyfluoroalkyl substances in consumer products*, Environmental Science and Pollution Research, 22, 14546. Available at: <https://doi.org/10.1007/s11356-015-4202-7>

population, for example, dietary consumption of fish and meat (in particular offal) also led to increased PFAS serum levels in maternal blood.⁵⁰

In contrast, PFOA was the most prevalent PFAS in cord blood, followed by PFOS, PFNA and PFHxS. Increased levels of PFHxS in cord blood were associated with daily consumption of meat, whilst increased PFNA levels were associated with consumption of offal. Other factors were investigated, and the results suggested that previous breastfeeding (and increased duration of previous breastfeeding) resulted in lower levels of PFAS in cord blood as the PFAS is transferred from the mother to the breastfed child. As with the observation for primipara birth noted in maternal blood, breastfeeding is another primary route of elimination of PFAS from the human body for the mother, with concomitant transfer to the child.⁵¹

People living near contaminated sites

Industrial processes, such as the manufacture of some chemicals and consumer goods, can be associated with relatively higher levels of PFAS in the environment near the site, resulting in higher levels of PFAS exposure for people living nearby. The 2019 Nordic Council study especially highlights contamination near chemical manufacturing sites, as well as manufacturing sites for textile and leather, paper and paper products, metal plating, paints and varnishes, cleaning products, plastics, resins and rubbers, and car washes.⁵²

In the 2019 study conducted for the Nordic Council of Ministers, the authors assumed that 3% (1-5%) of the European population lives near contaminated sites and is exposed to excess levels of PFAS via drinking contaminated water. Annex 1 of that study also highlights where EEA Member States monitor PFAS contamination levels which may pose a risk to human health. As of 2019, the following countries undertook PFAS monitoring activities: Denmark (groundwater monitoring), Sweden (surface water and groundwater monitoring), Finland (surface water, ground water, wastewater and soils and sediments in military sites and use of AFFFs), Belgium (groundwater and soil).⁵³

There are several key studies that report on PFAS levels in populations living near contaminated sites in Europe. In 2013, the Veneto Region (Northwest Italy) was found to be contaminated with high levels of PFAS (particularly PFOA) from a PFAS manufacturing plant. Several studies have been conducted on the local population. In 2020, Pinner *et al.* reported that blood serum PFOA concentrations were higher in exposed populations compared to non-exposed populations (median concentration 44.4 µg/L compared to 1.64 µg/L in non-exposed residents). PFHxS and PFOS were also present at elevated levels, with median concentrations of 3.9 µg/L in both instances.⁵⁴

A retrospective cohort study was also conducted in this region to examine the link between PFAS exposure and 'small for gestational age' (SGA) as an adverse health outcome (see Q1.2 for further information on this endpoint). Maternal PFAS levels in the contaminated region were also found to be higher compared to non-exposed populations (PFOA 13.77 vs 1.64 ng/g; PFOS 8.69 vs 5.84 ng/g), with a concomitant increase in the incidence of SGA (3.44% vs 2.67%).⁵⁵

A study conducted in the Netherlands (Dordrecht) on people living near a fluorochemical production plant (FPP) found similar results. Median blood serum levels for people living within 1 km of the site

⁵⁰ Fábelová *et al.*, (2023). PFAS levels and exposure determinants in sensitive population groups, *Chemosphere*, 313, 137530. Available at: <https://doi.org/10.1016/j.chemosphere.2022.137530>

⁵¹ Fábelová *et al.*, (2023). PFAS levels and exposure determinants in sensitive population groups, *Chemosphere*, 313, 137530. Available at: <https://doi.org/10.1016/j.chemosphere.2022.137530>

⁵² Goldenman *et al.* (2019). *The cost of inaction: A socioeconomic analysis of environmental and health impacts linked to exposure to PFAS*. Available at: [THE COST OF INACTION](#)

⁵³ Goldenman *et al.* (2019). *The cost of inaction: A socioeconomic analysis of environmental and health impacts linked to exposure to PFAS*. Available at: [THE COST OF INACTION](#)

⁵⁴ Pitter *et al.*, (2020). Serum Levels of Perfluoroalkyl Substances (PFAS) in Adolescents and Young Adults Exposed to Contaminated Drinking Water in the Veneto Region, Italy: A Cross-Sectional Study Based on a Health Surveillance Program, *Environmental Health Perspectives*, 128, 027007. Available at: <https://doi.org/10.1289/EHP5337>

⁵⁵ Manea *et al.*, (2020). Exposure to PFAS and small for gestational age new-borns: A birth records' study in Veneto Region (Italy), *Environmental Research*, 184, 109282. Available at: <https://doi.org/10.1016/j.envres.2020.109282>

were 10.2 µg/L (maximum 147 µg/L) compared to 3.4 µg/L when living 2 km from the site. People living 6.5 km from the site were treated as a control group, where median PFOA levels were also 3.4 µg/L.⁵⁶

In Sweden (Ronneby), one third of households were found to be exposed to PFAS in drinking water with concentrations >10 µg/L (noting that the DWD limit for total PFAS is 0.5 µg/l) following contamination from fire-fighting foams used at a nearby airport between 2005 and 2013. A 2021 study found that serum PFHxS (114 µg/L) and PFOS (135 µg/L) were 114 and 135 times higher than a non-exposed control group (Ronneby residents who had never resided in the boundary of contamination), with blood serum PFOA levels (6.8 µg/L) 4.5 times higher than the general population.⁵⁷

In addition, other contaminated sites in Europe are known. such as in Lyon, France, where 'tonnes of PFAS' were reportedly released into the environment over several decades. As of June 2023, local residents were campaigning for longitudinal studies to examine exposure levels and potential human health hazards following their exposures.^{58,59} There are some published studies detailing environmental concentrations, but no reported findings for human biomonitoring as of January 2025.

More broadly, the Forever Pollution project^{60,61} has estimated there might be around 23,000 PFAS-contaminated sites in Europe, of which approximately 2,300 are considered hotspots. That is, sites characterised by relatively high levels of PFAS pollution, which could pose risks to human health and the environment.

Recent publications examining trends in populations living near contaminated sites reveal similar findings as for occupational exposures. Higher blood serum levels of PFAS are consistently observed, with these elevated levels often being statistically significant. The findings from the studies considered in this report align with those of the 2019 Nordic Council of Ministers study, i.e., people living near contaminated sites have elevated blood serum levels of several PFAS compared to the general population.

F-Gases

A literature review of human exposure levels to F-gases was conducted, focussing on hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), sulfur hexafluoride (SF₆) and nitrogen trifluoride (NF₃).

The literature identified in this review primarily concerned HFCs and SF₆. Inhalation exposure was documented as the primary route of F-gas exposure, which occurs primarily following equipment leaks such as from refrigeration systems, recycling systems or other uses.⁶²

There is a paucity of literature relating to human exposure and/or blood serum levels of F-gases. One study investigated the toxicokinetic profiles of several F-gases in an experimental (non-real world) setting. Humans were exposed to vapours of several HFCs (HFC 143a (1,1,1-trifluoroethane), HFC 134a (1,1,1,2-tetrafluoroethane), HFC 245fa (1,1,1,3,3-pentafluoropropane), HFC 152a (1,1-difluoroethane), HFC 125a (pentafluoroethane)) for two hours during light exercise. The study found that blood serum levels were below the detection limit 22 hours post-exposure, which is consistent with findings of other

⁵⁶ Gebbink et al., (2020). *Environmental contamination and human exposure to PFASs near a fluorochemical production plant: Review of historic and current PFOA and GenX contamination in the Netherlands*, Environment International, 137, 105583. Available at: <https://doi.org/10.1016/j.envint.2020.105583>

⁵⁷ Xu et al., (2021). *Serum perfluoroalkyl substances in residents following long-term drinking water contamination from firefighting foam in Ronneby, Sweden*, Environment International, 147, 106333. Available at: <https://doi.org/10.1016/j.envint.2020.106333>

⁵⁸ Le Monde (2023). *Arkema faces criminal charges for forever chemical contamination in Lyon region*. Available at: [Arkema faces criminal charges for forever chemical contamination in Lyon region](https://www.lemonde.fr/arkema-faces-criminal-charges-for-forever-chemical-contamination-in-lyon-region)

⁵⁹ Euro news (2023). *Forever chemicals: French company poisoned environment near Lyon for decades, locals claim*. Available at: [Forever chemicals: French company poisoned environment near Lyon for decades, locals claim | Euronews](https://www.euronews.com/forever-chemicals-french-company-poisoned-environment-near-lyon-for-decades-locals-claim)

⁶⁰ EEA (2024). *PFAS pollution in European waters*. Available at: <https://www.eea.europa.eu/en/analysis/publications/pfas-pollution-in-european-waters>

⁶¹ <https://foreverpollution.eu/>

⁶² Ernstgård et al., (2014). *Blood and exhaled air can be used for biomonitoring of hydrofluorocarbon exposure*, Toxicology Letters, 225, 102. Available at: <https://doi.org/10.1016/j.toxlet.2013.11.026>

toxicokinetic studies.⁶³ This suggests that HFCs are short-lived in the human body and blood serum monitoring is not a reliable indicator of exposure. However, continuous exposure (e.g., in occupational settings or *via* leaks) may lead to some adverse health outcomes, which are outlined in Section 3.1.2. Specific exposure values were not attributed to these outcomes.

In Sweden, there is an 8-hour time weighted occupational exposure limit of 50 ppm (2,000 mg/m³) for HFC 134a to protect workers from exposure and potential health risks.⁶⁴

Fluoropolymers

A review was also conducted on fluoropolymers, focussing on PTFE and PVDF (as set out in Section 2.3). No specific human exposure data was found for fluoropolymers, following both generic and target (substance-by-substance) searches. Some studies report blood serum levels of PFAAs in fluoropolymer production facilities. PFAAs are used in the manufacture of fluoropolymers and, historically, this has been a significant source of PFAA exposure in humans and emissions to the environment.⁶⁵ The findings of these studies, where relevant, have been incorporated into the previous Table 3-2.

Conclusions

People living in the EU are exposed to a broad range of PFAS, with recent (2019-2024) human biomonitoring studies finding these substances in human blood serum. For example, adults in the general EU population might have ~7 [0.1-54.8] µg/L of PFOA in blood serum, ~5 [0.5-32.6] µg/L of PFOS, and much lower concentration levels of PFNA and PFHxS (<1 µg/L) and even lower concentrations of other (non-legacy) PFAS.

People exposed to PFAS in occupational settings, or living near contaminated sites (e.g., drinking contaminated water), or using PFAS-containing products are more likely to have higher blood serum concentrations of PFAS compared to non-exposed members of the general population. These findings align with those of earlier PFAS exposure studies, including the 2019 Nordic Council of Ministers study.

There are a range of routes of exposure. For the general population, the main routes of PFAS exposure include food intake, drinking water, and breathing contaminated indoor air and dust. One study⁶⁶ stated that dietary exposure accounted for 92% of PFAS intake (inclusive of food and drinking water), followed by house dust (4%), indoor air (3%) and dermal absorption (1%).

Interview findings

A PFAS expert from ETH Zurich confirmed that HBM4EU is the most comprehensive source in Europe, to their knowledge. They also highlighted research on certain pollution hotspots (Veneto, Lyon, etc.). As previously noted, the research team has considered pollution hotspots in Europe when reviewing and documenting the exposure levels of people living near contaminated sites, also covered by 2019 Nordic Council Study.

A representative of the Global PFAS Science Panel recommended the use of the U.S. NHANES datasets where necessary as it can be assumed that exposure is similar in the US and Europe, as they considered this a more comprehensive database than the European data (HBM4EU). The study team

⁶³ Gunnare et al., (2006). Toxicokinetics of 1,1,1,2-tetrafluoroethane (HFC-134a) in male volunteers after experimental exposure, Toxicology Letters, 167, 54. Available at : <https://doi.org/10.1016/j.toxlet.2006.08.009>

⁶⁴ Ernstgård et al., (2014). Blood and exhaled air can be used for biomonitoring of hydrofluorocarbon exposure, Toxicology Letters, 225, 102. Available at: <https://doi.org/10.1016/j.toxlet.2013.11.026>

⁶⁵ Dalmijn et al., (2024). Emission inventory of PFASs and other fluorinated organic substances for the fluoropolymer production industry in Europe, Environmental Science: Processes & Impacts, 26, 269. Available at: <https://doi.org/10.1039/D3EM00426K>

⁶⁶ Poonthong et al., (2020). Multiple pathways of human exposure to poly- and perfluoroalkyl substances (PFASs): From external exposure to human blood, Environment International, 134, 105244. Available at: <https://doi.org/10.1016/j.envint.2019.105244>

has reviewed the available exposure evidence from U.S. NHANES and confirmed that gaps identified in EU human exposure evidence could not be addressed from this source.

The NGOs ChemSec and EEB recommended EU-PARC⁶⁷ (the continuation of HBM4EU) and EFSA⁶⁸ as relevant sources of information. The study team reviewed the publicly available information concerning EU-PARC and has not identified additional evidence. In addition, the team has reached out to EU-PARC to potentially organise a meeting to discuss emerging evidence sources; however, a response was not received in time. Separately, one author of the EEA's ETC HE Report (see below), who is also a member of EU-PARC, mentioned that results of their ongoing work on human exposure to PFAS and immune effects have not yet been published. Sources from EFSA have been considered in the literature review (see Q1.2 below).

Authors of the EEA's ETC HE Report 2023/13⁶⁹, including representatives from VITO⁷⁰ and UBA⁷¹, emphasised that HMB4EU is the most comprehensive, up-to-date and robust source of PFAS exposure evidence in Europe as all measurements within HMB4EU are done using the same QA/QC protocols, implying that the results are comparable. They also mentioned ongoing research on the 3M hotspot in Zwijndrecht, Belgium; where researchers are collecting cross-sectional exposure data from more than 10,000 participants and linking it with a primary care morbidity database for in-depth examination and analysis.⁷² The results will not be ready to capture in this study.

3.1.2. Q1.2 What PFAS exposure is associated with human health risks?

Evidence suggests that human exposure to PFAS can be associated with human health risks. The literature has been reviewed to identify the human health risks associated with PFAS exposure and, to the extent that evidence is available, the levels of exposure that could lead to adverse health outcomes. The review has focussed on human epidemiology studies and, as such, does not include a summary of animal toxicology studies. Comprehensive studies of this nature have been published by, for example, the EFSA and were reviewed during the literature selection process.⁷³

Annex 2, Part 2 of the 2019 Nordic Council of Ministers study 'The Costs of Inaction' provides an overview of the epidemiological studies considered in that study.⁷⁴ The human health findings from the Nordic Council of Ministers report formed the basis of this research, complemented by additional literature published since, which was used to corroborate and/or contrast these findings. The findings from the 2019 report are incorporated throughout the following discussions on human health endpoints.

The health risks associated with PFAS exposure as found in the epidemiological studies underpinning the 2019 Nordic Council of Ministers study comprise premature mortality and increased morbidity related to cancers, increased uric acid levels, increased serum lipid levels, thyroid hormones, hypertension, high cholesterol, stroke, incidence of ulcerative colitis, cardiovascular diseases, decreased foetal growth, and low birthweight.⁷⁵ The Nordic Council of Ministers study reported that

⁶⁷ <https://www.eu-parc.eu/>

⁶⁸ <https://www.efsa.europa.eu/en/topics/per-and-polyfluoroalkyl-substances-pfas>

⁶⁹ Plass et al., (2023). Estimating the burden of disease due to lead, PFAS, phthalates, cadmium, pyrethroids and bisphenol A using HBM4EU data – test of feasibility and first results for selected countries. Available at: [ETC HE Report 2023/13: Estimating the burden of disease due to lead, PFAS, phthalates, cadmium, pyrethroids and bisphenol A using HBM4EU data – test of feasibility and first results for selected countries — Eionet Portal](#)

⁷⁰ <https://vito.be/en>

⁷¹ <https://www.umweltbundesamt.de/>

⁷² Jansen et al. (2025). Integrating human biomonitoring exposure data into a primary care morbidity database: a feasibility study. *Environ Health* 24, 1. <https://doi.org/10.1186/s12940-024-01152-5>

⁷³ European Food Safety Authority (2020). Risk to human health related to the presence of perfluoroalkyl substances in food. Available at: [Risk to human health related to the presence of perfluoroalkyl substances in food](#)

⁷⁴ Goldenman et al. (2019). The cost of inaction: A socioeconomic analysis of environmental and health impacts linked to exposure to PFAS. Available at: [THE COST OF INACTION](#)

⁷⁵ Goldenman et al. (2019). The cost of inaction: A socioeconomic analysis of environmental and health impacts linked to exposure to PFAS. Available at: [THE COST OF INACTION](#)

there are contradictory conclusions in the scientific and regulatory literature regarding individual endpoints, but that consensus was emerging for the following endpoints: liver damage, high serum cholesterol levels, decreased immune response, thyroid disease, decreased fertility, pregnancy-induced-hypertension, pre-eclampsia, lower birth weight, testicular cancer and kidney cancer.⁷⁶

These findings are broadly aligned with the conclusions reached as part of the current 'Cost of PFAS pollution' study on the human health risks associated PFAS exposure, updated to 2024, which are summarised in the following subsections.

PFAA and PFAA precursors

Table 3-3 focusses on the evidence concerning exposure to PFAAs and PFAA precursors, which have well-explored toxicological profiles and more readily available information. This and other tables also include an assessment of the level of confidence in the association between human exposure to PFAS and the specific health outcome/risk, using a scoring system of 5 for the associations with the highest confidence. In more detail, a score of:

- 5, when meta-analyses underpinned by robust science that reports a causal link between PFAS exposure and an adverse health outcome, and without any conflicting evidence.
- 4, when meta-analyses underpinned by robust science report associations, which could be causal but not necessarily proven, between PFAS exposure and health risks, and without any conflicting evidence or notable uncertainties.
- 3, when meta-analyses underpinned by robust science report associations, which could be causal but not necessarily proven, between PFAS exposure and health risk, with some conflicting evidence, areas of uncertainty and/or weaknesses (e.g., some papers saying that PFAS exposure poses a health risk, whilst others do not).
- 2, when meta-analyses OR a limited number of scientific papers report associations OR several scientific papers report suggestive or weak associations between PFAS exposure and health risk, with or without conflicting evidence and/or areas of uncertainty.
- 1, when meta-analyses OR scientific papers report inconclusive associations between PFAS exposure and health risk, with/without conflicting evidence or areas of uncertainty.

Following the table, subsections present more detailed evidence concerning the adverse health outcomes most confidently linked to PFAS exposure, delving into the links between specific PFAS and human health effects and any particularly vulnerable populations.

Finally, separate subsections present the available evidence on the human health hazards associated with F-gases and fluoropolymers, based on the limited available evidence from human health studies.

⁷⁶ Goldenman et al. (2019). *The cost of inaction: A socioeconomic analysis of environmental and health impacts linked to exposure to PFAS*. Available at: [THE COST OF INACTION](#)

PFAS and PFAS precursors

Table 3-3: Summary of human health outcomes or risks associated with PFAS exposure, with a focus on PFASs and PFAS precursors

Health outcome/ risk 'Group'	Specific health outcomes or risks attributable to PFAS exposure	Attribution or links by PFAS type (or unspecified PFAS*)	Confidence (0=None, 5=High)
Infections	Respiratory infections	✓ PFOA, PFOS, PFHxS	4
	Other infections	✓ PFOS	3
Autoimmune disorders	Autoimmune thyroid disease (ATD)	✓ PFAS*, PFOA, PFOS	4
	Inflammatory Bowel Diseases	✓ PFAS*, PFOA, PFOS	3
Musculoskeletal disorder	Osteoporosis	✓ PFOA, PFOS, PFHxS, PFNA, PFUnDA	3
Cardiovascular disease risk factors	Diabetes	✓ PFAS*	1
	Obesity (incl. childhood adiposity)	✓ PFAS*	2
	Hypertension	✓ PFOA, PFOS, PFNA, PFHxS x PFDA, PFUnDA	2
	High cholesterol (serum cholesterol levels)	✓ PFAS*, PFOA, PFOS	3
Kidney diseases	Chronic kidney disease (CKD, incl. increased uric acid and dysfunction)	✓ PFAS* PFOA, PFOS, PFNA, PFHxS	2
Liver diseases	Liver disease	✓ PFAS*	4
	Non-alcoholic fatty liver disease (NAFLD)	✓ PFOS, PFHxS	4
	Cirrhosis	✓ PFOA	3
Cancers	Kidney cancer	✓ PFAS* x PFOA, PFOS	3
	Liver cancer	✓ PFOA	2

Health outcome/ risk 'Group'	Specific health outcomes or risks attributable to PFAS exposure	Attribution or links by PFAS type (or unspecified PFAA*)	Confidence (0-None, 5-High)
	Breast cancer	✓ PFOSA	1
	Testicular cancer	✓ PFOA, PFOS	2
	Prostate cancer	✓ PFOA ~ PFNA, PFHxS, PFDA, PFUnDA (if relatives too)	2
	Other cancers (generic)	✓ PFOA, PFOS	3
Reproductive disorders	Affected (later/earlier) puberty onset	✓ PFOA	2
	Low sperm count and mobility	✓ PFOA	4
	Menstruation alterations and endometriosis	✓ PFAA*	2
	Time to pregnancy (decreased fecundity)	✓ PFOS	2
	Decreased fertility	✓ PFOA, PFHxS	1
Maternal and neonatal risks	Gestational hypertension	✓ PFOA	4
	Gestational diabetes	✓ PFOA	1
	Preeclampsia	✓ PFOA, PFHxS, PFOS	3
	Decreased foetal growth	✓ PFOA, PFOS	4
	Lower birth weight / small for gestational age (birth defects and development problems are indirectly associated with this)	✓ PFOA, PFOS	4

Infections

Published studies and regulatory bodies have highlighted decreased immune response, observed through increased incidence of infections, as a health risk following exposure to PFAS.^{77,78} For example, studies have found a link between lower respiratory infections in children (requiring hospitalisation) following exposure to PFOS (median blood serum 19.4 µg/L) or PFOA (median blood serum 4.62 µg/L), via a reduction in immune response reactions.^{79,80} Risk of respiratory infections in children have also been associated with prenatal exposures to PFOS and PFHxS, linearly correlated with PFAS concentrations in cord blood.⁸¹ Decreased response to vaccinations in children has also been attributed to PFAS (general) exposure, in particular for diphtheria (PFOS), rubella, mumps and influenza.⁸²

The available evidence suggests that there are links between PFAS exposure and decreased immune response, resulting in higher risk of respiratory infections, particularly in relation to children. EFSA also states that PFOS and PFOA are associated with reduced antibody response to vaccination as well as increased propensity for infection.⁸³ Associations between PFAS exposure and other types of immune responses (e.g., asthma or allergies, because of a hyperactive immune system) have been explored. Some associations have been identified, but there is no consensus for these endpoints.^{84,85}

Based on this, it was concluded that the association between PFAS exposure and respiratory infections has been confidently established, with a score of 4 out of 5, albeit there is a lack of consensus and thus lower confidence in associations with other types of decreased immune responses, such as asthma or allergies.

Autoimmune disorders

Studies have found relationships between PFAS exposure and autoimmune disorders. The most widely studied endpoint of this type is autoimmune thyroid disease or ATD. A meta-analysis conducted by Fenton *et al.* in 2020 concluded that there is a “probable link” of ATD following exposure to PFOA, particularly for women and children.⁸⁶ These conclusions are aligned with the findings from

⁷⁷ Goldenman *et al.* (2019). *The cost of inaction: A socioeconomic analysis of environmental and health impacts linked to exposure to PFAS*. Available at: [THE COST OF INACTION](#)

⁷⁸ Fenton *et al.*, (2021). *Per- and Polyfluoroalkyl Substance Toxicity and Human Health Review: Current State of Knowledge and Strategies for Informing Future Research*, Environmental Chemistry and Toxicology, 40, 606. Available at: <https://doi.org/10.1002/etc.4890>

⁷⁹ European Environment Agency (2023). *Estimating the burden of disease due to lead, PFAS, phthalates, cadmium, pyrethroids and bisphenol A using HBM4EU data - test of feasibility and first results for selected countries*. Available at: [ETC HE Report 2023/13: Estimating the burden of disease due to lead, PFAS, phthalates, cadmium, pyrethroids and bisphenol A using HBM4EU data - test of feasibility and first results for selected countries – Eionet Portal](#)

⁸⁰ Kvaem *et al.*, (2020). *Perfluoroalkyl substances, airways infections, allergy and asthma related health outcomes - implications of gender, exposure period and study design*, Environment International, 134, 105269. Available at: <https://doi.org/10.1016/j.envint.2019.105259>

⁸¹ Fenton *et al.*, (2021). *Per- and Polyfluoroalkyl Substance Toxicity and Human Health Review: Current State of Knowledge and Strategies for Informing Future Research*, Environmental Chemistry and Toxicology, 40, 606. Available at: <https://doi.org/10.1002/etc.4890>

⁸² Fenton *et al.*, (2021). *Per- and Polyfluoroalkyl Substance Toxicity and Human Health Review: Current State of Knowledge and Strategies for Informing Future Research*, Environmental Chemistry and Toxicology, 40, 606. Available at: <https://doi.org/10.1002/etc.4890>

⁸³ EFSA CONTAM Panel (EFSA Panel on Contaminants in the Food Chain) (2020). *Scientific Opinion on the risk to human health related to the presence of perfluoroalkyl substances in food*. EFSA Journal 2020;18(9):6223, 391 pp. Available at: <https://doi.org/10.2903/j.efsa.2020.6223>

⁸⁴ Fenton *et al.*, (2021). *Per- and Polyfluoroalkyl Substance Toxicity and Human Health Review: Current State of Knowledge and Strategies for Informing Future Research*, Environmental Chemistry and Toxicology, 40, 606. Available at: <https://doi.org/10.1002/etc.4890>

⁸⁵ EFSA CONTAM Panel (EFSA Panel on Contaminants in the Food Chain) (2020). *Scientific Opinion on the risk to human health related to the presence of perfluoroalkyl substances in food*. EFSA Journal 2020;18(9):6223, 391 pp. Available at: <https://doi.org/10.2903/j.efsa.2020.6223>

⁸⁶ Fenton *et al.*, (2021). *Per- and Polyfluoroalkyl Substance Toxicity and Human Health Review: Current State of Knowledge and Strategies for Informing Future Research*, Environmental Chemistry and Toxicology, 40, 606. Available at: <https://doi.org/10.1002/etc.4890>

earlier studies, such as those included in the 2019 Costs of Inaction report (e.g., C8 Science Panel, 2012).⁸⁷

One study found that blood serum levels of PFOA >5.7 µg/L in men and women were associated with hypothyroid disease. Findings from other studies (e.g., C8 Science Panel) have corroborated these effects, in particular noting associations between PFAS exposure and hypothyroidism in children.⁸⁸

Newborns diagnosed with congenital hypothyroidism had higher serum levels of PFOA (5.40 vs 2.12 µg/L), PFNA (1.93 vs 0.63 µg/L), PFDA (0.52 vs 0.30 µg/L) and PFUnDA (0.98 vs 0.44 µg/L) compared to those without a diagnosis, though a causative link was not confirmed.⁸⁹

Experimental data, supported by human studies, suggests that PFAS exposure is associated with increased incidence of autoimmune disorders, as PFAS have been shown to interact with various thyroid proteins and enzymes *in vitro*.⁹⁰ On the basis of these findings, it is concluded that PFAS exposure can be associated with the likely alteration of human thyroid hormones, and thyroid disease risks.

Some evidence has also been presented for other autoimmune disorders, such as ulcerative colitis and/or inflammatory bowel disease. Several studies have noted an association between PFOA exposure and ulcerative colitis (an inflammatory bowel disease) in several populations, including workers, children/young adults, and those living in contaminated communities.⁹¹ There is however, some remaining ambiguity regarding this endpoint due to mixed findings across different studies.

Based on this evidence, it is concluded there is confidence in the association of PFAS exposure and autoimmune thyroid disease, with a score of 4 out of 5, especially given the conclusions reported in meta-analyses. However, there remain areas of uncertainty and/or ambiguity for other types of autoimmune disorders, which were thus assigned lower confidence scores.

Musculoskeletal disorders

Associations between PFAS and decreased bone mineral density (BMD) have been reported, whilst some studies have explored these links further and investigated the relationship between PFAS exposure and osteoporosis.

A meta-analysis by Mahdavi *et al.* (2024) examined the links between PFAS exposure and human bone health. Associations have been found following PFOS exposure, such as femoral neck BMD in men and women and postmenopausal women, and spinal and total femur BMD in women. Total femur BMD in women was also inversely associated with blood serum levels of PFOA. One study reported that a one-unit rise in serum PFOS levels was associated with a 0.022 g/cm² decrease in total lumbar spine BMD.⁹²

Natural log (ln) transformed PFAS blood serum values and the risk of osteoporosis have been investigated. The study found that exposures in the second, third and fourth quartiles presented a 2.3 – 96-fold increase in the odds of being diagnosed with osteoporosis for the following PFAS (presented

⁸⁷ Goldenman *et al.* (2019). *The cost of inaction: A socioeconomic analysis of environmental and health impacts linked to exposure to PFAS*. Available at: [THE COST OF INACTION](#)

⁸⁸ Fenton *et al.*, (2021). *Per- and Polyfluoroalkyl Substance Toxicity and Human Health Review: Current State of Knowledge and Strategies for Informing Future Research*, Environmental Chemistry and Toxicology, 40, 606. Available at: <https://doi.org/10.1002/etc.4890>

⁸⁹ Kim *et al.*, (2016). *Perfluoroalkyl substances in serum from South Korean infants with congenital hypothyroidism and healthy infants – Its relationship with thyroid hormones*, Environmental Research, 147, 399. Available at: <https://doi.org/10.1016/j.envres.2016.02.037>

⁹⁰ Fenton *et al.*, (2021). *Per- and Polyfluoroalkyl Substance Toxicity and Human Health Review: Current State of Knowledge and Strategies for Informing Future Research*, Environmental Chemistry and Toxicology, 40, 606. Available at: <https://doi.org/10.1002/etc.4890>

⁹¹ Fenton *et al.*, (2021). *Per- and Polyfluoroalkyl Substance Toxicity and Human Health Review: Current State of Knowledge and Strategies for Informing Future Research*, Environmental Chemistry and Toxicology, 40, 606. Available at: <https://doi.org/10.1002/etc.4890>

⁹² Mahdavi *et al.*, (2024). *Exposure to Environmental Chemicals and Human Bone Health; A Systematic Review and Meta-Analysis*, Exposure and Health, 16, 861. Available at: <https://doi.org/10.1007/s12403-023-00596-3>

in order of risk): PFUnDA (mean concentration 0.08 µg/L, max 0.31 µg/L), PFOA (mean concentration 1.76 µg/L, max 10.5 µg/L), PFNA (mean concentration 0.70 µg/L, max 4.49 µg/L), PFOS (mean concentration 6.28 µg/L, max 30.1 µg/L) and PFHxS (mean concentration 2.70 µg/L, max 44.8 µg/L).⁹³

Kai Tao et al. (2024)⁹⁴ also performed a meta-analysis of 11 studies and found that exposure to PFOS and PFOA was associated with lower bone mineral density in men whereas exposure to PFOS and PFNA was associated with lower bone mineral density in women.

Prenatal and maternal PFAS exposure has also been associated with decreased childhood and adolescent BMD, e.g., in forearms (PFOA, PFHxS) and the spine (PFHxS), though associations were weaker for PFHxS compared to PFOA. Higher PFAS levels in children have also been associated with lower BMD.^{95,96}

A 2023 cohort study in Sweden examined the link between PFAS exposure and increased risk of major osteoporotic fractures (MOF, comprised of hip, vertebrae, proximal humerus and distal forearm fractures). Increased risks of major osteoporotic fractures and hip fractures were observed in the highest exposure groups compared to low exposure or control groups (low exposure groups were considered as those not living near a contaminated water site). Increased odds ratios of MOF (1.11) and hip fractures (1.12) were associated with increased levels of median PFAS exposures (PFHxS – low exposure 34 µg/L, elevated exposure 48 µg/L; PFOS – low exposure 42 µg/L, elevated exposure 50 µg/L; PFOA – low exposure 4 µg/L, elevated exposure 13 µg/L).⁹⁷

The links between PFAS exposure and musculoskeletal disorders, particularly decreased bone mineral density as a risk factor of osteoporosis, have been explored. Associations have been identified between PFAS exposure and both BMD and osteoporosis, using a combination of human biomonitoring data and historical longitudinal study data. The relationship between PFAS exposure and osteoporosis is less well studied compared to BMD, but recent studies support the hypothesis that exposure leads to adverse musculoskeletal outcomes. These outcomes are typically more prevalent in adults over 50, with elevated risk levels in women compared to men.

The scientific literature reports known associations between PFAS exposure and reduced bone mineral density and/or osteoporosis, but there remain uncertainties regarding modes of action. However, EFSA suggests that epidemiological studies provide insufficient evidence for associations between exposure to PFAS and low bone mineral density or osteoporosis. As a result, a confidence score of 3 was assigned to the association between PFAS exposure and musculoskeletal disorders.

Cardiovascular diseases and risk factors

Available studies suggest there is a relationship between human exposure to PFAS and cardiovascular risk factors, namely hypertension, high cholesterol levels and obesity, and cardiovascular diseases (CVD)⁹⁸.

The 2019 Nordic Council of Ministers report states that there is consensus of the links between PFAS exposure and high cholesterol levels. Meta-analyses published in the intervening years support this conclusion, as increased exposure to long chain PFAS has been consistently associated with

⁹³ Banjabi et al., (2020). Serum concentrations of perfluoroalkyl substances and their association with osteoporosis in a population in Jeddah, Saudi Arabia, *Environmental Research*, 187, 109676. Available at: <https://doi.org/10.1016/j.envres.2020.109676>

⁹⁴ Kai Tao et al. (2024). Associations between Per- and Polyfluoroalkyl Substances Exposures and Bone Mineral: A Systematic Review and Best Evidence Synthesis. *Environ. Health*. Available at: <https://doi.org/10.1021/envhealth.4c00143>

⁹⁵ Mahdavi et al., (2024). Exposure to Environmental Chemicals and Human Bone Health: A Systematic Review and Meta-Analysis, *Exposure and Health*, 16, 861. Available at: <https://doi.org/10.1007/s12403-023-00596-3>

⁹⁶ Blomberg, et al. (2022). Bone mass density following developmental exposures to perfluoroalkyl substances (PFAS): a longitudinal cohort study. *Environmental health: a global access science source*, 21(1), 113. Available at: <https://doi.org/10.1186/s12940-022-00929-w>

⁹⁷ Xu et al., (2023) High exposure to perfluoroalkyl substances in drinking water is associated with increased risk of osteoporotic fractures – A cohort study from Ronneby, Sweden, *Environmental Research*, 271, 114796. Available at: <https://doi.org/10.1016/j.envres.2022.114796>

⁹⁸ Eurostat (2024). Cardiovascular disease statistics. Available at: [Cardiovascular diseases statistics - Statistics Explained](#)

increased serum cholesterol levels in adults and children.⁹⁹ Experimental findings indicate a saturable mechanism whereby serum lipids increase linearly with PFAS exposure before attenuating.¹⁰⁰ A recent study (2024) investigated, *inter alia*, cardiovascular disease mortality from those living in the PFAS-contaminated region of Veneto, Italy. The study found an increase in cardiovascular disease mortality in the Veneto (exposed) region, with the most consistent associations reported with total cholesterol levels.¹⁰¹

The risk of hypertension associated with PFAS exposure was considered in depth in the 2019 Nordic Council report, in particular to quantify and monetise the impacts of background levels of PFAS exposure.¹⁰² There is, however, conflicting evidence regarding the extent to which people exposed to PFAS may face an increased risk of hypertension. A 2023 study by the European Environment Agency 'estimating the burden of disease due to ... PFAS' notes that the evidence to support an association between PFAS exposure (PFOS, PFOA) and hypertension in the general population is limited, whilst there is a 'suggestive association' following exposure during pregnancy.¹⁰³ EFSA have also noted that there is 'no clear association' between PFAS exposure and hypertension.¹⁰⁴

Conversely, a meta-analysis conducted by Pan *et al.* in 2023 concluded that PFNA, PFOA, and PFOS were significantly associated with hypertension in men, whilst exposure to PFHxS was significantly associated with hypertension in men and women. Differences observed between men and women could be related to higher oestrogen levels in women, which are considered to have protective effects on the cardiovascular system.¹⁰⁵ Despite conflicting findings, the evidence suggests that PFAS exposure can be linked to higher risk of hypertension (particularly for men and pregnant women).

The literature found consistently reported associations between PFAS exposure and high cholesterol, with some areas of uncertainty remaining, and thus given a confidence score of 3. However, the evidence identified on PFAS exposure and hypertension, obesity or diabetes reported weaker associations or conflicts across primary study findings and meta-analyses; and thus, were scored a 2, 2 and 1 respectively.

Non-cancer kidney disease

Some studies have associated exposure to legacy PFAS (PFOA, PFOS) with chronic kidney disease (based on diminished glomerular filtration rates¹⁰⁶, which are tested to determine kidney function and determine the stages of kidney disease¹⁰⁷).¹⁰⁸ Additional studies have also suggested causative

⁹⁹ Uhl *et al.*, (2023). PFASs: What can we learn from the European Human Biomonitoring Initiative HBM4EU, International Journal of Hygiene and Environmental Health, 250, 114168. Available at: <https://doi.org/10.1016/j.ijheh.2023.114168>

¹⁰⁰ Fenton *et al.*, (2021). Per- and Polyfluoroalkyl Substance Toxicity and Human Health Review: Current State of Knowledge and Strategies for Informing Future Research, Environmental Chemistry and Toxicology, 40, 606. Available at: <https://doi.org/10.1002/etc.4890>

¹⁰¹ Biggeri *et al.* (2024). All-cause, cardiovascular disease and cancer mortality in the population of a large Italian area contaminated by perfluoroalkyl and polyfluoroalkyl substances (1980–2018), Environmental Health, 23, 1. Available at: <https://doi.org/10.1186/s12940-024-01074-2>

¹⁰² Goldenman *et al.* (2019). The cost of inaction: A socioeconomic analysis of environmental and health impacts linked to exposure to PFAS. Available at: [THE COST OF INACTION](#)

¹⁰³ European Environment Agency (2023). Estimating the burden of disease due to lead, PFAS, phthalates, cadmium, pyrethroids and bisphenol A using HBM4EU data - test of feasibility and first results for selected countries. Available at: [ETC HE Report 2023/13: Estimating the burden of disease due to lead, PFAS, phthalates, cadmium, pyrethroids and bisphenol A using HBM4EU data - test of feasibility and first results for selected countries – Eionet Portal](#)

¹⁰⁴ European Food Safety Authority (2020). Risk to human health related to the presence of perfluoroalkyl substances in food. Available at: [Risk to human health related to the presence of perfluoroalkyl substances in food](#)

¹⁰⁵ Pan *et al.*, (2023). The relationship between perfluoroalkyl substances and hypertension: A systematic review and meta-analysis, Environmental Research, 232, 116362. Available at: <https://doi.org/10.1016/j.envres.2023.116362>

¹⁰⁶ Diminished glomerular filtration is when kidneys do not filter blood properly.

¹⁰⁷ National Kidney Foundation (2023). Can my GFR get better? Available at: [Can my GFR get better? | National Kidney Foundation](#)

¹⁰⁸ Fenton *et al.*, (2021). Per- and Polyfluoroalkyl Substance Toxicity and Human Health Review: Current State of Knowledge and Strategies for Informing Future Research, Environmental Chemistry and Toxicology, 40, 606. Available at: <https://doi.org/10.1002/etc.4890>

links; however, there remains uncertainty regarding this health endpoint. Studies have reported remaining gaps in the evidence, including on the proposed mode of action.¹⁰⁹

PFAS exposure has also been associated with changes in uric acid levels, with high uric acid levels linked to the decline in the glomerular filtration rate (used as a biomarker for kidney disease).¹¹⁰ A dose-response relationship is observed between PFAS and uric acid levels (starting at historic background levels); however, there is scientific debate on the extent to which these links are causal or whether other factors, such as the presence of albumin in the urine, might contribute.¹¹¹

In 2020, EFSA concluded that there was insufficient epidemiological evidence to support the link between PFAs exposure and increased risk of chronic kidney disease, and that further study would be required.¹¹²

The literature identified suggested weak or uncertain associations between PFAS exposure and kidney disease, and thus a confidence score of 2 was assigned. Many studies looked at biological precursors to kidney disease, e.g., glomerular filtration rate or uric acid levels, rather than kidney disease itself. The ongoing scientific debate regarding causal links was considered.

Liver diseases

It is widely established that long-chain PFAS accumulate in the liver.¹¹³ Studies have investigated how PFAS exposure may lead to various liver diseases, including non-alcoholic fatty liver disease (NAFLD) and cirrhosis. Exploratory studies using NAFLD biomarkers identified that increased liver PFAS concentrations may induce steatosis, whereby fat accumulates in liver cells.^{114,115} Increased steatosis in humans may lead to increased likelihood of advanced liver disease, including NAFLD.¹¹⁶ In children aged 7-19 with clinically proven NAFLD, higher levels of PFOS and PFHxS were associated with more advanced liver disease.¹¹⁷

Liver disease is also the primary endpoint of concern for trifluoroacetic acid (TFA) as TFA derivatives are formed in the body following exposures to other PFAS, e.g., halothane (see below). Trifluoroacetyl halides can react in the body to produce trifluoroacetylated proteins, which can cause liver damage in humans.¹¹⁸

¹⁰⁹ Fenton et al., (2021). *Per- and Polyfluoroalkyl Substance Toxicity and HumanHealth Review: Current State of Knowledge and Strategiesfor Informing Future Research*, Environmental Chemistry and Toxicology, 40, 606. Available at: <https://doi.org/10.1002/etc.4890>

¹¹⁰ Fenton et al., (2021). *Per- and Polyfluoroalkyl Substance Toxicity and HumanHealth Review: Current State of Knowledge and Strategiesfor Informing Future Research*, Environmental Chemistry and Toxicology, 40, 606. Available at: <https://doi.org/10.1002/etc.4890>

¹¹¹ Fenton et al., (2021). *Per- and Polyfluoroalkyl Substance Toxicity and HumanHealth Review: Current State of Knowledge and Strategiesfor Informing Future Research*, Environmental Chemistry and Toxicology, 40, 606. Available at: <https://doi.org/10.1002/etc.4890>

¹¹² European Environment Agency (2023). *Estimating the burden of disease due to lead, PFAS, phthalates, cadmium, pyrethroids and bisphenol A using HBM4EU data - test of feasibility and first results for selected countries*. Available at: [ETC HE Report 2023/13: Estimating the burden of disease due to lead, PFAS, phthalates, cadmium, pyrethroids and bisphenol A using HBM4EU data - test of feasibility and first results for selected countries – Eionet Portal](https://www.eionet.europa.eu/portal/en/etec/etec-report-2023-13-estimating-the-burden-of-disease-due-to-lead-pfas-phthalates-cadmium-pyrethroids-and-bisphenol-a-using-hbm4eu-data-test-of-feasibility-and-first-results-for-selected-countries-eionet-portal)

¹¹³ Fenton et al., (2021). *Per- and Polyfluoroalkyl Substance Toxicity and HumanHealth Review: Current State of Knowledge and Strategiesfor Informing Future Research*, Environmental Chemistry and Toxicology, 40, 606. Available at: <https://doi.org/10.1002/etc.4890>

¹¹⁴ Fenton et al., (2021). *Per- and Polyfluoroalkyl Substance Toxicity and HumanHealth Review: Current State of Knowledge and Strategiesfor Informing Future Research*, Environmental Chemistry and Toxicology, 40, 606. Available at: <https://doi.org/10.1002/etc.4890>

¹¹⁵ Medical News Today (2023). *What to know about steatosis*. Available at: [Steatosis: Definition, symptoms, treatment, and more](https://www.medicalnewstoday.com/articles/steatosis-definition-symptoms-treatment-and-more)

¹¹⁶ Fenton et al., (2021). *Per- and Polyfluoroalkyl Substance Toxicity and HumanHealth Review: Current State of Knowledge and Strategiesfor Informing Future Research*, Environmental Chemistry and Toxicology, 40, 606. Available at: <https://doi.org/10.1002/etc.4890>

¹¹⁷ Fenton et al., (2021). *Per- and Polyfluoroalkyl Substance Toxicity and HumanHealth Review: Current State of Knowledge and Strategiesfor Informing Future Research*, Environmental Chemistry and Toxicology, 40, 606. Available at: <https://doi.org/10.1002/etc.4890>

¹¹⁸ Ball et al., (1993). *Formation of Trifluoroacetic Acid from the Atmospheric Degradation of Hydrofluorocarbon 134a: A Human Health Concern?*, Air and Waste, 43, 1260. Available at: [Formation of Trifluoroacetic Acid from the Atmospheric Degradation of Hydrofluorocarbon 134a: A Human Health Concern? A Human Health Concern?](https://www.sciencedirect.com/science/article/pii/S004313049390009I)

Some occupational studies have also identified higher levels of cirrhosis mortality following extremely high exposures to PFOA (median serum level 4,048 µg/L), though this has not been consistently reported in other occupational exposure studies.¹¹⁹

Whilst some studies report insufficient evidence for an association between liver disease and PFAS exposure, the 2019 Nordic Council of Ministers study reported that there is consensus emerging regarding liver disease as an adverse health outcome. Studies published in the intervening years support this conclusion.

Liver diseases, including NAFLD, were awarded a confidence score of 4. Several studies have reported direct associations between PFAS exposure and liver disease (or liver disease biomarkers). Cirrhosis was awarded a confidence score of 3, as there were areas of uncertainty reported in the literature.

Cancer

The carcinogenicity of PFAS has been widely explored. The 2019 Nordic Council of Ministers study noted that human exposure to PFAS appears linked to the increased incidence of particular cancers, such as of the liver, bladder, kidney, and breast.¹²⁰

Confidence in the links between human exposure to PFAS and cancer is highest for kidney cancer. There is also evidence suggesting that PFAS exposure is associated with increased risk of testicular cancer and prostate cancer. For example, three instances of occupational exposure to PFAS have been associated with prostate cancer (PFOS, PFOA), whilst a general population study found a 'slight but not strictly monotonic' association between blood serum PFOS levels and prostate cancer incidence. Other studies have also reported increased incidence of prostate cancer associated with increased PFAS exposure in instances where a first degree relative has prostate cancer.¹²¹

Similarly, there is suggestive evidence that PFAS exposure may increase the incidence of testicular cancer in the general population. However, the scientific literature reports conflicting findings, particularly noting that some modes of action observed in rats may not be relevant in humans.¹²²

Biggeri *et al.* (2024) found that those living in the PFAS-contaminated region of Veneto, Italy faced an increased risk of mortality from cancer, with the consistent increase in mortality in the exposed population being observed for kidney cancer, and testicular cancer before the year 2000.¹²³

Liver, breast, testicular and prostate cancer risks were scored a 1 or 2 based on either a lack of suggestive evidence, a lack of consensus in findings, or non-statistically significant results found in the literature. Kidney cancer (below) was assigned a confidence score of 3 out of 5, based on evidence associating kidney cancer risk to high levels of PFAS exposure, such as e.g., in an occupational setting, and with remaining areas of uncertainty in the literature.

Concerning kidney cancer, studies report that the association between PFAS exposure and kidney cancer was most convincing for occupational exposures, i.e., the highest levels of exposure (based on findings that workers exposed to high levels of PFAS suffered from an elevated risk of mortality from kidney cancer).¹²⁴ Steenland *et al.* published a meta-analysis in 2021, reviewing previous literature

¹¹⁹ Fenton *et al.*, (2021). *Per- and Polyfluoroalkyl Substance Toxicity and Human Health Review: Current State of Knowledge and Strategies for Informing Future Research*, Environmental Chemistry and Toxicology, 40, 606. Available at: <https://doi.org/10.1002/etc.4890>

¹²⁰ Goldenman *et al.* (2019). *The cost of inaction: A socioeconomic analysis of environmental and health impacts linked to exposure to PFAS*. Available at: [THE COST OF INACTION](https://doi.org/10.1016/j.envres.2020.110690)

¹²¹ Steenland *et al.*, (2021). *PFAS and cancer, a scoping review of the epidemiologic evidence*, Environmental Research, 194, 110690. Available at: <https://doi.org/10.1016/j.envres.2020.110690>

¹²² Steenland *et al.*, (2021). *PFAS and cancer, a scoping review of the epidemiologic evidence*, Environmental Research, 194, 110690. Available at: <https://doi.org/10.1016/j.envres.2020.110690>

¹²³ Biggeri *et al.* (2024). *All-cause, cardiovascular disease and cancer mortality in the population of a large Italian area contaminated by perfluoroalkyl and polyfluoroalkyl substances (1980–2018)*, Environmental Health, 23, 1. Available at: <https://doi.org/10.1186/s12940-024-01074-2>

¹²⁴ Goldenman *et al.* (2019). *The cost of inaction: A socioeconomic analysis of environmental and health impacts linked to exposure to PFAS*. Available at: [THE COST OF INACTION](https://doi.org/10.1016/j.envres.2020.110690)

pertaining to PFAS and kidney cancer. It was noted that earlier evidence attributing PFAS exposure to kidney cancer may be, at most suggestive, or only applicable to PFOA and no other PFAS.¹²⁵ Steenland *et al.* reviewed 16 occupational exposure studies. Across these studies, median serum concentration levels for PFOA ranged from 113-5,200 µg/L (maximum level 92,030 µg/L), whilst the geometric mean for PFOS serum levels was 941 µg/L (maximum concentration 10,600 µg/L).¹²⁶

Recent meta-analyses (Fenton *et al.*, 2020, Steenland *et al.*, 2021) concluded that evidence is 'accumulating' to support kidney cancer as an adverse health outcome following PFAS exposure and is typically linked to particularly high levels of exposure (e.g., in occupational settings or from contaminated sites).^{127,128} There remains some ambiguity regarding this, and different occupational studies reporting high levels of PFAS exposure (reported in the Nordic Council of Ministers study) reached different conclusions.¹²⁹ In 2020, EFSA concluded that available studies provided insufficient evidence to attribute PFOS and PFOA exposure to increased risk of kidney cancer.¹³⁰ Despite this, there is consensus that people may face increased risk of kidney cancer as a result of exposure to high levels of PFAS.

Reproductive disorders

In this context, 'reproductive disorders' refers to any health outcome that may impact reproductive systems and/or fertility prior to pregnancy. The next section discusses maternal and neonatal risks towards pregnant women and babies.

In 2019, the European Environment Agency published a schematic representation of the human health effects of PFAS exposure, stating early puberty onset, increased time to pregnancy, increased miscarriage risk and low sperm count and mobility, albeit these were concluded with lower certainty than other health endpoints such as those described above (e.g., increased cholesterol, liver damage, etc).¹³¹

The scientific consensus from studies published in the intervening years supports the conclusion of the EEA (2019). However, in 2023, Pinney *et al.* published the results of a study investigating the link between PFAS exposures, pubertal onset, and serum reproductive hormones. The study was conducted in the United States, but the results are considered applicable to European populations based on the study design and groups of participants. The study found an association between blood serum levels of PFOA, increased body mass index (BMI) and the onset of different pubertal milestones (menarche, thelarche and pubarche¹³²).¹³³ But in contrast to the EEA conclusions (early onset of puberty), Pinney *et al.* found that increased PFOA concentrations had a statistically significant effect

¹²⁵ Steenland *et al.*, (2021). *PFAS and cancer, a scoping review of the epidemiologic evidence*, Environmental Research, 194, 110690. Available at: <https://doi.org/10.1016/j.envres.2020.110690>

¹²⁶ Steenland *et al.*, (2021). *PFAS and cancer, a scoping review of the epidemiologic evidence*, Environmental Research, 194, 110690. Available at: <https://doi.org/10.1016/j.envres.2020.110690>

¹²⁷ Steenland *et al.*, (2021). *PFAS and cancer, a scoping review of the epidemiologic evidence*, Environmental Research, 194, 110690. Available at: <https://doi.org/10.1016/j.envres.2020.110690>

¹²⁸ Fenton *et al.*, (2021). *Per- and Polyfluoroalkyl Substance Toxicity and Human Health Review: Current State of Knowledge and Strategies for Informing Future Research*, Environmental Chemistry and Toxicology, 40, 606. Available at: <https://doi.org/10.1002/etc.4890>

¹²⁹ Goldenman *et al.* (2019). *The cost of inaction: A socioeconomic analysis of environmental and health impacts linked to exposure to PFAS*. Available at: [THE COST OF INACTION](#)

¹³⁰ European Environment Agency (2023). *Estimating the burden of disease due to lead, PFAS, phthalates, cadmium, pyrethroids and bisphenol A using HBM4EU data - test of feasibility and first results for selected countries*. Available at: [ETC HE Report 2023/13: Estimating the burden of disease due to lead, PFAS, phthalates, cadmium, pyrethroids and bisphenol A using HBM4EU data - test of feasibility and first results for selected countries - Eionet Portal](#)

¹³¹ European Environment Agency (2019). *Emerging chemical risks in Europe – PFAS*. Available at: [Emerging chemical risks in Europe – 'PFAS' – European Environment Agency](#)

¹³² Menarche – first menstrual cycle; thelarche – breast budding; pubarche – first appearance of pubic hair.

¹³³ Pinney *et al.*, (2023). *Exposure to Perfluoroalkyl Substances and Associations with Pubertal Onset and Serum Reproductive Hormones in a Longitudinal Study of Young Girls in Greater Cincinnati and the San Francisco Bay Area*, Environmental Health Perspectives, 131, 097009-1. Available at: <https://doi.org/10.1289/EHP11811>

on delaying all three milestones. PFNA and PFDeA were associated with later thelarche, whilst Me-PFOA-AcOH was associated with both later thelarche and pubarche.¹³⁴

Studies have shown that high serum levels of PFOS (i.e., median concentration 35.5 ng/mL) are associated with decreased fertility. These findings were duplicated in parous women (having given birth at least once already) but not non-parous women (first time mothers), suggesting that reverse causation may be a factor.¹³⁵ Other studies have also attributed PFNA (1.66 ng/mL) and PFHxS (concentration not specified) exposures with overall infertility.¹³⁶

There is an intention under Regulation (EC) 1272/2008 on classification, labelling and packaging of substances and mixtures to classify TFA as, amongst other things, a presumed human reproductive toxicant (Reproductive. 1B, H360Df) based on animal studies (rabbits) exhibiting embryo-foetal developmental toxicity.¹³⁷

Low sperm count and mobility risks were associated with PFAS exposure consistently in the literature, thus a confidence score of 4 out of 5 was assigned. Studies of other, potential reproductive health risks reported unknown modes of action, conflicting findings and/or were based on small sample sizes; thus, affected puberty onset or decreased fertility risks were assigned a confidence score of 1; and menstruation alterations or time to pregnancy, a score of 2 was assigned.

Maternal and neonatal risks

Several maternal and neonatal risks have also been associated with PFAS exposure. For example, some studies have suggested a probable link between PFOA exposure and pregnancy-induced hypertension and pre-eclampsia.¹³⁸ This aligns with the findings reported by the European Environment Agency, which noted that associations between PFAS exposure and hypertension were notable in pregnant women.¹³⁹ Links have also been explored between PFAS exposure and gestational diabetes, but the identified associations are weak and have wide confidence intervals.¹⁴⁰

Evidence regarding neonatal risks is strongest for low birth weight. The EEA has reported that an interquartile increase of PFOA concentration in cord serum (approximately equal to 900 µg/L) led to a reduction in birth weight, with further studies reporting that an increase of 1 µg/L was associated with a 19 g decrease.^{141,142} The same risk following PFOS exposure was not observed. Decreased birth

¹³⁴ Pinney et al., (2023). *Exposure to Perfluoroalkyl Substances and Associations with Pubertal Onset and Serum Reproductive Hormones in a Longitudinal Study of Young Girls in Greater Cincinnati and the San Francisco Bay Area*, Environmental Health Perspectives, 131, 097009-1. Available at: <https://doi.org/10.1289/EHP11811>

¹³⁵ Fenton et al., (2021). *Per- and Polyfluoroalkyl Substance Toxicity and HumanHealth Review: Current State of Knowledge and Strategiesfor Informing Future Research*, Environmental Chemistry and Toxicology, 40, 606. Available at: <https://doi.org/10.1002/etc.4890>

¹³⁶ Fenton et al., (2021). *Per- and Polyfluoroalkyl Substance Toxicity and HumanHealth Review: Current State of Knowledge and Strategiesfor Informing Future Research*, Environmental Chemistry and Toxicology, 40, 606. Available at: <https://doi.org/10.1002/etc.4890>

¹³⁷ European Chemicals Agency (no date). *Registry of CLH intentions until outcome – trifluoroacetic acid*. Available at: [Registry of CLH intentions until outcome - ECHA](https://echa.europa.eu/CLH/intentions/until/outcome) [date accessed 27.01.2025]

¹³⁸ Fenton et al., (2021). *Per- and Polyfluoroalkyl Substance Toxicity and HumanHealth Review: Current State of Knowledge and Strategiesfor Informing Future Research*, Environmental Chemistry and Toxicology, 40, 606. Available at: <https://doi.org/10.1002/etc.4890>

¹³⁹ European Environment Agency (2023). *Estimating the burden of disease due to lead, PFAS, phthalates, cadmium, pyrethroids and bisphenol A using HBM4EU data - test of feasibility and first results for selected countries*. Available at: [ETC HE Report 2023/13: Estimating the burden of disease due to lead, PFAS, phthalates, cadmium, pyrethroids and bisphenol A using HBM4EU data - test of feasibility and first results for selected countries - Eionet Portal](https://www.eea.europa.eu/en/press-releases/2023/13-estimating-the-burden-of-disease-due-to-lead-pfas-phthalates-cadmium-pyrethroids-and-bisphenol-a-using-hbm4eu-data-test-of-feasibility-and-first-results-for-selected-countries-eionet-portal)

¹⁴⁰ Birru et al., (2021). *A pathway level analysis of PFAS exposure and risk of gestational diabetes mellitus*, Environmental Health, 20, 1. Available at: <https://doi.org/10.1186/s12940-021-00740-z>

¹⁴¹ European Environment Agency (2023). *Estimating the burden of disease due to lead, PFAS, phthalates, cadmium, pyrethroids and bisphenol A using HBM4EU data - test of feasibility and first results for selected countries*. Available at: [ETC HE Report 2023/13: Estimating the burden of disease due to lead, PFAS, phthalates, cadmium, pyrethroids and bisphenol A using HBM4EU data - test of feasibility and first results for selected countries - Eionet Portal](https://www.eea.europa.eu/en/press-releases/2023/13-estimating-the-burden-of-disease-due-to-lead-pfas-phthalates-cadmium-pyrethroids-and-bisphenol-a-using-hbm4eu-data-test-of-feasibility-and-first-results-for-selected-countries-eionet-portal)

¹⁴² Fenton et al., (2021). *Per- and Polyfluoroalkyl Substance Toxicity and HumanHealth Review: Current State of Knowledge and Strategiesfor Informing Future Research*, Environmental Chemistry and Toxicology, 40, 606. Available at: <https://doi.org/10.1002/etc.4890>

weight, or 'small for gestational age' (SGA), is associated with premature death and impaired cognitive development, potentially reducing IQ levels by up to 8 points.

Uncertainty remains regarding the exact mode of action for this endpoint. PFOA has been shown to bind to PPAR γ ligands (peroxisome proliferator – activated receptor gamma protein). PPAR γ regulates placenta metabolism and the flow of nutrients from the placenta to the foetus. By binding to this ligand, PFOA may adversely affect foetal growth. Other hypotheses suggest that decreased foetal growth may occur through endocrine effects on different hormones that influence body growth.¹⁴³

Despite uncertainties regarding the mode of action, EFSA concluded there is “*possibly a causal association*” between PFOA exposure and SGA.¹⁴⁴

Gestational hypertension, decreased foetal growth, and small for gestational age were assigned a confidence score of 4 out of 5 based on the consistency of findings of association between PFAS exposure and these health risks in the literature, though the causal link (or mode of action) remains under investigation. Preeclampsia was assigned a confidence score of 3, because a range of studies reported findings of a 'probable link' between PFAS exposure and this health risk, but without evidence of the mode of action. Gestational diabetes was scored 1, given that the evidence identified exploring its association with PFAS exposure reports low certainty and the absence of an elucidated mode of action.

F-gases

Several studies outside the temporal scope of this project (pre-2019) were identified and summarised based on a lack of recent literature.

A range of F-gases (desflurane, sevoflurane, isoflurane) are used as anaesthetics in medical procedures, and the resulting extremely high levels of exposure have been associated with central nervous system depression and/or cardiac sensitisation (as is expected when using general anaesthetic).^{145,146} SF₆ is an asphyxiant which may cause suffocation and/or unconsciousness, with symptoms including nausea, increased pulse and/or breathing rate, and muscle convulsions.¹⁴⁷

The results of mammalian animal studies (rats, rabbits) have not indicated significant adverse outcomes for reproductive or developmental toxicity.¹⁴⁸ Similarly, there is a lack of observable evidence in humans to indicate the abovementioned effects, as well as no supporting evidence for carcinogenicity or mutagenicity.¹⁴⁹ As such, and based on their physicochemical properties, HFCs indicate a low potential for toxicity in mammals and humans.¹⁵⁰

¹⁴³ Plass et al. (2023). Estimating the burden of disease due to lead, PFAS, phthalates, cadmium, pyrethroids and bisphenol A using HBM4EU data - test of feasibility and first results for selected countries. Available at: [ETC HE Report 2023/13: Estimating the burden of disease due to lead, PFAS, phthalates, cadmium, pyrethroids and bisphenol A using HBM4EU data - test of feasibility and first results for selected countries – Eionet Portal](#)

¹⁴⁴ Plass et al. (2023). Estimating the burden of disease due to lead, PFAS, phthalates, cadmium, pyrethroids and bisphenol A using HBM4EU data - test of feasibility and first results for selected countries. Available at: [ETC HE Report 2023/13: Estimating the burden of disease due to lead, PFAS, phthalates, cadmium, pyrethroids and bisphenol A using HBM4EU data - test of feasibility and first results for selected countries – Eionet Portal](#)

¹⁴⁵ Sherman et al., (2022), Inhaled anaesthesia and analgesia contribute to climate change, The British Medical Journal, 377, 1301. Available at: <https://doi.org/10.1136/bmj.o1301>

¹⁴⁶ Wen-Tien Tsai (2005). An overview of environmental hazards and exposure risk of hydrofluorocarbons (HFCs), Chemosphere, 11, 1539. Available at: <https://doi.org/10.1016/j.chemosphere.2005.03.084>

¹⁴⁷ Parthiban et al., (2021). Disposal methods, health effects and emission regulations for sulfur hexafluoride and its by-products, Journal of Hazardous Materials, 417, 126107. Available at: <https://doi.org/10.1016/j.jhazmat.2021.126107>

¹⁴⁸ Wen-Tien Tsai (2005). An overview of environmental hazards and exposure risk of hydrofluorocarbons (HFCs), Chemosphere, 11, 1539. Available at: <https://doi.org/10.1016/j.chemosphere.2005.03.084>

¹⁴⁹ Emmen et al., (2000). Human Safety and Pharmacokinetics of the CFC Alternative Propellants HFC 134a (1,1,2-Tetrafluoroethane) and HFC 227 (1,1,1,2,3,3,3-Heptafluoropropane) Following Whole-Body Exposure, Regulatory Toxicology and Pharmacology, 32, 22. Available at: <https://doi.org/10.1006/rtp.2000.1402>

¹⁵⁰ Ema et al., (2010). Reproductive and developmental toxicity of hydrofluorocarbons used as refrigerants, Reproductive Toxicology, 29, 125. Available at: <https://doi.org/10.1016/j.reprotox.2009.11.005>

A limited number of animal studies have indicated potential liver hepatotoxicity following exposure to F-gases.¹⁵¹ Halothane (CF₃CHClBr) is an anaesthetic introduced in the 1950s which is now known to induce mild hepatitis and/or severe hepatotoxicity, though the incidence rate has not been significant in large scale studies.¹⁵² A 1997 study identified nine humans who had 'repeated and accidental' occupational exposure to 1,1-dichloro-2,2,2-trifluoroethane (HCFC 123) and 1-chloro-1,2,2,2-tetrafluoroethane (HCFC 124), which are structurally similar to halothane, for extensive periods. The biopsies revealed hepatocellular coagulative necrosis (liver disease) and the study concluded that repeated exposures can result in serious liver injury.¹⁵³

The above studies do not indicate the required exposures for effects. However, these effects were only observed following extremely high exposures (such as when used as an anaesthetic). Several studies also conclude there are minimal risks to human health at typical and even likely environmental concentrations.

The more prominent concern regarding F-gases, however, is their degradation to form trifluoroacetic acid (TFA).¹⁵⁴ TFA has been considered in the previous 'PFAA and PFAA precursor' section. In summary, regarding human health concerns, TFA currently has a proposed classification in the EU as Acute Tox. 4 (H332, harmful if inhaled), Skin Corr. 1A (H314d, causes severe skin burns and eye damage). It is proposed for classification instead as Acute Tox. 3 (H331, toxic if inhaled), Skin Corr. 1A (as previous) and Repr. 1B (H360Df, may damage fertility or the unborn child).¹⁵⁵

Fluoropolymers

Fluoropolymers, particularly focussing on PTFE and PVDF, are generally regarded as safe (in the polymer form) due to their high molecular weight and chemical inertness. However, their manufacture and waste stage can lead to human exposures to other PFAS (e.g., PFAAs) which can affect human health as already outlined in this report.¹⁵⁶ Some studies also report that there is insufficient evidence to conclude fluoropolymers as a group are safe due to the data gaps for large numbers of chemicals.¹⁵⁷

PTFE is considered non-toxic in its polymer form. However, it is used in non-stick coatings in cooking appliances and evidence suggested that at elevated temperatures, such as those used when cooking, ultrafine particles (<100 nm) and known toxic gases (e.g., TFA, PFOA, etc) are released.¹⁵⁸ Ultrafine PTFE particles have been shown to cause high pulmonary toxicity and sometimes death in rats.¹⁵⁹ Despite this, no specific human health outcomes were identified.

PVDF is a non-toxic polymer and its constituent monomer (vinylidene fluoride) is approved for use in food contact materials in the EU, according to Regulation 10/2011 on plastic materials and articles

¹⁵¹ Hoet et al., (1997), Epidemic of liver disease caused by hydrochlorofluorocarbons used as ozone-sparing substitutes of chlorofluorocarbons, *The Lancet*, 350, 556. Available at: [https://doi.org/10.1016/S0140-6736\(97\)03094-8](https://doi.org/10.1016/S0140-6736(97)03094-8)

¹⁵² Habibollahi et al., (2011), Halothane-induced hepatitis: A forgotten issue in developing countries, *Hepatitis Monthly*, 2011, 11, 3. Available at: <https://pubmed.ncbi.nlm.nih.gov/22087107/>

¹⁵³ Hoet et al., (1997), Epidemic of liver disease caused by hydrochlorofluorocarbons used as ozone-sparing substitutes of chlorofluorocarbons, *The Lancet*, 350, 556. Available at: [https://doi.org/10.1016/S0140-6736\(97\)03094-8](https://doi.org/10.1016/S0140-6736(97)03094-8)

¹⁵⁴ Umwelt Bundesamt (2024). Degradation products of fluorinated greenhouse gases. Available at: [Degradation products of fluorinated greenhouse gases | Umweltbundesamt](#)

¹⁵⁵ European Chemicals Agency (no date). Registry of CLH intentions until outcome – trifluoroacetic acid. Available at: [Registry of CLH intentions until outcome - ECHA](#) [date accessed 19.02.2025]

¹⁵⁶ Sajid et al., (2017), PTFE-coated non-stick cookware and toxicity concerns: a perspective, *Environmental Science and Pollution Research*, 24, 23436. Available at: <https://doi.org/10.1007/s11356-017-0095-y>

¹⁵⁷ Lohmann et al., (2020). Are Fluoropolymers Really of Low Concern for Human and Environmental Health and Separate from Other PFAS?, *Environmental Science and Technology*, 54, 12820. Available at: <https://doi.org/10.1021/acs.est.0c03244>

¹⁵⁸ Sajid et al., (2017), PTFE-coated non-stick cookware and toxicity concerns: a perspective, *Environmental Science and Pollution Research*, 24, 23436. Available at: <https://doi.org/10.1007/s11356-017-0095-y>

¹⁵⁹ Oberdurst et al., (2000). Toxicology of ultrafine particles: in vivo studies, *Philosophical Transactions of the Royal Society A*,

intended to come into contact with food.¹⁶⁰ As with PTFE, PVDF manufacturing processes and waste stage may lead to exposures to other PFAS that are hazardous to human health.¹⁶¹

Conclusions

In 2019, the Nordic Council of Ministers reported consensus or emerging evidence on human health risks associated with PFAS exposure, most notably for increased cholesterol, liver damage, and decreased immune responses. This 2019 report also concluded that there were uncertainties relating to other health risks, such as cancer and endocrine disruption effects.¹⁶²

Several comprehensive meta-analyses and primary research studies have been published since. Upon review, the consensus within the scientific literature appears broadly unchanged. The evidence has strengthened for the association of some health risks to PFAS exposure, such as kidney cancer¹⁶³, whilst the links to other health risks (such as diabetes or ulcerative colitis) remain more suggestive or speculative. The level of certainty regarding the more conclusive endpoints (e.g., decreased immune response, liver damage) has not been contradicted in the intervening years.

In summary, findings from this research suggest that there are eight health risks across five categories confidently (with a score of 4 or 5 out of 5) associated with PFAS exposure. Table 3-4 below summarises these and highlights, where known, the exposure levels associated with each outcome.

Table 3-4: High confidence human health outcomes and PFAS levels associated with a risk.

Health outcome/ risk 'Group'	Specific health outcomes or risks attributable to PFAS exposure	Attribution or links by PFAS type (or *general)	Confidence (0=None, 5=High)	Blood serum levels associated with risk* (µg/L)
Infections	Respiratory infections	✓ PFOA, PFOS, PFHxS	4	PFOS: 19.4 PFOA: 4.62
Autoimmune disorders	Autoimmune thyroid disease	✓ PFAS*, PFOA, PFOS	4	PFOA: >5.7
Liver diseases	Liver disease	✓ PFAS*	4	Not stated
	Non-alcoholic fatty liver disease (NAFLD)	✓ PFOS, PFHxS	4	Not stated
Reproductive disorders	Low sperm count and mobility	✓ PFOA	4	Not stated
Maternal and neonatal risks	Gestational hypertension	✓ PFOA	4	Not stated
	Decreased foetal growth	✓ PFOA, PFOS	4	1 µg/L increase in PFOA associated with 19 g decrease in birth weight,
	Lower birth weight / small for gestational age (birth defects and	✓ PFOA, PFOS	4	

¹⁶⁰ European Commission (2011). Regulation (EC) 10/2011 on plastic materials and articles intended to come into contact with food. Available at: [Regulation - 10/2011 - EN - EUR-Lex](#)

¹⁶¹ Lohmann et al., (2020). Are Fluoropolymers Really of Low Concern for Human and Environmental Health and Separate from Other PFAS?, Environmental Science and Technology, 54, 12820. Available at: <https://doi.org/10.1021/acs.est.0c03244>

¹⁶² Goldenman et al. (2019). The cost of inaction: A socioeconomic analysis of environmental and health impacts linked to exposure to PFAS. Available at: [THE COST OF INACTION](#)

¹⁶³ Li et al (2025). Associations between per- and polyfluoroalkyl substances (PFAS) and county-level cancer incidence between 2016 and 2021 and incident cancer burden attributable to PFAS in drinking water in the United States, Journal of Exposure Science and Environmental Epidemiology. Available at: <https://doi.org/10.1038/s41370-024-00742-2>

Health outcome/ risk 'Group'	Specific health outcomes or risks attributable to PFAS exposure	Attribution or links by PFAS type (or *general)	Confidence (0-None, 5-High)	Blood serum levels associated with risk* (µg/L)
	development problems are indirectly associated with this)			which could lead to a reduction in up to 8 IQ points.

* - not exhaustive.

3.1.3. Q1.3 What are the observed risk relationships and/or predicted human health impacts from those risks?

Exposure-risk relationships

Exposure-health risk relationships characterise, quantitatively, the links between human exposure to a hazard, such as PFAS, and a specific adverse health outcome or risk, such as those described previously (Q1.2). These exposure-risk or exposure-response relationships or functions (ERRs or ERFs) can be defined as odds ratios (ORs), risk ratios (RRs) or the excess risk of acquiring or experiencing an adverse health outcome as a result of being exposed to certain levels of PFAS (or other) during periods of time.

Ahead of presenting the literature findings, we provide a summary of these ratios:

- An odds ratio (OR) is a measure of association used to compare the odds of an event occurring in an 'exposed' group to the odds of such an event occurring in a reference group. An OR > 1 suggests a positive association between the exposure and the outcome, an OR = 1 suggests no association and an OR < 1 suggests a negative association. For example, evidence presented in this section concerning PFOA exposure and kidney cancer (renal cell carcinoma) presents an odds ratio of 1.71, which means that individuals with PFOA exposure are 1.71 times more likely to have cancer compared to those with reference PFOA exposure.
- A risk ratio (RR) (also called a relative risk) is a measure used to compare the risk (or probability) of an event happening in an 'exposed' group to the risk of such a happening in a reference group. A RR = 1 implies no difference in risk between two groups, a RR > 1 implies a higher risk in the 'exposed' group compared to a reference group, and a RR < 1 implies a lower risk in the 'exposed' group. For example, evidence presented in this section suggests that there might be a RR of 1.27 for pneumonia and PFOA exposure, which means that individuals exposed to PFOA are 27% more likely to get pneumonia than those exposed to reference levels of PFOA.
- Excess risk is a measure that quantifies the absolute difference in the risk (or probability) of an event between two groups, usually an 'exposed' and a reference group. No evidence has been collected so far characterising the excess risk of PFAS exposure in this way.

The 2019 Nordic Council of Ministers study¹⁶⁴ reviewed epidemiological studies from 1980 to 2019. This review has been used as a basis to work from, complemented by new published sources of evidence and updates to previous PFAS exposure-risk relationships.

The Table below presents a mapping of the available literature evidence on exposure-risk association (see Q1.2) versus quantified exposure-risk relationships for key health risks (Q1.3). The literature review has been conducted for all of the endpoints captured in the exposure-risk association (Q1.2), regardless of the level of confidence, for completion and further consideration as part of the development of suitable methodologies for this study (Task 2). The confidence rating follows the

¹⁶⁴ Goldenman et al. (2019). *The cost of inaction: A socioeconomic analysis of environmental and health impacts linked to exposure to PFAS*. Available at: [THE COST OF INACTION](#)

same scoring criteria to that applied for the risk-exposure association under Q1.2. In general, there remain a number of health risks attributable to PFAS exposure which do not have (or for which we have not found) quantified risk relationships.

Table 3-5: Mapping of the risk relationships found in the literature, structured by the health risk 'group' and specific health risks attributable to PFAS Exposure

Health outcome/ risk 'Group'	Specific health outcomes or risks attributable to PFAS exposure	Attribution or links	Quantified risk relationships	Confidence in risk relationships (0=None, 5=High)
Infections	Respiratory infections	✓ PFOA, PFOS, PFHxS	✓ PFOA, PFOS	4
	Other infections	✓ PFOS	✓ PFOA, PFOS	3
Autoimmune disorders	Autoimmune thyroid disease	✓ PFAS*, PFOA, PFOS	✓ PFOA, PFOS	3
	Inflammatory Bowel Diseases	✓ PFAS*, PFOA, PFOS	x	-
Musculoskeletal disorders	Osteoporosis	✓ PFOA, PFOS, PFHxS, PFNA, PFUnDA	✓ PFOA, PFOS, PFHxS, PFNA	3
Cardiovascular disease risk factors	Diabetes	✓ PFAS*	✓ PFOA	2
	Obesity (incl. childhood adiposity)	✓ PFAS*	✓ PFOA, PFOS	2
	Hypertension	✓ PFOA, PFOS, PFNA, PFHxS x PFDA, PFUnDA	✓ PFOA, PFOS, PFNA, PFHxS	2
	High cholesterol (serum cholesterol levels)	✓ PFAS*, PFOA, PFOS	✓ PFOA, PFOS	1
Kidney diseases	Chronic kidney disease (incl. increased uric acid and dysfunction)	✓ PFAS* PFOA, PFOS, PFNA, PFHxS	✓ PFOA, PFOS, PFNA, PFHxS, PFDeA	1
Liver diseases	Liver disease	✓ PFAS*	x	-
	Non-alcoholic fatty liver disease (NAFLD)	✓ PFOS, PFHxS	✓ PFHxS	1
	Cirrhosis	✓ PFOA	x	-
Cancers	Kidney cancer	✓ PFAS* x PFOA, PFOS	✓ PFOA	3
	Liver cancer	✓ PFOA	x	-
	Breast cancer	✓ PFOSA	✓ PFOA, PFOS	1
	Testicular cancer	✓ PFOA, PFOS	✓ PFOA	3
	Prostate cancer	✓ PFOA ~ PFNA, PFHxS, PFDA, PFUnDA (if relatives too)	x	-
	Other cancers (generic)	✓ PFOA, PFOS	x	-
Reproductive disorders	Affected (later/earlier) puberty onset	✓ PFOA	x	-
	Low sperm count and mobility	✓ PFOA	x	-
	Menstruation alterations and endometriosis	✓ PFAS*	✓ PFOA, PFOS	2
	Time to pregnancy (decreased fecundity)	✓ PFOS	✓ PFOA, PFOS	2
	Decreased fertility	✓ PFOA, PFHxS	x	-
Maternal and neonatal risks	Gestational hypertension	✓ PFOA	✓ PFOS	1
	Gestational diabetes	✓ PFOA	✓ PFOA	1

Health outcome/ risk 'Group'	Specific health outcomes or risks attributable to PFAS exposure	Attribution or links	Quantified risk relationships	Confidence in risk relationships (0=None, 5=High)
	Preeclampsia	✓ PFOA, PFOS, PFHxS	✓ PFOA, PFOS, PFHxS	1
	Decreased foetal growth	✓ PFOA, PFOS	✓ PFOA	4
	Lower birth weight / small for gestational age (birth defects and development problems are indirectly associated with this)	✓ PFOA, PFOS	✓ PFOA, PFOS	3

The following sections summarise the detailed risk relationships documented in the literature, by health risk 'group', for further consideration and use in the next steps of this study.

Infections

Dalsager et al. (2021)¹⁶⁵ studied the relationship between exposure to PFOS, PFOA, PFHxS, PFNA and PFDA and lower respiratory tract infections using samples of blood serum from first trimester pregnant women in the Odense Child cohort in Denmark collected in 2010–2012. Data on child hospitalisations for infectious disease was obtained from the Danish National Patient Register. They found that every doubling of maternal PFOA or PFOS concentration increased the risk of lower respiratory tract infections by 27% (95% Confidence Interval or CI: 1%-59%) and 54% (95% CI: 11%-115%) respectively.

Impinen et al. (2019)¹⁶⁶ observed RRs of 1.27 (95% CI: 1.12–1.43) and 1.20 (95% CI: 1.07–1.34) for pneumonia/bronchitis and PFOA and PFOS exposure, respectively, in 0–3-year-olds from an analysis of 1,270 maternal-child pairs in the Norwegian Mother and Child Cohort Study.

For other infections, previous findings from the Odense Child cohort have shown that PFOS and PFOA concentrations in maternal blood serum were positively associated with the number of days that the children experienced fever. In a sample of 359 children aged 1–4 years, Dalsager et al. (2016)¹⁶⁷ found that PFOS and PFOA exposure in the top tertile compared to the low tertile was associated with a statistical increase in odds of experiencing days with fever above the median, with an Odd Ratio of 2.35 (95% CI: 1.31–4.11 and 1.97 (95% CI: 1.07–3.62) respectively.

Autoimmune disorders

For subclinical hypothyroidism in females, Wen et al. (2013)¹⁶⁸ estimated an OR of 7.42 (95% CI: 1.14–48.12) per natural logarithm (ln)-unit¹⁶⁹ increase of PFOA serum concentration and an OR of 3.03 (95% CI: 1.14–8.07) per natural logarithm (ln)-unit increase of PFOS serum concentration based on 2007–2010 U.S. National Health and Nutrition Examination Survey (NHANES) data from 1,181 adults.

No studies were found that supported the association between PFAS exposure and inflammatory bowel disease.

¹⁶⁵ Dalsager et al. (2021). Exposure to perfluoroalkyl substances during fetal life and hospitalization for infectious disease in childhood: A study among 1,503 children from the Odense Child Cohort. *Environment international*, 149, 106395. Available at: <https://doi.org/10.1016/j.envint.2021.106395>

¹⁶⁶ Impinen et al. (2019) Maternal levels of perfluoroalkyl substances (PFASs) during pregnancy and childhood allergy and asthma related outcomes and infections in the norwegian mother and child (MoBa) cohort. *Environ Int* 124:462–472. Available at: <https://doi.org/10.1016/j.envint.2018.12.041>

¹⁶⁷ Dalsager et al. (2016). Association between prenatal exposure to perfluorinated compounds and symptoms of infections at age 1–4 years among 359 children in the Odense Child Cohort. *Environment international*, 96, 58–64. Available at: <https://doi.org/10.1016/j.envint.2016.08.026>

¹⁶⁸ Wen et al. (2013). Association between serum perfluorinated chemicals and thyroid function in U.S. adults: the National Health and Nutrition Examination Survey 2007–2010. *The Journal of clinical endocrinology and metabolism*, 98(9), E1456–E1464. Available at: <https://doi.org/10.1210/jc.2013-1282>

¹⁶⁹ Could be approximated to 'percentage growth' against an original series/baseline

Musculoskeletal disorders

Khalil et al. (2016)¹⁷⁰ found that in a representative sample of the U.S. adult population, serum PFAS concentrations, mostly in women, were associated with lower bone mineral density and osteoporosis, which varied according to the specific PFAS assessed. The OR for osteoporosis prevalence in women with a one ln-unit increase in serum PFOA, PFHxS, and PFNA were as follows: 1.84 (95% CI: 1.17, 2.905), 1.64 (95% CI: 1.14, 2.38), and 1.45 (95% CI: 1.02, 2.05), respectively. More recently, Kai Tao et al. (2024)¹⁷¹ performed a meta-analysis of 11 studies and found that exposure to PFAS was associated with lower bone mineral density.

Prenatal exposure to PFAS may also play a role in bone development and future risk of osteoporosis. Bloomberg et al. (2022)¹⁷² performed a cohort study of 366 mother-child pairs in Norway and observed that PFAS exposures in childhood were negatively associated with bone mineral density. A doubling in age-5 PFNA was associated with a 0.15 decrease in the bone mineral density z-score (95% CI: - 0.26, - 0.039), with the association being stronger in males than females.

Cardiovascular disease risk factors

Sun et al. (2018)¹⁷³ conducted a prospective nested case-control study of type 2 diabetes to evaluate whether background exposures to PFASs in the late 1990s were associated with higher type 2 diabetes risk during the following years. They estimated an OR of type 2 diabetes of 1.54 (95% CI: 1.04–2.28) in the highest tertile of PFOA exposure compared to lowest tertile using a sample of 1,586 women in the Nurses' Health Study II (NHSII) in the U.S.

Min et al. (2012)¹⁷⁴ estimated the association between blood serum levels of PFAS and hypertension, which was used in the Nordic Council study (Goldenman et al., 2019) and EEA Study (Plass et al., 2023) to estimate the burden of disease. The exposure response function estimated based on U.S. NHANES data shows that hypertension is associated with PFOA in blood of participants older than 20 years. The adjusted OR for the 80th exposure percentile compared to the 20th percentile of log transformed PFOA concentrations is equal to 2.62 (95 % CI: 2.09 - 3.14). Pan et al. (2023)¹⁷⁵ showed that PFNA (OR = 1.11, 95% CI: 1.04–1.19), PFOA (OR = 1.12, 95% CI: 1.02–1.23), PFOS (OR = 1.19, 95% CI: 1.06–1.34) and PFHxS (OR = 1.03, 95% CI: 1.00–1.06) were associated with hypertension, while other types of PFAS (PFDA, PFUnDA) had no statistical significance.

For childhood obesity, Liu et al. (2018a)¹⁷⁶ in their meta-analysis of 10 cohort studies comprising 6,076 participants with PFOA exposure identified a 0.09 (95% CI: 0.02-0.17) increase in body mass index (BMI) z-score¹⁷⁷ per ng/ mL increase in prenatal PFOA. For PFOS exposure, Lauritzen et al. (2018)¹⁷⁸ identified a 0.18 (95% CI: 0.01-0.35) increase in BMI z-score per ln-unit ng/ mL increase in prenatal

¹⁷⁰ Khalil et al. (2016). Association of perfluoroalkyl substances, bone mineral density, and osteoporosis in the U.S. population in NHANES 2009–2010. *Environ Health Perspect* 124:81–87. Available at: <https://doi.org/10.1289/ehp.1307909>

¹⁷¹ Kai Tao et al. (2024). Associations between Per- and Polyfluoroalkyl Substances Exposures and Bone Mineral: A Systematic Review and Best Evidence Synthesis. *Environ. Health*. Available at: <https://doi.org/10.1021/envhealth.4c00143>

¹⁷² Bloomberg, et al. (2022). Bone mass density following developmental exposures to perfluoroalkyl substances (PFAS): a longitudinal cohort study. *Environmental health : a global access science source*, 21(1), 113. Available at: <https://doi.org/10.1186/s12940-022-00929-w>

¹⁷³ Sun et al. (2018). Plasma Concentrations of Perfluoroalkyl Substances and Risk of Type 2 Diabetes: A Prospective Investigation among U.S. Women. *Environmental health perspectives*, 126(3), 037001. Available at: <https://doi.org/10.1289/EHP2619>

¹⁷⁴ Min et al. (2012). Perfluorooctanoic acid exposure is associated with elevated homocysteine and hypertension in US adults. *Occupational and environmental medicine*, 69(9), 658–662. Available at: <https://doi.org/10.1136/oemed-2011-100288>

¹⁷⁵ Pan et al., (2023). The relationship between perfluoroalkyl substances and hypertension: A systematic review and meta-analysis, *Environmental Research*, 232, 116362. Available at: <https://doi.org/10.1016/j.envres.2023.116362>

¹⁷⁶ Liu et al. (2018a). Perfluorooctanoic Acid (PFOA) Exposure in Early Life Increases Risk of Childhood Adiposity: A Meta-Analysis of Prospective Cohort Studies. *International Journal of Environmental Research and Public Health*, 15(10), 2070. Available at: <https://doi.org/10.3390/ijerph15102070>

¹⁷⁷ Body mass index (BMI) is a measurement of body fat based on height and weight. The z-score, the number resulting from the calculation, indicates where a particular measurement falls in the range of body fat measurements.

¹⁷⁸ Lauritzen et al. (2018). Prenatal exposure to persistent organic pollutants and child overweight/obesity at 5-year follow-up: a prospective cohort study. *Environmental health : a global access science source*, 17(1), 9. Available at: <https://doi.org/10.1186/s12940-017-0338-x>

PFOS, using serum from 412 pregnant Norwegian and Swedish women participating in a Scandinavian prospective cohort study collected in 1986-88.

Liu et al. (2018b)¹⁷⁹ estimated the relationship between PFOS exposure and adult obesity using a study of 520 adults followed for 6–24 months after the end of a 2-year clinical trial of energy-restricted diets on weight change. The study reported that those with PFOS levels >32.1 ng/mL gained 3.2 kg over the study period, those with levels 19.2–32.1 ng/mL gained 3.5 kg, and those with levels <19.2 ng/mL gained 1.5 kg.

For the relationship between PFAS exposure and high cholesterol levels, Eriksen et al. (2013)¹⁸⁰ observed a 4.4 (95 % CI 1.1-7.8) higher concentration of total cholesterol (mg/dL) per interquartile range (IQR) of PFOA and 4.6 (95 % CI 0.8-8.5) higher concentration of total cholesterol (mg/dL) per IQR change of PFOS in a sample of 753 individuals (663 men and 90 women), 50–65 years of age. However, the EEA Study (Plass et al., 2023) notes that concentrations identified in the ERF were observed to be higher than data gathered under HBM4EU for adults and therefore, the ERF was not valid. The U.S. EPA (2024)¹⁸¹ estimated a positive increase in total cholesterol (TC) of 1.57 (95% CI: 0.02-3.13) mg/dL per ng/mL serum PFOA, and of 0.08 (95% CI: -0.01-0.16) mg/dL per ng/mL serum PFOS based on a meta-analysis of 14 studies reporting linear associations between TC and serum PFOA or PFOS.

Kidney diseases

Shankar et al. (2011)¹⁸² used data for 4,587 adults and found that the odds ratio for chronic kidney disease (CKD) was 1.73 (95% CI: 1.04-2.88) for PFOA and 1.82 (95% CI: 1.01-3.27) for PFOS among subjects in quartile 4 compared with subjects in quartile 1.

However, the evidence of the association between PFAS exposure and the risk of kidney disease remains inconclusive.

- In addition to findings from Shankar et al. (2011), more recent studies highlight that the links between human exposure to PFAS and kidney disease risk are not conclusive. For example, Blake et al. (2018)¹⁸³ used data for 210 individuals from a highly exposed community and observed that higher PFNA, PFHxS and PFDeA blood serum levels were significantly associated with lower measures of reduced kidney function but found null association between PFOA and reduced kidney function. However, Dhingra et al. (2017)¹⁸⁴ used data for 29,499 highly exposed individuals from the US C8 Health Project and concluded that reduced kidney function was the cause rather than the result of elevated serum PFOA level.
- The EFSA CONTAM Panel (2020)¹⁸⁵ also states that there is insufficient evidence from epidemiological studies to conclude that exposure to PFAS decreases glomerular filtration rate in the kidney or leads to an increase in uric acid in serum.

¹⁷⁹ Liu et al. (2018b). Perfluoroalkyl substances and changes in body weight and resting metabolic rate in response to weight-loss diets: A prospective study. *PLoS medicine*, 15(2), e1002502. Available at: <https://doi.org/10.1371/journal.pmed.1002502>

¹⁸⁰ Eriksen et al. (2013). Association between plasma PFOA and PFOS levels and total cholesterol in a middle-aged Danish population. *PloS one*, 8(2), e56969. Available at: <https://doi.org/10.1371/journal.pone.0056969>

¹⁸¹ U.S. EPA (2024). Economic Analysis for the Final Per- and Polyfluoroalkyl Substances National Primary Drinking Water Regulation. EPA Document Number: EPA-815-R-24-001. Available at: https://www.epa.gov/system/files/documents/2024-04/pfas-npdwr_final-rule_ea.pdf

¹⁸² Shankar et al. (2011). Perfluoroalkyl chemicals and chronic kidney disease in US adults. *American journal of epidemiology*, 174(8), 893-900. Available at: <https://doi.org/10.1093/aje/kwr171>

¹⁸³ Blake et al. (2018). Associations between longitudinal serum perfluoroalkyl substance (PFAS) levels and measures of thyroid hormone, kidney function, and body mass index in the Fernald Community Cohort. *Environmental pollution (Barking, Essex: 1987)*, 242(Pt A), 894-904. Available at: <https://doi.org/10.1016/j.envpol.2018.07.042>

¹⁸⁴ Dhingra et al. (2017). A Study of Reverse Causation: Examining the Associations of Perfluorooctanoic Acid Serum Levels with Two Outcomes. *Environmental health perspectives*, 125(3), 416-421. Available at: <https://doi.org/10.1289/EHP273>

¹⁸⁵ EFSA CONTAM Panel (EFSA Panel on Contaminants in the Food Chain) (2020). Scientific Opinion on the risk to human health related to the presence of perfluoroalkyl substances in food. *EFSA Journal* 2020;18(9):6223, 391 pp. Available at: <https://doi.org/10.2903/j.efsa.2020.6223>

- Overall, there is a lack of long-term exposure studies and lack of conclusive evidence on this endpoint, alongside the possibility that the observed associations are a result of reverse causality.

Liver diseases

No consistent or valid quantified exposure response relationships were evidenced for liver diseases.

Costello et al. (2022)¹⁸⁶ in their meta-analysis of 24 human studies found that higher serum alanine aminotransferase levels, considered to be an indicator of liver injury, were associated with exposure to PFOA, PFOS and PFNA. However, they did not estimate any exposure-response functions.

Based on 2017-2018 NHANES cross-sectional study data for participants, Zhang et al (2023)¹⁸⁷ observed an odds ratio for fatty liver disease (FLD) per ln-transformed SD increase in PFHxS was 1.13 (95% CI: 1.01-1.26). However, when stratified by alcohol intake status no association was found for non-alcoholic fatty liver disease (NAFLD) in never or light drinkers. In addition, confounders such as environmental exposure to other liver toxicants were not controlled in the models.

Cancer

Bartell and Vieira (2021)¹⁸⁸ observed an average relative increase in cancer risk per 10 ng/mL increase in serum PFOA of 16% (95% CI: 3%, 30%) for kidney cancer based on a meta-analysis of 4 studies. Shearer et al. (2021) observed a positive association with renal cell carcinoma (RCC) risk for PFOA (OR = 1.71, 95% CI = 1.23-2.37) per doubling in serum concentration, which was used by the U.S. EPA (2024)¹⁸⁹ to estimate the costs of implementing the National Primary Drinking Water Regulations (NPDWRs) for drinking water contaminants.

Similarly, they also observed an average relative increase in cancer risk per 10 ng/mL increase in serum PFOA of 3% (95% CI: 2%, 4%) for testicular cancer based on a meta-analysis of 2 studies. However, these results are limited by the overlapping study populations and the lack of measured or modelled serum PFOA concentrations for several studies.

For breast cancer, Wielsøe et al. (2017)¹⁹⁰ found ORs of 1.26 per ng/mL of serum PFOA and 1.02 per ng/mL of serum PFOS from a case-control study of 161 Inuit women in Greenland (including 77 breast cancer cases and 84 controls), where the sampling was carried out in two time periods (2000–2003 and 2011–2014).

Reproductive disorders

Buck Louis et al. (2012)¹⁹¹ found an association between serum PFOA levels and endometriosis and an OR of 1.89 (95% CI: 1.17-3.06), using data from the Endometriosis: Natural History, Diagnosis, and Outcomes (ENDO) study, a case-control study of 495 women aged 18–44 years in the U.S.

Vagi et al. (2014)¹⁹² conducted a case-control study with 52 polycystic ovarian syndrome (PCOS) case-patients and 50 controls recruited in 2007–2008 in the U.S. They found a 6.93 (95% CI: 1.79–29.92) OR

¹⁸⁶ Costello et al. (2022). Exposure to per- and Polyfluoroalkyl Substances and Markers of Liver Injury: A Systematic Review and Meta-Analysis. *Environmental health perspectives*, 130(4), 46001. Available at: <https://doi.org/10.1289/EHP10092>

¹⁸⁷ Zhang, et al. (2023). Association of per- and polyfluoroalkyl substance exposure with fatty liver disease risk in US adults. *JHEP reports : innovation in hepatology*, 5(5), 100694. Available at: <https://doi.org/10.1016/j.jhepr.2023.100694>

¹⁸⁸ Bartell and Vieira (2021). Critical review on PFOA, kidney cancer, and testicular cancer. *Journal of the Air & Waste Management Association* (1995), 71(6), 663–679. Available at: <https://doi.org/10.1080/10962247.2021.1909668>

¹⁸⁹ Shearer et al. (2021). Serum Concentrations of Per- and Polyfluoroalkyl Substances and Risk of Renal Cell Carcinoma. *Journal of the National Cancer Institute*, 113(5), 580–587. Available at: <https://doi.org/10.1093/inci/djaa143>

¹⁹⁰ Wielsøe et al. (2017). Serum levels of environmental pollutants is a risk factor for breast cancer in Inuit: a case control study. *Environmental health: a global access science source*, 16(1), 56. Available at: <https://doi.org/10.1186/s12940-017-0269-6>

¹⁹¹ Buck Louis et al. (2012). Perfluorochemicals and endometriosis: the ENDO study. *Epidemiology (Cambridge, Mass.)*, 23(6), 799–805. Available at: <https://doi.org/10.1097/EDE.0b013e31826cc0cf>

¹⁹² Vagi et al. (2014). Exploring the potential association between brominated diphenyl ethers, polychlorinated biphenyls, organochlorine pesticides, perfluorinated compounds, phthalates, and bisphenol A in polycystic ovary syndrome: a case-control study. *BMC endocrine disorders*, 14, 86. Available at: <https://doi.org/10.1186/1472-6823-14-86>

of PCOS in highest tertile of PFOA exposure compared to lowest (Tertile 1: <2.6 ng/mL, Tertile 3: >4.1 ng/mL). They also found a 5.79 (95% CI: 1.58–24.12) OR of PCOS in highest tertile of PFOS exposure compared to lowest (Tertile 1: <6.2 ng/mL, Tertile 3: >8.6 ng/mL). However, these conclusions are limited by the small sample size and its statistical implications.

Drawing on data from a case–control analysis of 910 women nested within the Norwegian Mother and Child Cohort Study, Whitworth et al. (2012)¹⁹³ estimated a 0.67 (95% CI: 0.51–0.88) fecundability ratio per ln unit PFOA exposure and a 0.62 (95% CI: 0.47–0.83) fecundability ratio per log unit PFOS exposure for couple infertility, defined as time to pregnancy of more than 12 months.

Maternal and neonatal risks

Using data from 1,739 participants in a Canadian cohort, Borgehese et al. (2020)¹⁹⁴ found that neither PFOA nor PFOS were associated with gestational hypertension or preeclampsia. However, each doubling of PFHxS plasma concentration was associated with higher odds of developing preeclampsia (OR = 1.32; 95% CI: 1.03, 1.70). A meta-analysis of 6 studies by Hu et al. (2023)¹⁹⁵ showed that risk of preeclampsia increased with each ln-unit increment exposure to PFOA (RR = 1.39, 95% CI: 1.05–1.85; low certainty), PFOS (RR = 1.51, 95% CI: 1.23–1.86; moderate certainty), and PFHxS (RR = 1.39, 95% CI: 1.10–1.76; low certainty). Each ln-unit increment in PFOS exposure was also associated with an increased risk of hypertensive disorders of pregnancy (including gestational hypertension and preeclampsia) (RR = 1.39, 95% CI: 1.10–1.76; low certainty). Ebel et al. (2023)¹⁹⁶ found no evidence of increased risk of gestational hypertension and preeclampsia (OR 0.80; CI 0.63–1.03) after high PFAS exposure based on data on 27,292 childbirths between 1995 and 2013 from the National Medical Birth Register in Ronneby, Sweden.

Zhang et al. (2015)¹⁹⁷ found an odds ratio of gestational diabetes of 1.61 (1.05–2.49) per standard deviation increment of PFOA exposure in preconception serum. These results were based on a prospective cohort study in the U.S. where 501 women were recruited, 258 (51%) became pregnant and were eligible for the study, and 28 (11%) reported having physician diagnosed gestational diabetes during follow-up. However, Ebel et al. (2023)¹⁹⁸ found no evidence of gestational diabetes (OR 1.03; CI 0.67–1.58) after high PFAS exposure based on data on 27,292 childbirths between 1995 and 2013 from the National Medical Birth Register in Ronneby, Sweden.

Govarts et al. (2018)¹⁹⁹ reported that an interquartile increase of PFOA concentrations in cord serum (equal to 900 ng of PFOA/L) was associated with a higher risk of being born small for gestational age (SGA), defined as newborns with a weight below the 10th percentile of a standard weight by the age at birth, the country and sex of the baby) with an OR of 1.64 (95 % CI: 0.97 to 2.76), albeit the OR was borderline non-significant and larger than for the other analysed chemicals in the study. These risks were expected to present above the 25th percentile cord serum (equal to 300 ng of PFOA/L).

¹⁹³ Whitworth et al. (2012). Perfluorinated compounds and subfecundity in pregnant women. *Epidemiology (Cambridge, Mass.)*, 23(2), 257–263. Available at: <https://doi.org/10.1097/EDE.0b013e31823b5031>

¹⁹⁴ Borgehese et al. (2020). Association of perfluoroalkyl substances with gestational hypertension and preeclampsia in the MIREC study. *Environment international*, 141, 105789. Available at: <https://doi.org/10.1016/j.envint.2020.105789>

¹⁹⁵ Hu et al. (2023). Perfluoroalkyl and polyfluoroalkyl substances and hypertensive disorders of pregnancy: A systematic review and meta-analysis. *Environmental research*, 231(Pt 2), 116064. Available at: <https://doi.org/10.1016/j.envres.2023.116064>

¹⁹⁶ Ebel et al. (2023). Gestational hypertension, preeclampsia, and gestational diabetes mellitus after high exposure to perfluoroalkyl substances from drinking water in Ronneby, Sweden. *Environmental research*, 239(Pt 1), 117316. Available at: <https://doi.org/10.1016/j.envres.2023.117316>

¹⁹⁷ Zhang et al. (2015). A prospective study of prepregnancy serum concentrations of perfluorochemicals and the risk of gestational diabetes. *Fertility and sterility*, 103(1), 184–189. Available at: <https://doi.org/10.1016/j.fertnstert.2014.10.001>

¹⁹⁸ Ebel et al. (2023). Gestational hypertension, preeclampsia, and gestational diabetes mellitus after high exposure to perfluoroalkyl substances from drinking water in Ronneby, Sweden. *Environmental research*, 239(Pt 1), 117316. Available at: <https://doi.org/10.1016/j.envres.2023.117316>

¹⁹⁹ Govarts et al. (2018). Prenatal exposure to endocrine disrupting chemicals and risk of being born small for gestational age: Pooled analysis of seven European birth cohorts. *Environment international*, 115, 267–278. Available at: <https://doi.org/10.1016/j.envint.2018.03.017>

Other studies have also described quantified relationships between PFAS exposure and Low birth weight (LBW) (defined as a birthweight lower than 2,500g). The Nordic Council study (2019) used the ERF from Stein et al. (2009)²⁰⁰ which found that PFOA was not associated with an increase in low birth weight, but PFOS showed an increased risk above the median (OR = 1.5, 95% CI: 1.1-1.9). However, the association was small, limited in precision, and based solely on self-reported health outcomes.

Johnson et al. (2014)²⁰¹ estimated through meta-analysis, that a 1 ng/mL increase of PFOA in serum or plasma was associated with a -18.9 g (95% CI: -29.8, -7.9) difference in birth weight. Meng et al. (2018)²⁰² observed a 45.2 g decrease (95% CI: -76.8, -13.6) in birth weight per doubling of early pregnancy maternal plasma concentrations of PFAS, based on a study of 3,535 mother–infant pairs in the Danish National Birth Cohort study. In their meta-analysis of 24 studies, Steenland et al. (2018)²⁰³ found a change of birthweight of -10.5 g (-16.7, -4.4) for every ng/mL of PFOA in maternal or cord blood serum, but the results were sensitive to the exposure and blood sampling stage (early or later in pregnancy).

LBW/SGA also presents an increased risk for impaired cognitive development or IQ loss. Eves et al. (2020)²⁰⁴ found that newborns with SGA have an IQ retardation of 8 IQ points lower than newborns with normal weight for gestational age and this retardation was reduced to 3 points during the development until adulthood. Based on these results, Plass et al. (2023)²⁰⁵ estimated an age-weighted loss of IQ over life of 4.25 points per SGA case.

In **summary**, the evidence identified in the literature comprises quantified risk-relationships for infections (such as lower respiratory tract infections, pneumonia/ bronchitis, and days with fever), autoimmune disorders (such as subclinical hypothyroidism), musculoskeletal disorders (such as lower bone mineral density and osteoporosis), chronic kidney disease, non-alcoholic fatty liver disease, cardiovascular disease risk factors (such as type 2 diabetes, hypertension, obesity, and high cholesterol levels), cancer (including of the kidney, breasts and testicles), reproductive disorders (such as endometriosis, polycystic ovarian syndrome, and time to pregnancy) and maternal and neonatal risks (such as gestational hypertension, diabetes, small for gestational age, low birth weight, and impaired cognitive development or IQ loss).

Human health impact analysis

These risk-relationships can also be used to quantify potential human health impacts across populations of interest. Potential health impacts could be described in terms of:

- Cases of ill health, including infections
- Healthcare events or episodes (admissions, consultations, etc)
- Days of sickness or ill health
- Years lived with disability (YLDs)
- Years of life lost (YLLs) due to preventable mortality
- Disability-Adjusted Life Years (DALYs)

²⁰⁰ Stein et al. (2009). Serum levels of perfluorooctanoic acid and perfluorooctane sulfonate and pregnancy outcome. *American journal of epidemiology*, 170(7), 837–846. Available at: <https://doi.org/10.1093/aje/kwp212>

²⁰¹ Johnson et al. (2014). The Navigation Guide - evidence-based medicine meets environmental health: systematic review of human evidence for PFOA effects on fetal growth. *Environmental health perspectives*, 122(10), 1028–1039. Available at: <https://doi.org/10.1289/ehp.1307893>

²⁰² Meng et al. (2018). Prenatal Exposure to Perfluoroalkyl Substances and Birth Outcomes: An Updated Analysis from the Danish National Birth Cohort. *International journal of environmental research and public health*, 15(9), 1832. Available at: <https://doi.org/10.3390/ijerph15091832>

²⁰³ Steenland et al. (2018). Serum Perfluorooctanoic Acid and Birthweight: An Updated Meta-analysis With Bias Analysis. *Epidemiology (Cambridge, Mass.)*, 29(6), 765–776. Available at: <https://doi.org/10.1097/EDE.0000000000000903>

²⁰⁴ Eves et al. (2020). Small for gestational age-cognitive performance from infancy to adulthood: an observational study. *BJOG : an international journal of obstetrics and gynaecology*, 127(13), 1598–1606. Available at: <https://doi.org/10.1111/1471-0528.16341>

²⁰⁵ European Environment Agency (2023). Estimating the burden of disease due to lead, PFAS, phthalates, cadmium, pyrethroids and bisphenol A using HBM4EU data - test of feasibility and first results for selected countries. Available at: [ETC HE Report 2023/13: Estimating the burden of disease due to lead, PFAS, phthalates, cadmium, pyrethroids and bisphenol A using HBM4EU data - test of feasibility and first results for selected countries – Eionet Portal](https://www.eea.europa.eu/en/press/2023/13-estimating-the-burden-of-disease-due-to-lead-pfas-phthalates-cadmium-pyrethroids-and-bisphenol-a-using-hbm4eu-data-test-of-feasibility-and-first-results-for-selected-countries-fionet-portal)

- Preventable deaths

Only a limited number of studies found in the literature contain some quantification of potential human health impacts associated with PFAS exposure, and this is primarily in terms of events/ days of ill health, attributable prevalence (e.g., population attributable factors (PAFs)), YLDs, DALYs, and to a lower extent, preventable deaths. The available evidence is mapped in the Table below, against the health risks for which there are available risk-relationships.

Table 3-6: Mapping of the human health impacts identified in the literature, structured by the health risk 'group', specific health risks attributable to PFAS exposure (in contrast to the evidence of quantified risk relationships), focusing on PFAA and PFAA precursors.

Group of adverse health outcomes or risks attributable to PFAS exposure	Specific health risks attributable to PFAS exposure	Exposure-Risk Functions or Quantified relationships	Events/ days of illness (e.g., days of admission, with fever, etc)	Incidence/ attributable prevalence (Numbers, %, etc.)	Years lived with disability	Years of life lost due to preventable mortality	Disability Adjusted Life Years	Preventable deaths
Infections	Respiratory	✓ PFOS	✓	✓	✓	x	x	x
	Other	✓ PFOS	✓	x	x	x	x	x
Autoimmune	ATD	✓ PFOA, PFOS	x	✓	x	x	x	x
Musculoskeletal disorders	Osteoporosis	✓ PFOA, PFHxS, PFNA	x	x	x	x	x	x
Cardiovascular risks or diseases	Diabetes	✓ PFOA	✓	✓	x	x	x	x
	Obesity	✓ PFOA, PFOS	✓	✓	x	x	x	x
	Hypertension	✓ PFOA, PFOS, PFNA, PFHxS	x	x	x	✓	x	✓
Kidney diseases Liver diseases	High cholesterol	✓ PFOA, PFOS	x	x	x	x	x	x
	CKD	✓ PFOA, PFOS, PFNA, PFHxS, PFDeA	x	x	x	x	x	x
	NAFLD	✓ PFHxS	x	x	x	x	x	x
Cancers	Kidney cancer	✓ PFOA	✓	✓	x	x	✓	x
	Breast cancer	✓ PFOA, PFOS	✓	✓	x	x	✓	x
	Testicular cancer	✓ PFOA	✓	✓	x	x	✓	x

Group of adverse health outcomes or risks attributable to PFAS exposure	Specific health risks attributable to PFAS exposure	Exposure-Risk Functions or Quantified relationships	Events/ days of illness (e.g., days of admission, with fever, etc)	Incidence/ attributable prevalence (Numbers, %, etc.)	Years lived with disability	Years of life lost due to preventable mortality	Disability Adjusted Life Years	Preventable deaths
Reproductive disorders	Menstruation alterations/ endometriosis	✓ PFOA, PFOS	✓	✓	x	x	x	x
	Time to pregnancy	✓ PFOA, PFOS	✓	✓	x	x	x	x
Maternal and neonatal risks	Gestational hypertension	✓ PFOS	x	x	x	x	x	x
	Gestational diabetes	✓ PFOA	✓	✓	x	x	x	x
	Decreased foetal growth	✓ PFOA	x	x	x	x	x	x
	Lower birth weight*	✓ PFOA, PFOS	✓	✓	x	x	✓	x

*and small for gestational age (which is linked with birth defects and development problems)

As can be observed in the Table above, there are health risks for which risk-relationships exist and yet, we have not identified literature which has used this information to quantify attributable health impacts.

The following sections provide a more in-depth presentation of the quantified health impacts of PFAS exposure identified in the literature, structured by health risk 'group'.

Infections

Using the exposure-response function from Dalsager et al. (2021)²⁰⁶, the EEA study (Plass et al., 2023)²⁰⁷ estimated the years lived with disability (YLDs) as a result of hospitalisation due to lower respiratory tract infections (LRTI) for six countries in the EU (Austria, Belgium, Czechia, Denmark, Norway, and Spain). Exposure data for their calculations are based on concentrations in blood of adults from the HBM4EU dashboard. A disability weight of 0.65 and hospitalization duration of 14 days was used for this purpose. The burden of disease for LRTI due to exposure to PFOS in 2021 was estimated, in Disability-Adjusted Life Years, as: Austria: 0; Belgium: 91 (95% CI: 27-134); Czechia: 28 (95% CI: 8-41); Denmark: 52 (95% CI: 15-77); Norway: 71 (95%CI: 22-98); and Spain: 253 (95% CI: 74-376).²⁰⁸ It must be noted that the estimates do not consider mortality risks, and thus, the actual DALY contribution of PFAS exposure may be underestimated.

Using Impinen et al. (2019)'s²⁰⁹ exposure-response functions, Obsekov, Kahn and Trasande (2023)²¹⁰ estimated 447 to 6,759 PFOA/PFOS-attributable cases of pneumonia in children under age 3 per year in the U.S., resulting in an attributable fraction of 0.58%-8.81%.

The Nordic Council study (Goldenman et al., 2019)²¹¹ estimated the PFAS-attributable days of fever per year for the exposed population using the ERF identified by Dalsager et al. (2016)²¹², amounting to 83,7421 days in the Nordic countries and 453,059 fever days in the EEA countries.

Autoimmune disorders

Obsekov, Kahn and Trasande (2023)²¹³ estimated the PFOA/PFOS-attributable fraction of hypothyroidism in females to be 5.0% in the U.S. in 2017-2018 (with a high estimate of 20.7%). 14,572 cases of hypothyroidism in females (with a high estimate of 59,939) were attributed to PFAS/PFOS using the ERF derived by Wen et al. (2013)²¹⁴.

²⁰⁶ Dalsager et al. (2021). Exposure to perfluoroalkyl substances during fetal life and hospitalization for infectious disease in childhood: A study among 1,503 children from the Odense Child Cohort. *Environment international*, 149, 106395. Available at: <https://doi.org/10.1016/j.envint.2021.106395>

²⁰⁷ European Environment Agency (2023). Estimating the burden of disease due to lead, PFAS, phthalates, cadmium, pyrethroids and bisphenol A using HBM4EU data - test of feasibility and first results for selected countries. Available at: [ETC HE Report 2023/13: Estimating the burden of disease due to lead, PFAS, phthalates, cadmium, pyrethroids and bisphenol A using HBM4EU data - test of feasibility and first results for selected countries – Eionet Portal](https://etcreport2023/13-estimating-the-burden-of-disease-due-to-lead-pfas-phthalates-cadmium-pyrethroids-and-bisphenol-a-using-hbm4eu-data-test-of-feasibility-and-first-results-for-selected-countries-eionet-portal)

²⁰⁸ PFAS exposure levels for Austria were observed to be very low according to HBM4EU serum concentration data, leading to 0 attributable cases of LRTI.

²⁰⁹ Impinen et al. (2019) Maternal levels of perfluoroalkyl substances (PFASs) during pregnancy and childhood allergy and asthma related outcomes and infections in the Norwegian mother and child (MoBa) cohort. *Environ Int* 124:462-472. Available at: <https://doi.org/10.1016/j.envint.2018.12.041>

²¹⁰ Obsekov, Kahn & Trasande (2023). Leveraging Systematic Reviews to Explore Disease Burden and Costs of Per- and Polyfluoroalkyl Substance Exposures in the United States. *Exposure and health*, 15(2), 373-394. Available at: <https://doi.org/10.1007/s12403-022-00496-y>

²¹¹ Goldenman et al. (2019). The cost of inaction: A socioeconomic analysis of environmental and health impacts linked to exposure to PFAS. Available at: [THE COST OF INACTION](https://www.eionet.europa.eu/etcreport2019/1-the-cost-of-inaction)

²¹² Dalsager et al. (2016). Association between prenatal exposure to perfluorinated compounds and symptoms of infections at age 1-4 years among 359 children in the Odense Child Cohort. *Environment international*, 96, 58-64. Available at: <https://doi.org/10.1016/j.envint.2016.08.026>

²¹³ Obsekov, Kahn & Trasande (2023). Leveraging Systematic Reviews to Explore Disease Burden and Costs of Per- and Polyfluoroalkyl Substance Exposures in the United States. *Exposure and health*, 15(2), 373-394. Available at: <https://doi.org/10.1007/s12403-022-00496-y>

²¹⁴ Wen et al. (2013). Association between serum perfluorinated chemicals and thyroid function in U.S. adults: the National Health and Nutrition Examination Survey 2007-2010. *The Journal of clinical endocrinology and metabolism*, 98(9), E1456-E1464. Available at: <https://doi.org/10.1210/jc.2013-1282>

Cardiovascular disease risk factors

Plass et al. (2023)²¹⁵ estimated the DALYs from hypertension using the ERF from Min et al. (2012)²¹⁶. Serum PFOA level data for adults was gathered from the HBM4EU studies for six countries in the EU (Austria, Belgium, Czechia, Denmark, Norway, and Spain). The number of attributable cases were calculated in line with the Nordic Council study (Goldenman et al., 2019) and only focussed on YLL, and thus, it does not account for YLD. The burden of disease in DALYs (driven by YLL) in 2021 resulting from hypertension associated with PFOA exposures were estimated as: Austria: 0, Belgium: 1,024 (95%CI: 320-1,828), Czechia: 100 (1-227), Denmark: 140 (34-280), Norway: 243 (95%CI: 77-416), and Spain: 2,591 (95%CI: 1,003-4,193).²¹⁷

Obsekov, Kahn and Trasande (2023)²¹⁸ estimated the burden of disease from several cardiovascular disease risk factors:

- The incident cases of type 2 diabetes in females in the U.S. in 2017–18 due to PFOA exposure were estimated using an exposure-response function from Sun et al. (2018)²¹⁹. This resulted in an estimate of 1,728 attributable incident cases per year and an attributable fraction of 0.37%.
- For childhood obesity, incremental increases in obesity were calculated using ERFs from Liu et al. (2018a)²²⁰, associated with PFOA/PFOS, and then multiplied by the number of 10-year-olds in 2018. The result is 127,362 – 462,119 PFOA/PFOS-attributable incident cases per year and an attributable fraction of 3.78% – 13.70%.
- The increase in adult obesity estimated using Liu et al. (2018b)'s²²¹ ERF was multiplied by the number of adults in the US in 2018 and adjusted for a baseline prevalence of obesity (42.4%). This resulted in 4,294,379 PFOS-attributable incident cases per year and an attributable fraction of 2.98%.

Cancers

The 2019 Nordic Council study (Goldenman et al., 2019)²²² compiled information on the potential impacts of exposure to PFAS for workers involved in PFAS production and manufacture of PFAS-containing products. The study estimating between 3.6 and 11.8 additional deaths per year from kidney cancer attributable to elevated PFAS exposure, using epidemiological evidence identified by Steenland and Woskie (2012)²²³ and extrapolating it to the European context by making assumptions about the number of PFAS-producing, PFAS-using and PFAS-emitting plants in Europe as well as their employees.

²¹⁵ European Environment Agency (2023). Estimating the burden of disease due to lead, PFAS, phthalates, cadmium, pyrethroids and bisphenol A using HBM4EU data - test of feasibility and first results for selected countries. Available at: [ETC HE Report 2023/13: Estimating the burden of disease due to lead, PFAS, phthalates, cadmium, pyrethroids and bisphenol A using HBM4EU data - test of feasibility and first results for selected countries - Eionet Portal](https://doi.org/10.1136/oemed-2011-100288)

²¹⁶ Min et al. (2012). Perfluorooctanoic acid exposure is associated with elevated homocysteine and hypertension in US adults. *Occupational and environmental medicine*, 69(9), 658–662. Available at: <https://doi.org/10.1136/oemed-2011-100288>

²¹⁷ PFAS exposure levels for Austria were observed to be very low according to HBM4EU serum concentration data, leading to 0 attributable cases of hypertension.

²¹⁸ Obsekov, Kahn & Trasande (2023). Leveraging Systematic Reviews to Explore Disease Burden and Costs of Per- and Polyfluoroalkyl Substance Exposures in the United States. *Exposure and health*, 15(2), 373–394. Available at: <https://doi.org/10.1007/s12403-022-00496-y>

²¹⁹ Sun et al. (2018). Plasma Concentrations of Perfluoroalkyl Substances and Risk of Type 2 Diabetes: A Prospective Investigation among U.S. Women. *Environmental health perspectives*, 126(3), 037001. Available at: <https://doi.org/10.1289/EHP2619>

²²⁰ Liu et al. (2018a). Perfluorooctanoic Acid (PFOA) Exposure in Early Life Increases Risk of Childhood Adiposity: A Meta-Analysis of Prospective Cohort Studies. *International Journal of Environmental Research and Public Health*, 15(10), 2070. Available at: <https://doi.org/10.3390/ijerph15102070>

²²¹ Liu et al. (2018b). Perfluoroalkyl substances and changes in body weight and resting metabolic rate in response to weight-loss diets: A prospective study. *PLoS medicine*, 15(2), e1002502. Available at: <https://doi.org/10.1371/journal.pmed.1002502>

²²² Goldenman et al. (2019). The cost of inaction: A socioeconomic analysis of environmental and health impacts linked to exposure to PFAS. Available at: [THE COST OF INACTION](https://doi.org/10.1093/aje/kws171)

²²³ Steenland & Woskie. (2012). Cohort mortality study of workers exposed to perfluorooctanoic acid. *American journal of epidemiology*, 176(10), 909–917. Available at: <https://doi.org/10.1093/aje/kws171>

In the U.S., Obsekov, Kahn and Trasande (2023)²²⁴ estimated an attributable fraction of 0.34% of kidney cancer cases and 142 attributable cases per year in the U.S. using data on PFOA exposure for 2017-2018. They also estimated an attributable fraction of 0.076% of testicular cancer cases and 5 attributable cases per year in the U.S. using data on PFOA exposure for adult males in 2017-2018. These estimates were based on Bartell and Vieira (2021)'s²²⁵ ERFs.

Obsekov, Kahn and Trasande (2023)²²⁶ also estimated the PFOA/PFOS-attributable fraction of breast cancer cases in females aged 18-49 to be between 0.5% to 3.65%, based on the ERF derived by Wielsøe et al. (2017)²²⁷. The resulting attributable cases per year in the U.S. were estimated to be between 421 and 3,095.

Reproductive disorders

Obsekov, Kahn and Trasande (2023)²²⁸ estimated the burden of disease in the U.S. for several reproductive disorders as part of their sensitivity analysis.

- For endometriosis, they estimated 696 to 18,062 PFOA-attributable cases in females aged 18-49 in the U.S. and an attributable fraction of 0.43% to 11.27%, using the ERF from Buck Louis et al. (2012)²²⁹.
- Using the ERFs from Vagi et al. (2014)²³⁰, they estimated 7,209 to 7,505 PFOA/PFOS-attributable cases of polycystic ovarian syndrome (PCOS) in females aged 15-45 in the U.S. and an attributable fraction of 5.92% to 6.16%.
- Employing the ERFs from Whitworth et al. (2012)²³¹, they estimate 593 to 26,160 PFOA/PFOS-attributable cases of the use of assistive reproductive technologies (ART) per year and an attributable fraction of 0.25% to 10.86%, using data for females aged 18-49 in the U.S.

Maternal and neonatal risks

Based on the ERF from Zhang et al. (2015)²³², they also estimated between 6061 to 12,474 PFOA-attributable incident cases of gestational diabetes per year in the U.S. and an attributable fraction of 2.85% to 5.87%.

²²⁴ Obsekov, Kahn & Trasande (2023). Leveraging Systematic Reviews to Explore Disease Burden and Costs of Per- and Polyfluoroalkyl Substance Exposures in the United States. *Exposure and health*, 15(2), 373-394. Available at: <https://doi.org/10.1007/s12403-022-00496-y>

²²⁵ Bartell and Vieira (2021). Critical review on PFOA, kidney cancer, and testicular cancer. *Journal of the Air & Waste Management Association* (1995), 71(6), 663-679. Available at: <https://doi.org/10.1080/10962247.2021.1909668>

²²⁶ Obsekov, Kahn & Trasande (2023). Leveraging Systematic Reviews to Explore Disease Burden and Costs of Per- and Polyfluoroalkyl Substance Exposures in the United States. *Exposure and health*, 15(2), 373-394. Available at: <https://doi.org/10.1007/s12403-022-00496-y>

²²⁷ Wielsøe et al. (2017). Serum levels of environmental pollutants is a risk factor for breast cancer in Inuit: a case control study. *Environmental health: a global access science source*, 16(1), 56. Available at: <https://doi.org/10.1186/s12940-017-0269-6>

²²⁸ Obsekov, Kahn & Trasande (2023). Leveraging Systematic Reviews to Explore Disease Burden and Costs of Per- and Polyfluoroalkyl Substance Exposures in the United States. *Exposure and health*, 15(2), 373-394. Available at: <https://doi.org/10.1007/s12403-022-00496-y>

²²⁹ Buck Louis et al. (2012). Perfluorochemicals and endometriosis: the ENDO study. *Epidemiology (Cambridge, Mass.)*, 23(6), 799-805. Available at: <https://doi.org/10.1097/EDE.0b013e31826cc0cf>

²³⁰ Vagi et al. (2014). Exploring the potential association between brominated diphenyl ethers, polychlorinated biphenyls, organochlorine pesticides, perfluorinated compounds, phthalates, and bisphenol A in polycystic ovary syndrome: a case-control study. *BMC endocrine disorders*, 14, 86. Available at: <https://doi.org/10.1186/1472-6823-14-86>

²³¹ Whitworth et al. (2012). Perfluorinated compounds and subfecundity in pregnant women. *Epidemiology (Cambridge, Mass.)*, 23(2), 257-263. Available at: <https://doi.org/10.1097/EDE.0b013e31823b5031>

²³² Zhang, et al. (2023). Association of per- and polyfluoroalkyl substance exposure with fatty liver disease risk in US adults. *JHEP reports : innovation in hepatology*, 5(5), 100694. Available at: <https://doi.org/10.1016/j.jhepr.2023.100694>

Using the exposure-response functions from Govarts et al. (2018)²³³, Plass et al. (2023)²³⁴ estimated the PFAS-attributable Disability-Adjusted Life Years (DALYs) from 'Small for Gestational Age' cases and resulting IQ loss in 9 EU countries (Belgium, France, Germany, Greece, Norway, Slovakia, Slovenia, Spain, Sweden). Data of PFAS blood serum concentrations in teenagers from HBM4EU were used in the absence of maternal concentration data and reduced by 40 % to account for the placenta transfer efficiency. As mentioned previously, the study estimated an age-weighted loss of IQ over life of 4.25 points per 'Small for Gestational Age' case. The burden of disease from 'Small for Gestational Age' cases and resulting IQ loss from exposure to PFOA in 2021 was estimated in DALYs (Bellanger et al., 2013) for Belgium: 3,282 (95%CI: 0-6,390); France: 29,552 (95%CI: 0-52,971); Germany: 22,923 (95%CI: 0-41,516); Greece: 1,677 (95%CI: 0-3,298); Norway: 2,282 (95%CI: 0-4,247); Slovakia: 471 (95%CI: 0-1,000); Slovenia: 267 (95%CI: 0-565); Spain: 2,722 (95%CI: 0-6,231); and Sweden: 3,664 (95%CI: 0-6,880).

Calculations were also made using PFAS concentrations in cord blood, albeit for a smaller set of three countries for which data was available (Austria, Belgium, Slovakia). The burden of disease from 'Small for Gestational Age' cases and resulting IQ loss from exposure to PFOA in 2021 was estimated, in DALYs, for Austria: 2,099 (95%CI: 0-3,819); Belgium: 5,320 (95%CI: 0-9,065); Slovakia: 1,230 (95%CI: 0-2,133).

Based on an exposure-response function from Sten et al. (2009)²³⁵, the Nordic Council study²³⁶ estimated 3,354 births of low weight every year in the EEA countries in areas close to PFAS contamination.

Obsekov, Kahn and Trasande (2023)²³⁷ estimated 10,053 PFOA/PFOS-attributable cases of low birth weight (LBW) per year in the U.S. in 2017-2018 (with a high estimate of 96,847) using the exposure-response functions identified by Meng et al. (2018)²³⁸ and Steenland et al. (2018)²³⁹. The attributable fractions of LBW cases were estimated to be 3.17% (with a high estimate of 30.7%).

Interview findings

During the interview with ChemSec and EEB, it was discussed that human health impacts are well-researched using standard tests for a few substances, whereas there are gaps for other substances, non-standard end points (e.g. mental health), long-term exposure, and mixture effects. The interviewees recommended that these areas with weaker evidence should not be ignored, but further investigated.

The interviewees recommended to consider the EFSA risk assessments²⁴⁰, which have been reviewed and documented previously, where relevant, as well as any other sources shared following the interview.

²³³ Govarts et al. (2018). Prenatal exposure to endocrine disrupting chemicals and risk of being born small for gestational age: Pooled analysis of seven European birth cohorts. *Environment international*, 115, 267–278. Available at : <https://doi.org/10.1016/j.envint.2018.03.017>

²³⁴ European Environment Agency (2023). Estimating the burden of disease due to lead, PFAS, phthalates, cadmium, pyrethroids and bisphenol A using HBM4EU data - test of feasibility and first results for selected countries. Available at: [ETC HE Report 2023/13: Estimating the burden of disease due to lead, PFAS, phthalates, cadmium, pyrethroids and bisphenol A using HBM4EU data - test of feasibility and first results for selected countries – Eionet Portal](https://www.eea.europa.eu/en/press/2023/13-estimating-the-burden-of-disease-due-to-lead-pfas-phthalates-cadmium-pyrethroids-and-bisphenol-a-using-hbm4eu-data-test-of-feasibility-and-first-results-for-selected-countries-eionet-portal)

²³⁵ Stein et al. (2009). Serum levels of perfluorooctanoic acid and perfluorooctane sulfonate and pregnancy outcome. *American journal of epidemiology*, 170(7), 837–846. Available at: <https://doi.org/10.1093/aje/kwp212>

²³⁶ Goldenman et al. (2019). The cost of inaction: A socioeconomic analysis of environmental and health impacts linked to exposure to PFAS. Available at: [THE COST OF INACTION](https://www.efsa.europa.eu/en/topics/per-and-polyfluoroalkyl-substances-pfas)

²³⁷ Obsekov, Kahn & Trasande (2023). Leveraging Systematic Reviews to Explore Disease Burden and Costs of Per- and Polyfluoroalkyl Substance Exposures in the United States. *Exposure and health*, 15(2), 373–394. Available at: <https://doi.org/10.1007/s12403-022-00496-y>

²³⁸ Meng et al. (2018). Prenatal Exposure to Perfluoroalkyl Substances and Birth Outcomes: An Updated Analysis from the Danish National Birth Cohort. *International journal of environmental research and public health*, 15(9), 1832. Available at: <https://doi.org/10.3390/ijerph15091832>

²³⁹ Steenland et al. (2018). Serum Perfluorooctanoic Acid and Birthweight: An Updated Meta-analysis With Bias Analysis. *Epidemiology (Cambridge, Mass.)*, 29(6), 765–776. Available at: <https://doi.org/10.1097/EDE.0000000000000903>

²⁴⁰ <https://www.efsa.europa.eu/en/topics/per-and-polyfluoroalkyl-substances-pfas>

A representative of the Global PFAS Science Panel confirmed Obsekov, Kahn and Trasande (2023) as a key source, which has already been considered in this review. The interviewee also highlighted mixture effects and immune system effects as current data gaps.

Authors of the EEA's ETC HE Report 2023/13²⁴¹ agreed with the list of health risks confidently associated with PFAS exposure and recommended incorporating evidence and conclusions from EFSA, Agency for Toxic Substances and Disease Registry (ATSDR) and National Toxicology Program (NTP), which have been accounted for. They highlighted a potential data gap concerning the longer term health effects of continued PFAS exposure (10-20 years), especially at low levels of exposure, which remains an area of uncertainty.

3.1.4. Q1.4 What are the costs associated with the human health impacts?

A few studies, including Goldman et al (2019) for the Nordic Council of Ministers, followed by Obsekov, Kahn and Trasande (2023), have developed estimates of the potential human health costs of PFAS. The EEA study by Plass et al. (2023) identifies the burden of disease for a subset of European countries; however, this burden is not monetised.

The Nordic Council study (Goldenman et al., 2019)²⁴² estimated the impacts of three levels of exposure to PFAS on five human health risks or endpoints using an impact pathway approach and 'what-if' scenarios. Based on this, the authors also monetised these impacts using a 'value of statistical life' valuation method. The study presents estimates of annualised health-related costs due to PFAS exposure ranging between €52 billion and €84 billion per year in the EEA region.

PFAS-attributable human health costs in the U.S. were estimated by Obsekov, Kahn and Trasande (2023) at \$5.52 billion in 2018 (equivalent to €6.36 billion in 2024²⁴³), focussing on five health risks or endpoints shown to be associated with PFAS exposure in meta-analyses.²⁴⁴ Authors suggest that this estimate represents a lower bound of the potential human health costs, with alternative estimates suggesting that PFAS exposure could lead to human health costs valued at \$62.6 billion/year (equivalent to €72.2 billion in 2024) (by including and monetising the impacts associated with health risks for which links to PFAS exposure had been identified in systematic and scoping reviews but had not been meta-analysed).

These studies have primarily focussed on monetising the attributable disease burden, using different non-market valuation techniques (such as contingent valuation); healthcare costs, using costing or market-based valuation methodologies on the attributable healthcare demand; and economic productivity costs, drawing on market-based methods. Other types of direct or indirect costs of human health burden attributable to PFAS exposure have not been assessed in the literature identified.

The Table below presents a mapping of three human health cost categories associated with PFAS exposure, as found in the literature by health risk. This is followed by a summary of the scale of annualised costs estimated across these studies.

²⁴¹ Plass et al., (2023). *Estimating the burden of disease due to lead, PFAS, phthalates, cadmium, pyrethroids and bisphenol A using HBM4EU data – test of feasibility and first results for selected countries*. Available at: [ETC HE Report 2023/13: Estimating the burden of disease due to lead, PFAS, phthalates, cadmium, pyrethroids and bisphenol A using HBM4EU data – test of feasibility and first results for selected countries — Eionet Portal](#)

²⁴² Goldenman et al. (2019). *The cost of inaction: A socioeconomic analysis of environmental and health impacts linked to exposure to PFAS*. Available at: [THE COST OF INACTION](#)

²⁴³ Adjusted for inflation (based on an assumption of \$1 in 2018 = \$1.25 in 2024, available at: https://www.bls.gov/data/inflation_calculator.htm) and an exchange rate of €1 = US\$1.0824 (2024 annual average exchange rate according to the European Central Bank, available at: https://www.ecb.europa.eu/stats/policy_and_exchange_rates/euro_reference_exchange_rates/html/eurofxref-graph-usd.en.html). This approach applies to any other currency conversions.

²⁴⁴ Obsekov, Kahn & Trasande (2023). *Leveraging Systematic Reviews to Explore Disease Burden and Costs of Per- and Polyfluoroalkyl Substance Exposures in the United States*. *Exposure and health*, 15(2), 373-394. Available at: <https://doi.org/10.1007/s12403-022-00496-y>

Table 3-7: Mapping of the quantified costs to human health associated with exposure to various PFAS as found in the literature, primarily for PFAA and PFAA precursors, structured by the health risk 'group'

Group of adverse health outcomes/ risks attributable to PFAS exposure	Specific health outcomes or risks attributable to PFAS exposure	Exposure-Risk Functions or Quantified relationships	Disease burden (non-market costs)	Healthcare costs	Economic productivity costs
Infections	Respiratory	✓ PFOS	x	✓	✓
	Other	✓ PFOS	x	x	x
Autoimmune	ATD	✓ PFOA, PFOS	✓	✓	x
Musculoskeletal disorders	Osteoporosis	✓ PFOA, PFHxS, PFNA	x	x	x
Cardiovascular risks or diseases	Diabetes	✓ PFOA	x	✓	x
	Obesity	✓ PFOA, PFOS	✓	✓	x
	Hypertension	✓ PFOA, PFOS, PFNA, PFHxS	✓	x	x
Kidney diseases Liver diseases	High cholesterol	✓ PFOA, PFOS	x	x	x
	CKD	✓ PFOA, PFOS, PFNA, PFHxS, PFDaA	x	x	x
	NAFLD	✓ PFHxS	x	x	x
Cancers	Kidney cancer	✓ PFOA	✓	✓	x
	Breast cancer	✓ PFOA, PFOS	✓	✓	x
Reproductive disorders	Testicular cancer	✓ PFOA	✓	✓	x
	Menstruation alterations/ endometriosis	✓ PFOA, PFOS	✓	✓	x
	Time to pregnancy	✓ PFOA, PFOS	x	x	x
Maternal and neonatal risks	Gestational hypertension	✓ PFOS	x	x	x
	Gestational diabetes	✓ PFOA	x	✓	✓
	Decreased foetal growth	✓ PFOA	x	x	x

Group of adverse health outcomes/ risks attributable to PFAS exposure	Specific health outcomes or risks attributable to PFAS exposure	Exposure-Risk Functions or Quantified relationships	Disease burden (non-market costs)	Healthcare costs	Economic productivity costs
	Lower birth weight*	✓ PFOA, PFOS	✓	✓	✓
All-cause mortality	All-cause mortality	✓ PFAS	✓	x	x

*also, small for gestational age (linked to birth defects and development problems)

Infections

Obsekov, Kahn and Trasande (2023)²⁴⁵ estimated the economic burden of pneumonia in children aged 3 years and under as part of their sensitivity analysis. The average direct cost (emergency room visit, hospitalisation, or outpatient treatment) per case of pneumonia was determined to be \$2,952 in 2018 and the indirect cost in lost parental earnings per case was estimated to be \$372 in 2018 (equivalent to €2,988 and €429 in 2024, respectively). Overall, the total cost per incident case of pneumonia in [0–3]-year-olds in the U.S. in 2017–2018 were in the range of \$1.5–22.5 million (equivalent to €1.7–25.9 million in 2024). These estimates comprised of direct medical costs ranging from \$1.3–\$20.0 million (equivalent to €157–23.1 million in 2024) and indirect costs of parental absenteeism ranging from \$0.2–\$2.5 million (equivalent to €0.2–2.9 million in 2024).

Autoimmune disorders

Obsekov, Kahn and Trasande (2023)²⁴⁶ estimated the economic burden of hypothyroidism in females in the U.S. in 2017–2018, based on an estimated annual direct medical cost per case of hypothyroidism valued at \$2,555 and associated \$171 in indirect costs per case due to lost productivity in 2015 (equivalent to €3,115 and €209 in 2024, respectively). The total cost per annual incident case was estimated to be \$1.26–\$5.18 billion (equivalent to €1.46–5.98 billion in 2024), comprising of annual direct medical costs of new cases of hypothyroidism \$0.04–0.17 billion (equivalent to €0.05–0.2 billion in 2024) and indirect costs of \$1.2–5.0 billion (equivalent to €1.4–5.8 billion in 2024) associated with the DALY lost over 10 years.

Cardiovascular risk factors or diseases

The Nordic Council estimated between 3,066 and 10,035 deaths in the EEA region linked to hypertension and PFAS exposure, valued at an annual average of €10.7 billion–€35.0 billion²⁴⁷ using a ‘value of statistical life’ approach. These figures do not capture all the costs associated with hypertension, such as healthcare costs, productivity losses, utility costs etc.

Obsekov, Kahn and Trasande (2023)²⁴⁸ estimated the costs pertaining to several cardiovascular diseases and risk factors based on the attributable disease burden in the U.S. in 2017–2018.

- The lifetime cost of treating type 2 diabetes in adult females and associated complications due to annual incident cases to be \$140 million in the U.S. in 2017–2018 (equivalent to €162 million in 2024).
- For childhood obesity, the incremental lifetime medical cost of an obese child relative to normal weight child due to annual incident cases in the U.S. was estimated to be in the range of \$2.65 – \$9.60 billion (equivalent to €3.1–11.1 billion in 2024).
- For adult obesity, the total 15-year cost per annual incident case was estimated to be \$17.0 billion (equivalent to €19.6 billion in 2024), which included direct medical costs for newly obese 35-year-olds of \$3.2 billion and indirect costs of QALY lost over 15 years amounting to \$13.8 billion (equivalent to €3.7 billion and €15.9 billion in 2024, respectively).

²⁴⁵ Obsekov, Kahn & Trasande (2023). Leveraging Systematic Reviews to Explore Disease Burden and Costs of Per- and Polyfluoroalkyl Substance Exposures in the United States. *Exposure and health*, 15(2), 373–394. Available at: <https://doi.org/10.1007/s12403-022-00496-y>

²⁴⁶ Obsekov, Kahn & Trasande (2023). Leveraging Systematic Reviews to Explore Disease Burden and Costs of Per- and Polyfluoroalkyl Substance Exposures in the United States. *Exposure and health*, 15(2), 373–394. Available at: <https://doi.org/10.1007/s12403-022-00496-y>

²⁴⁷ Please see Table 29 of the Nordic Council study, which presents annual health-related costs of exposure to PFAS. Goldenman et al. (2019). *The cost of inaction: A socioeconomic analysis of environmental and health impacts linked to exposure to PFAS*. Available at: [THE COST OF INACTION](#)

²⁴⁸ Obsekov, Kahn & Trasande (2023). Leveraging Systematic Reviews to Explore Disease Burden and Costs of Per- and Polyfluoroalkyl Substance Exposures in the United States. *Exposure and health*, 15(2), 373–394. Available at: <https://doi.org/10.1007/s12403-022-00496-y>

Cancers

For deaths due to kidney cancer linked to PFAS exposure, the Nordic Council study (Goldenman et al., 2019)²⁴⁹ estimated a monetary value of €12.7 million to €41.4 million per year, on average, based on the 'value of a statistical life' (a non-market valuation approach).

Based on Obsekov, Kahn and Trasande (2023)'s²⁵⁰ estimates, the total cost per annual incident case of kidney cancer in the U.S. is \$184 million (equivalent to €212 million in 2024), comprising direct medical costs during the first year of diagnosis of \$4.7 million (equivalent to €5.4 million in 2024) and indirect costs as DALY lost over 10 years amounting to \$180 million (equivalent to €208 million in 2024). They also estimated the economic burden of testicular cancer in adult males in the U.S. in 2017-2018 to be \$6.85 million (equivalent to €7.91 million in 2024) per annual incident case, which included direct medical costs of treatment of \$139,000 (equivalent to €160,000 in 2024) and indirect costs as DALY lost over 10 years amounting to \$6.7 million (equivalent to €7.7 million in 2024).

As part of their sensitivity analysis, Obsekov, Kahn and Trasande (2023)²⁵¹ estimated the total 10-year cost per annual incident case of breast cancer in females aged 18-49 years to be in the range of \$0.55-\$4.08 billion in 2017-2018 (equivalent to €0.64-4.71 billion in 2024). The comprising direct medical costs for 6 months following diagnosis were estimated to be in the range of \$21.7-\$159.0 million (equivalent to €25.1-184 million in 2024) per annual incident case and the indirect costs as DALY lost over 10 years were estimated to be in the range of \$0.53-\$3.9 billion (equivalent to €0.6-4.5 billion in 2024).

Reproductive disorders

According to Obsekov, Kahn and Trasande (2023)²⁵², the estimated costs for the reproductive disorder identified above in the U.S. are as follows:

- The total 10-year cost per annual incident case of endometriosis in the U.S. is estimated to range from \$0.40-\$10.2 billion (equivalent to €0.5-11.8 billion in 2024). This includes direct medical costs of \$0.21-\$0.55 million (equivalent to €0.24-0.64 million in 2024) over 10 years as well as indirect cost as DALY lost over 10 years, ranging from \$0.38-\$9.76 billion (equivalent to €0.44-11.27 billion in 2024).
- The annual cost of initial polycystic ovarian syndrome (PCOS) evaluation and treatment of comorbidities due to annual incident cases to be in the range of \$10.5-\$10.9 million (equivalent to €12.1-12.6 million in 2024).
- For couple infertility (increased time to pregnancy), The cost of attributable assistive reproductive technologies (ART) utilisation was estimated to be between \$0.038 and \$1.66 billion (equivalent to €0.04-1.92 billion in 2024) per annual incident case in the U.S. in 2017-2018.

²⁴⁹ Please see Table 29 of the Nordic Council study, which presents annual health-related costs of exposure to PFAS. Goldenman et al. (2019). *The cost of inaction: A socioeconomic analysis of environmental and health impacts linked to exposure to PFAS*. Available at: [THE COST OF INACTION](#)

²⁵⁰ Obsekov, Kahn & Trasande (2023). *Leveraging Systematic Reviews to Explore Disease Burden and Costs of Per- and Polyfluoroalkyl Substance Exposures in the United States*. *Exposure and health*, 15(2), 373-394. Available at: <https://doi.org/10.1007/s12403-022-00496-y>

²⁵¹ Obsekov, Kahn & Trasande (2023). *Leveraging Systematic Reviews to Explore Disease Burden and Costs of Per- and Polyfluoroalkyl Substance Exposures in the United States*. *Exposure and health*, 15(2), 373-394. Available at: <https://doi.org/10.1007/s12403-022-00496-y>

²⁵² Obsekov, Kahn & Trasande (2023). *Leveraging Systematic Reviews to Explore Disease Burden and Costs of Per- and Polyfluoroalkyl Substance Exposures in the United States*. *Exposure and health*, 15(2), 373-394. Available at: <https://doi.org/10.1007/s12403-022-00496-y>

Maternal and neonatal risks

Obsekov, Kahn and Trasande (2023)²⁵³ estimated the costs pertaining to gestational diabetes. Each case was estimated to have an annual medical cost of \$12,089 and lifetime cost due to lost productivity for adverse birth outcomes of \$56,237 in 2018 dollars (equivalent to €13,961 and €64,945 in 2024 euros, respectively). The total cost per annual incident case was estimated to be in the range of \$414-\$852 million (equivalent to €478-984 million in 2024), which includes direct medical costs ranging from \$73-\$150 million and indirect cost of lost productivity from adverse birth effects ranging from \$341-\$702 million (equivalent to €84-173 million and €394-811 million in 2024, respectively).

Obsekov, Kahn and Trasande (2023)²⁵⁴ also estimated the economic burden per annual incident case of low birth weight in the U.S. in 2017-2018 to be \$1.42 billion (with a high estimate of \$13.70 billion). This comprised of direct cost of hospitalization of \$305 million (with a high estimate of \$2.94 billion) and indirect cost due to lost IQ points of \$1.11 billion (with a high estimate of \$10.70 billion).

All-cause mortality

Finally, the 2019 Nordic Council study (Goldenman et al., 2019)²⁵⁵ also considered the potential impacts on people's life expectancy associated with elevated PFAS exposure, primarily through drinking water, for populations living in close proximity to chemical plants and/or contaminated sites. These were estimated to account for a societal cost of around €41-49 billion per year, based on the 'value of a statistical life' (a non-market valuation approach).

Interview findings

None of the interviewees were aware of additional literature or studies that analysed and monetised the human health impacts of PFAS exposure.

A representative from ChemSec said that "it will be very difficult to monetise all effects from the heterogenous PFAS exposure, especially since all effects are not known. Should be relevant to also look at remediation costs to reach the Tolerable Weekly Intake, extrapolated to all PFAS."

Authors of the EEA's ETC HE Report 2023/13²⁵⁶ suggested the incorporation of social care and care-taking costs into the list of potential costs associated with human health impacts, and noted these costs might not necessarily be evenly distributed over time and across geographies and populations, which should ideally be considered as part of any assessment to the extent that is possible. They also suggested interviewing ChemSec, which had already been done as part of this Task 1.

OECD representatives were also interviewed. They confirmed that there were no updates to their PFAS exposure valuation work since the work already referenced in the Nordic Council study. Methodologically, they recommended their five working papers on valuing health risk reductions (published for very low birth weight, asthma, kidney disease, IQ losses in children, temporary infertility; and upcoming for thyroid dysfunction, hypertension, non-fatal cancer, miscarriage and skin sensitisation) as well as an update of the value of statistical life (VSL) estimates expected in April 2025.²⁵⁷

²⁵³ Obsekov, Kahn & Trasande (2023). *Leveraging Systematic Reviews to Explore Disease Burden and Costs of Per- and Polyfluoroalkyl Substance Exposures in the United States*. *Exposure and health*, 15(2), 373-394. Available at: <https://doi.org/10.1007/s12403-022-00496-y>

²⁵⁴ Obsekov, Kahn & Trasande (2023). *Leveraging Systematic Reviews to Explore Disease Burden and Costs of Per- and Polyfluoroalkyl Substance Exposures in the United States*. *Exposure and health*, 15(2), 373-394. Available at: <https://doi.org/10.1007/s12403-022-00496-y>

²⁵⁵ Goldenman et al. (2019). *The cost of inaction: A socioeconomic analysis of environmental and health impacts linked to exposure to PFAS*. Available at: [THE COST OF INACTION](https://www.oecd.org/en/topics/sub-issues/risk-management-risk-reduction-and-sustainable-chemistry/the-costs-and-benefits-of-regulating-chemicals.html)

²⁵⁶ Plass et al., (2023). *Estimating the burden of disease due to lead, PFAS, phthalates, cadmium, pyrethroids and bisphenol A using HBM4EU data – test of feasibility and first results for selected countries*. Available at: [ETC HE Report 2023/13: Estimating the burden of disease due to lead, PFAS, phthalates, cadmium, pyrethroids and bisphenol A using HBM4EU data – test of feasibility and first results for selected countries — Eionet Portal](https://www.oecd.org/en/topics/sub-issues/risk-management-risk-reduction-and-sustainable-chemistry/the-costs-and-benefits-of-regulating-chemicals.html)

²⁵⁷ <https://www.oecd.org/en/topics/sub-issues/risk-management-risk-reduction-and-sustainable-chemistry/the-costs-and-benefits-of-regulating-chemicals.html>

3.1.5. Q1.5 What are the geographical and temporal trends in human health costs?

There is no direct evidence of trends in human health costs of PFAS pollution in the literature. However, there is evidence on the factors driving the human health cost of PFAS pollution, such as PFAS blood serum concentrations in people, across EU geographies and over time, which is likely correlated with human health costs overall. This evidence of geographical and temporal trends in PFAS exposure in the EU is summarised in the following paragraphs.

Geographical trends

Evidence reported in Goldenman et al. (2019) suggests that average PFAS exposure levels in Europe, as measured by blood serum concentrations, are generally comparable to those observed in the United States and Canada. This same study, along with Richterova et al. (2023)²⁵⁸, reports that concentrations of specific PFAS, such as PFNA and PFHxS, are somewhat lower in European populations.

Within Europe, evidence reported by Richterova et al., (2023) suggests there are regional variations in PFAS blood serum concentrations in European teenagers (ages 12–19), showing **higher concentrations of four PFAS in Northern (Norway, Sweden) and Western Europe (France, Germany, Belgium) compared to lower levels in Southern (Spain, Greece, Slovenia) and Eastern Europe (Slovakia)**. These findings, summarized in Table 3-8, align with observations on PFOA and PFOS serum levels in European adults reported by Plass et al. (2023)²⁵⁹, based on the HBM4EU initiative, which also highlight elevated concentrations in Northern and Western regions.

Table 3-8 Teenager blood serum concentration in Europe by region

Teenager blood serum concentration	North	West	East	South
PFOA	1.12 µg/L	1.13 µg/L	0.63 µg/L	0.70 µg/L
PFOS	2.62 µg/L	2.22 µg/L	1.47 µg/L	1.45 µg/L
PFHxS	0.40 µg/L	0.46 µg/L	0.32 µg/L	0.25 µg/L
PFNA	0.34 µg/L	0.33 µg/L	0.12 µg/L	0.26 µg/L

Goldenman et al., (2019)²⁶⁰ caution that the generalizability of these geographical trends is limited by the relatively small sample sizes analysed per country, reducing the reliability of differentiating PFAS exposure risks across European regions. Consequently, they did not differentiate between regions in their assessment of exposure-related risks.

Cordner et al., (2024)²⁶¹, reporting results from *The Forever Pollution Project*, has provided further insights into the geographical distribution of PFAS contamination across Europe. The study identifies 22,934 locations where PFAS have been detected in water or solids at levels exceeding 10 ng/L or 10

²⁵⁸ Richterova et al., (2023). PFAS levels and determinants of variability in exposure in European teenagers – Results from the HBM4EU aligned studies (2014–2021), International Journal of Hygiene and Environmental Health, 247, 114057. Available at: <https://doi.org/10.1016/j.ijheh.2022.114057>

²⁵⁹ Plass et al. (2023). ETC HE Report 2023/13: Estimating the burden of disease due to lead, PFAS, phthalates, cadmium, pyrethroids and bisphenol A using HBM4EU data - test of feasibility and first results for selected countries. Available at: <https://www.eionet.europa.eu/etcs/etc-he/products/etc-he-products/etc-he-reports/etc-he-report-2023-13-estimating-the-burden-of-disease-due-to-lead-pfas-phthalates-cadmium-pyrethroids-and-bisphenol-a-using-hbm4eu-data-2013-test-of-feasibility-and-first-results-for-selected-countries>

²⁶⁰ Goldenman et al. (2019). The cost of inaction: A socioeconomic analysis of environmental and health impacts linked to exposure to PFAS. Available at: [THE COST OF INACTION](#)

²⁶¹ Cordner, A., et al. (2024). PFAS contamination in Europe: Generating knowledge and mapping known and likely contamination with “expert-reviewed” journalism. Environmental Science & Technology, 58(10), 1234–1245. <https://doi.org/10.1021/acs.est.3c09746>

ng/kg, including 98 sites in the sea without attributed countries. While the study acknowledges discrepancies in site identification due to differences in monitoring practices across countries, it offers valuable insights into the geographic distribution of contamination: 65% of sites are in Western Europe, 19% in Northern Europe, 14% in Southern Europe, and 1% in Eastern Europe²⁶².

These findings broadly align with the geographical distribution of blood serum concentrations reported by Richterova et al. (2023), suggesting regional variations in PFAS-contaminated sites and blood serum levels, with some differences observed between Northern and Western Europe compared to Southern and Eastern Europe.

Additionally, Cordner et al. (2024)²⁶³ identify 20 PFAS production facilities across seven European countries, including six from the EU-27 and the United Kingdom. This figure aligns with Goldenman et al., (2019)'s estimate of between 12 and 20 PFAS manufacturing facilities in Europe. Table 3-9 below displays the distribution of polluted sites and manufacturing facilities across European countries.

(reflecting findings)Table 3-9 Known Contamination Site Statistics Per Country (Not Including 98 Sites in the Sea without Attributed Countries)

Country	Number of known contamination sites	Number of known manufacturing facilities
Austria	41	-
Belgium	6,791	1
Bulgaria	17	-
Croatia	5	-
Cyprus	1	-
Czech Republic	31	-
Denmark	2,161	-
Estonia	2	-
Finland	180	-
France	1,067	5
Germany	2,032	6
Greece	12	-
Hungary	25	-
Ireland	1	-
Italy	2,726	2
Latvia	111	-
Lithuania	32	-
Luxembourg	4	-
Malta	22	-
Netherlands	4,989	1
Norway	60	-
Poland	12	1

²⁶² Northern Europe includes Denmark, Estonia, Finland, Ireland, Latvia, Lithuania, Norway, Sweden, and the United Kingdom. Western Europe includes Austria, Belgium, France, Germany, Luxembourg, the Netherlands, and Switzerland. Southern Europe includes Croatia, Cyprus, Greece, Italy, Malta, Portugal, Slovenia, and Spain. Eastern Europe includes Bulgaria, Czech Republic, Hungary, Poland, Romania, Serbia, Slovakia, and Ukraine. These regional classifications are in line with the European Commission's geographic definitions, as per [European Commission Regional Statistics](#).

²⁶³ Cordner, A., et al. (2024). PFAS contamination in Europe: Generating knowledge and mapping known and likely contamination with "expert-reviewed" journalism. *Environmental Science & Technology*, 58(10), 1234-1245. <https://doi.org/10.1021/acs.est.3c09746>

Country	Number of known contamination sites	Number of known manufacturing facilities
Portugal	9	-
Romania	21	-
Serbia	27	-
Slovakia	17	-
Slovenia	3	-
Spain	327	1
Sweden	222	-
Switzerland	216	-
Ukraine	3	-
United Kingdom	1,666	3

Temporal trends

Recent research reveals discernible temporal trends in PFAS exposure levels, influenced by production cycles and regulatory changes. Concentrations of PFOS and PFOA in human blood serum peaked during the 1990s and early 2000s, then declined following significant voluntary and regulatory actions (e.g., the inclusion of PFOS in the Stockholm Convention in 2009 and of PFOA in 2019). However, PFAS blood serum levels over time vary by substance. For example, PFHxS levels remained stable after 2001 due to its longer elimination half-life, while FOSA declined post-2001, reflecting a reduction in the use of this PFAA precursor. In contrast, consistent increases have been observed for blood serum levels of PFNA, PFDA, and PFUnDA, which could be due to continued production, their bioaccumulative properties, and longer persistence in the environment.

During peak production years (1979–2001), serum levels of specific PFAS, namely as PFOS, PFOA, and PFHxS, increased significantly. For example, Nøst, (2014)²⁶⁴ reports that that PFOS and PFOA concentrations rose approximately five-fold between 1979 and 2001, aligning with global production peaks and suggesting broad environmental and consumer exposure. PFHxS also demonstrated a steady increase during this period, although its levels did not decrease in the following years.

Nøst, (2014)²⁶⁵ reports that **human blood serum concentrations of PFOA and PFOS were reduced by 23% and 22%, respectively, between 2001 and 2007. By contrast, other substances such as PFHxS, PFNA, PFDA, and PFUnDA continued to rise after 2001**, likely due to continued use in specific applications, their role as substitutes to PFOA and PFOS, and their environmental persistence.

Table 3-10 below summarises changes in blood serum concentrations of selected PFAS over time, as indicated by the percentage changes in their concentrations across year intervals between 1979 and 2007. These trends are reflected in the following substances: PFOA, PFOS, FOSA, PFNA, PFDA, PFUnDA, and PFHxS (reflecting findings from Nøst, 2014).

²⁶⁴ Haugdahl Nøst (2014). Repeated measurements of per- and polyfluoroalkyl substances (PFASs) from 1979 to 2007 in males from Northern Norway: Assessing time trends, compound correlations and relations to age/birth cohort. Available at: <https://www.sciencedirect.com/science/article/pii/S0160412014000610>

²⁶⁵ Haugdahl Nøst (2014). Repeated measurements of per- and polyfluoroalkyl substances (PFASs) from 1979 to 2007 in males from Northern Norway: Assessing time trends, compound correlations and relations to age/birth cohort. Available at: <https://www.sciencedirect.com/science/article/pii/S0160412014000610>

Table 3-10 Variation of serum concentration over time

PFAS	1979-1986 (% change)	1986-1994 (% change)	1994-2001 (% change)	2001-2007 (% change)
PFOA	170%	72%	-6%	-23%
PFOS	170%	49%	25%	-22%
FOSA	210%	-6%	-10%	-60%
PFNA	500%	37%	38%	41%
PFDA	250%	100%	37%	18%
PFUnDA	850%	-6%	32%	8%
PFHxS	260%	85%	27%	-6%

The data above pertain solely to adult populations, with no longitudinal studies found tracking PFAS blood concentrations from childhood through adulthood. Goldenman et al (2019)²⁶⁶ reports cross-sectional U.S. data from the Centres for Disease Control and Prevention indicating that PFAS serum levels vary by age, with some PFAS concentrations, such as PFNA and PFOS, appearing higher in younger children. However, this gap in longitudinal research limits insights into how PFAS exposure and accumulation evolve across different life stages.

Nøst, (2014)²⁶⁷ indicates that the trends observed above for PFOS, PFOA and related substances are consistent with similar reductions reported in other European countries such as Germany, Norway and Sweden. Outside Europe, comparable patterns have been documented in countries such as the United States and Japan, suggesting a broad effectiveness of regulatory measures internationally.

However, the relatively rapid decline in human serum concentrations of PFOA and PFOS after phase-outs - despite their long biological half-lives - contrasts with the slower decline in wildlife populations. This discrepancy may indicate a significant role of consumer products in human exposure prior to phaseouts, as suggested by Nøst, (2014)²⁶⁸. As production ceased, dietary and other environmental sources may have become more important exposure pathways.

²⁶⁶ Goldenman et al. (2019). *The cost of inaction: A socioeconomic analysis of environmental and health impacts linked to exposure to PFAS*. Available at: [THE COST OF INACTION](#)

²⁶⁷ Haugdahl Nøst (2014). *Repeated measurements of per- and polyfluoroalkyl substances (PFASs) from 1979 to 2007 in males from Northern Norway: Assessing time trends, compound correlations and relations to age/birth cohort*. Available at: <https://www.sciencedirect.com/science/article/pii/S0160412014000610>

²⁶⁸ Haugdahl Nøst (2014). *Repeated measurements of per- and polyfluoroalkyl substances (PFASs) from 1979 to 2007 in males from Northern Norway: Assessing time trends, compound correlations and relations to age/birth cohort*. Available at: <https://www.sciencedirect.com/science/article/pii/S0160412014000610>

3.2. Environmental costs (Q2)

This section sets out the literature review findings against each of the five research questions exploring the environmental costs of PFAS pollution.

3.2.1. Q2.1 To what extent are environmental compartments (soil, water, air, and biota) contaminated with PFAS in the EU?

PFAS species are transported through several environmental pathways such as atmospheric transport, oxidation, diffuse releases and direct sources such as manufacturing industries and wastewater. From these sources and pathways, PFAS can now be found in several environmental compartments around the globe. Question 2.1 focuses on observed PFAS levels that have been found in different environmental compartments. The baseline of data used for this question came from the Annex B document of the Universal PFAS Restriction (2022)²⁶⁹ which provided data for soil, water and biota in Europe. Select data has been picked from this Annex to give a regional overview of the levels of PFAS in Europe, this has been further supplemented with other literature sources.

Other than the universal PFAS restriction (UPFAS) proposed by 5 national authorities to ECHA, there is a lack of studies which contained data for several environmental compartments and PFAS concentrations. The following section breaks down the values found for several PFAS species. Generally, the data found varied and demonstrated a lack of correlation between PFAS species and the concentrations that species were detected at in the environment (see the tables to show the scatter of PFAS values found within the environmental compartments). For this reason, it could be assumed that there is a current gap in Europe for a harmonised approach in the monitoring of different PFAS substances.

It is also important to note that a lack of information was found regarding polymeric PFAS and F-gases concentrations in the environment. When searching for key PFAS species (such as PTFE, ETFE and PFA), and f-gases alongside words such as “concentration”, no results were found to answer this research question. It should however be noted that some polymeric PFAS can degrade into PFAAs²⁷⁰, and F-gases can degrade into TFA (an ultra-short chain PFAA)²⁷¹, for which data on environmental concentrations is available and included in this section.

Another study covering PFAS concentrations across Europe which has recently been published includes the ‘forever pollution project’²⁷². The data generated by the project has been further developed by the French National Centre for Scientific Research (Centre national pour la recherche scientifique, CNRS) and is accessible on their PFAS Data Hub²⁷³. At the time of writing, the dataset covers 467,634 data points, where each data point includes the geolocation of a known or presumptive PFAS-polluted site, and where available sampling values for various PFAS species and other details about the site such as type of site and industry sector. The dataset contains data from all EEA countries (plus Serbia, Switzerland, Ukraine and the UK), but the number of datapoints varies widely across countries (from 7 for Ukraine to over 200,000 for France). Due to the size of the dataset, it is difficult to ensure the quality of the data and present the data in this report. Task 2 will consider how to use the data, potentially in combination with other data identified in the literature (as presented in the following sections).

²⁶⁹ ECHA (2022) ANNEX XV RESTRICTION REPORT – Per- and polyfluoroalkyl substances (PFASs), Annex B Information on hazard and risk. Available at: <https://echa.europa.eu/documents/10162/6f4a2076-7221-67a3-64f7-c67cc307f59c>

²⁷⁰ See e.g. Lohmann and Letcher (2023). The universe of fluorinated polymers and polymeric substances and potential environmental impacts and concerns. *Current Opinion in Green and Sustainable Chemistry*, Volume 41, 2023. <https://doi.org/10.1016/j.cogsc.2023.100795>.

²⁷¹ See e.g. <https://www.umweltbundesamt.de/en/topics/climate-energy/fluorinated-greenhouse-gases-fully-halogenated-cfcs/emissions-degradation-products/degradation-products-of-fluorinated-greenhouse>

²⁷² <https://foreverpollution.eu/map/dataset-and-maps/>

²⁷³ <https://pdh.cnrs.fr/en/>

The tables in Appendix B to Annex A have been split into several categories including the regions samples were taken from, the sector responsible for the PFAS pollution, and whether the values came from in-lab modelling, sampling or monitoring. The information from these tables have been summarised by the highest and lowest values found in the literature for PFAS within the environmental compartments. For some of the literature identified, the data had only summarised the values for a sum of PFAS species and not provided a breakdown of the names of the PFAS species (e.g. 11 species found between 0.3-6500ng/g in soil). Where this is the case, the information cannot be summarised in the main body of the text.

The main sources used to populate the table include:

- ECHA (2023) ANNEX XV RESTRICTION REPORT – Per- and polyfluoroalkyl substances (PFASs), Annex B Information on hazard and risk. Available at: <https://echa.europa.eu/documents/10162/6f4a2076-7221-67a3-64f7-c67cc307f59c>
- Kotthoff et al (2020) Per- and polyfluoroalkyl substances in the German environment – Levels and patterns in different matrices. Available at: <https://www.sciencedirect.com/science/article/pii/S0048969720336378>
- Panieri et al (2022) PFAS Molecules: A Major Concern for the Human Health and the Environment. Available at: <https://www.mdpi.com/2305-6304/10/2/44>
- Nazmul Ehsan et al (2024) PFAS contamination in soil and sediment: Contribution of sources and environmental impacts on soil biota. Available at: <https://www.sciencedirect.com/science/article/pii/S2666016424000379#:~:text=Exposure%20to%20PFAS%20has%20demonstrated%20negative%20effects%20on%20soil%20microorganisms%2C%20microbes%2C%20and%20benthic%20organisms%20in%20sediment.>
- Peritore et al (2023) Current Review of Increasing Animal Health Threat of Per- and Polyfluoroalkyl Substances (PFAS): Harms, Limitations, and Alternatives to Manage Their Toxicity. Available at: <https://www.mdpi.com/1422-0067/24/14/11707>
- Giara et al (2023), PFAS levels in fish species in the Po River (Italy): New generation PFAS, fish ecological traits and parasitism in the foreground. Available at: <https://www.sciencedirect.com/science/article/pii/S0048969723014444>
- Miljøstyrelsen, 2014. Screeningsundersøgelse af udvalgte PFAS for bindelser som jord- og grundvandsforurening i forbindelse med punktkilder. Available at: <https://www2.mst.dk/Udgiv/publikationer/2014/10/978-87-93178-96-0.pdf>
- Drenning et al (2023) Comparison of PFAS soil remediation alternatives at a civilian airport using cost-benefit analysis. Available at: <https://www.sciencedirect.com/science/article/pii/S0048969723022842>
- JRC, (2022). EQS Dossier_After SCHEER final opinion. Available at: https://circabc.europa.eu/ui/group/9ab5926d-bed4-4322-9aa7-9964bbe8312d/library/8b25bd1e-8b3c-47ce-93a8-638bf4b2b724?p=1&n=10&sort=modified_DESC
- Han et al., (2024). The Global Threat from the Irreversible Accumulation of Trifluoroacetic Acid (TFA). Environmental Science & Technology. 58(45). Available at: <https://pubs.acs.org/doi/10.1021/acs.est.4c06189>
- Brandsma et al., 2019. The PFOA substitute GenX detected in the environment near a fluoropolymer manufacturing plant in the Netherlands. Chemosphere. 220. 493-500. Available at: <https://www.sciencedirect.com/science/article/pii/S0045653518324706>
<https://www.sciencedirect.com/science/article/pii/S0045653518324706>

For the information below, it was difficult to determine what values were taken from a 'hotspot' and which ones were not. It is assumed that if a source has been taken from a known contaminated site,

then it could potentially be a hotspot, similarly if the value is exponentially higher than others found for that PFAS species in the environmental compartment. Difficulty also arose from defining a 'PFAS hotspot', with no clear definition of classification of a site. Looking at the forever pollution map²⁷⁴ there were several hundred sites which had 'known PFAS users/presumptive contamination, this shows how many potential 'hotspots' there could be.

Soil/Sediment

Soil that has been exposed to PFAS has consequently been seen to deteriorate in quality, mainly due to the PFAS affecting the soil microbes, plants and the food chain dependent on the soil/sediment (Ehsan et al., 2024)²⁷⁵. Several studies were identified looking at PFAS levels in soil/sediment near contaminated sites and in the natural environment.

Several studies were identified that covered PFAS levels in soil and sediment in the EU, however, many of these tests were either based on modelling or samples taken near a contaminated site, which may therefore not be representative of the wider geographical EU environment. The values found for PFAS in soil lacked correlation between the PFAS substance and the concentrations they were found at, showing a lack of harmonisation between the PFAS species found in soil, and the average range which that species can be found at. There was also a range of different units that were used, making it hard to compare some of the values identified, and highlighting the need for greater standardisation in monitoring approaches. The table below gives a summary of literature identified.

Table 3-11 gives an overview for the range of values of PFAS species identified in soil from relevant literature

PFAS name	Minimum concentration	Maximum concentration	Any samples taken from a contaminated site?	Sources used	Unit
PFOS	0.3	6500.0	AFFF (maximum concentration point).	Nazmul Ehsan et al., 2024	ng/g
PFOA	<200000	<800000	n/a	Nazmul Ehsan et al., 2024	ng/g*
PFBA (sea sediment)	n.d	0.54	n/a	ECHA, 2023	ng/g
PFHxA (sea sediment)	n.d.	00.06	n/a	ECHA, 2023	ng/g
PFHpA (sea sediment)	n.d	0.12	n/a	ECHA, 2023	ng/g
PFOA sea sediment)	n.d.	0.65	n/a	ECHA, 2023	ng/g
PFOS (sea sediment)	n.d.	0.39	n/a	ECHA, 2023	ng/g

²⁷⁴ https://www.lemonde.fr/en/les-decodeurs/article/2023/02/23/forever-pollution-explore-the-map-of-europe-s-pfas-contamination_6016905_8.html

²⁷⁵ Ehsan et al (2024) PFAS contamination in soil and sediment: Contribution of sources and environmental impacts on soil biota. Available at: <https://www.sciencedirect.com/science/article/pii/S2666016424000379#:~:text=Exposure%20to%20PFAS%20has%20demonstrated%20negative%20effects%20on,soil%20microorganisms%2C%20microbes%2C%20and%20benthic%20organisms%20in%20sediment.>

TFA	0.059	2400.0	n/a	Arp et al., 2024.	ng/g*
TFA (sediment)	4.9	200.0	n/a	Arp et al., 2024.	ng/g*

* Dry weight used

Water

Several PFAS substances have been identified in water samples within the EU where the level of contamination is a concern to the public. A close link has been observed between the anthroposphere and the hydrological cycle, showing a route for PFAS to enter the hydrological cycle (Kurwadkar, 2022)²⁷⁶. A recent report published by the EEA (2024)²⁷⁷ gave a concerning statistic about PFOS levels in waterbodies in Europe, with 51-60% of rivers, 11-35% of lakes and 47-100% of transitional and coastal waters exceeding the EQS for PFOS (0.65 nanograms of PFOS per litre (ng PFOS/l) for inland surface water, 0.13ng PFOS/l for transitional, territorial, and coastal waters).²⁷⁸ The study highlights the importance for increased monitoring of several PFAS species in waterbodies in Europe, showing a gap in monitoring.

In terms of the data found, several sources were identified containing information on PFAS values in waterbodies in Europe. As for soil, there was a lack of coherence between the concentrations found in each study, with values varying depending on the water type, the PFAS substance and the method of analysis. There was a lack of studies which brought together the overall available data in Europe for PFAS samples.

A key literature sources for some PFAS substances in water was the dossier submitted by the JRC for EQS standards of PFAS in Europe. The dossier gives a good overview of values of five PFAS substance across Europe.²⁷⁹

Table 3-12 gives an overview for the range of values of PFAS species identified in water from relevant literature

PFAS name	Minimum concentration	Maximum concentration	Any samples taken from a contaminated site?	Sources used	Unit
TFA	4	140000	n/a	ECHA, 2023; Arp et al., 2024.	ng/l
PFEtS	n.d.	2.9	n/a	ECHA, 2023	ng/l
PFPrS	n.d.	1.4	n/a	ECHA, 2023	ng/l
PFBA	n.d.	333.2	n/a	ECHA, 2023; JRC, 2022.	ng/l
PFPeA	n.d.	584.7	n/a	ECHA, 2023, JRC, 2022.	ng/l
PFHxA	0.017	5300	Fire drill site (maximum concentration point)	ECHA, 2023; Miljøstyrelsen, 2014	ng/l

²⁷⁶ Kurwadkar (2022). Per- and polyfluoroalkyl substances in water and wastewater: A critical review of their global occurrence and distribution. Available at: <https://www.sciencedirect.com/science/article/pii/S0048969721060812#:~:text=Due%20to%20their%20unique%20chemical%20properties%2C%20widespread%20production%2C,classified%20as%20persistent%20organic%20pollutants%20of%20significant%20concern.>

²⁷⁷ EEA (2024). PFAS pollution in European waters. Available at: <https://www.eea.europa.eu/en/analysis/publications/pfas-pollution-in-european-waters>

²⁷⁸ Annual average: 6.5x10⁻⁴µg PFOS/l for inland surface water and 1.3 5x10⁻⁴µg PFOS/L for coastal, transitional and territorial water MAC: 36 µg/l for inland surface water, 7.2 µg/l for coastal, transitional and territorial water. <https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:02008L0105-20130913>

²⁷⁹ JRC, (2022). EQS Dossier_After SCHEER final opinion. Available at: https://circabc.europa.eu/ui/group/9ab5926d-bed4-4322-9aa7-9964bbe8312d/library/8b25bd1e-8b3c-47ce-93a8-638bf4b2b724?p=1&n=10&sort=modified_DESC

PFAS name	Minimum concentration	Maximum concentration	Any samples taken from a contaminated site?	Sources used	Unit
PFHpA	n.d	1800	Fire drill site (maximum concentration point)	ECHA, 2023; Miljøstyrelsen, 2014	ng/l
PFOA	0.04	710	n/a	ECHA, 2023	ng/l
PFBS	0.015	1666	n/a	ECHA, 2023; JRC, 2022.	ng/l
PFHxS	n.d.	55	n/a	ECHA, 2023; Miljøstyrelsen, 2014	ng/l
PFOS	n.d.	2709.0	n/a	ECHA, 2023	ng/l
HFPOD	n.d.	108.0	n/a	ECHA, 2023	ng/l
PFECHS	n.d.	0.14	n/a	ECHA, 2023	ng/l
6:2 Cl-PFESA	0.001	0.08	n/a	ECHA, 2023	ng/l
PFNA	13	98	Fire drill site (maximum concentration point)	Miljøstyrelsen, 2014	

Air

From research, it is apparent that air is considered a less important transport pathway of PFAS compared to water and soil, although it could be important for diffuse emissions as depositions in rain water etc. Indoor air contains higher concentrations of PFAS compared to outdoor air due to air borne dusts contaminated with PFAS and the volatilisation of some PFAS substances (e.g. FTOHs, FOSAs, FOSEs and FTAs) (ECHA, 2022).²⁸⁰

As above, there was a lack of coherence between values of PFAS substances found in air samples between each study. There were also no identified literature sources that brought all available data within Europe together for a comparative analysis of PFAS substances across the EU. Table 3-13 gives an overview of the literature identified.

Table 3-13 gives an overview for the range of values of PFAS species identified in air from relevant literature

PFAS name	Minimum concentration	Maximum concentration	Any samples taken from a contaminated site?	Sources used	Unit
4:2 FTOH	n.d.	38	n/a	ECHA, 2023	pg/m ³
6:2 FTOH	2.0	101000	n/a	ECHA, 2023	pg/m ³
8:2 FTOH	7.5	446000	n/a	ECHA, 2023	pg/m ³
10:2 FTOH	<0.6	255000	n/a	ECHA, 2023	pg/m ³
EtFOSA	n.d.	1350	n/a	ECHA, 2023	pg/m ³
MeFOSE	n.d.	78300	n/a	ECHA, 2023	pg/m ³
6:2 FTACS	n.d.	2604	n/a	ECHA, 2023	pg/m ³
8:2 FTACS	n.d.	47739	n/a	ECHA, 2023	pg/m ³
10:2 FTAC	n.d.	17360	n/a	ECHA, 2023	pg/m ³
MeFOSA	n.d.	70	n/a	ECHA, 2023	pg/m ³
PFBA	n.d.	590	Above landfill (maximum concentration point)	ECHA, 2023	pg/m ³
PFPeA	n.d.	24	Above WwTP (maximum concentration point)	ECHA, 2023	pg/m ³
PFHxA	n.d.	63	Above WwTP (maximum concentration point)	ECHA, 2023	pg/m ³
PFHpA	n.d.	54	Above landfill (maximum concentration point)	ECHA, 2023	pg/m ³

²⁸⁰ ECHAPFBS (2023). ANNEX XV RESTRICTION REPORT – Per- and polyfluoroalkyl substances (PFASs), Annex B Information on hazard and risk. Available at: <https://echa.europa.eu/documents/10162/6f4a2076-7221-67a3-64f7-c67cc307f59c>

PFAS name	Minimum concentration	Maximum concentration	Any samples taken from a contaminated site?	Sources used	Unit
PFOA	n.d.	100	Above landfill (maximum concentration point)	ECHA, 2023	pg/m ³
PFBS	n.d.	70	Above landfill (maximum concentration point)	ECHA, 2023	pg/m ³
PFHxS	n.d.	0.62	n/a	ECHA, 2023	pg/m ³
PFOS	0.006	171	Above WwTP (maximum concentration point)	ECHA, 2023	pg/m ³
PFNS	n.d.	0.022	n/a	ECHA, 2023	pg/m ³
TFA	n.d.	170000	n/a	ECHA, 2023; Arp et al, 2024.	pg/m ³
PFPrA	64	360	Landfill	ECHA, 2023	pg/m ³

Biota

Due to their persistence, PFAS species have been found in several species across the globe, such as polar bears that have been thought to have been isolated from anthropogenic sources. PFAS has been observed in over 330 species, posing a serious threat to wildlife. A map created by the Environmental Working Group (EWG) shows the wildlife at risk from PFAS exposure.²⁸¹

As above, the relevant literature identified for PFAS exposure did not show any correlation between PFAS species and the concentrations which they were found at in the environment, with a lack of studies identified that provided an overview of the current PFAS data in biota within Europe.

Table 3-14 gives an overview for the range of values of PFAS species identified in biota from relevant literature

PFAS name	Minimum concentration	Maximum concentration	Any samples taken from a contaminated site?	Sources used*	Unit
PFBS	0.1	0.5	Fluoropolymer manufacturer (maximum concentration point)	Giara et al 2024; Brandsma et al., 2019	ng/g (w/w)
PFHxS	n/a	n.d.	n/a	Giara et al 2024	ng/g (w/w)
PFHpS	n/a	n.d.	n/a	Giara et al 2024	ng/g (w/w)
PFOS	13.1	62.2	n/a	Giara et al 2024	ng/g (w/w)

²⁸¹ https://www.ewg.org/interactive-maps/pfas_in_wildlife/map/

PFAS name	Minimum concentration	Maximum concentration	Any samples taken from a contaminated site?	Sources used*	Unit
PFBA	n.d.	42.0	Fluoropolymer manufacturer (maximum concentration point)	Giara et al 2024; Brandsma et al., 2019.	ng/g (w/w)
PFPeA	0.1	2.0	n/a	Giara et al 2024	ng/g (w/w)
PFHxA	n/a	n.d.	n/a	Giara et al 2024	ng/g (w/w)
PFHpA	n/a	n.d.	n/a	Giara et al 2024	ng/g (w/w)
PFOA	0.4	28.0	Fluoropolymer manufacturer (maximum concentration point)	Giara et al 2024; Brandsma et al., 2019.	ng/g (w/w)
PFNA	0.2	0.5	n/a	Giara et al 2024	ng/g (w/w)
PFDA	1.8	13.6	n/a	Giara et al 2024	ng/g (w/w)
PFUnDA	2.1	13.8	n/a	Giara et al 2024	ng/g (w/w)
PFDoDA	1.3	7.2	n/a	Giara et al 2024	ng/g (w/w)
PFTTrDA	1.0	6.2	n/a	Giara et al 2024	ng/g (w/w)
PFTeDA	0.1	1.6	n/a	Giara et al 2024	ng/g (w/w)
Gen X	1.0	86.0	Fluoropolymer manufacturer (maximum concentration point)	Brandsma et al., 2019.	ng/g (w/w)
TFA	4.9	3800000	n/a	Arp et al., 2024	ng/g (dw)

*For values provided by Giara et al 2024 and Brandsma et al., 2019, the mean value was used at the maximum concentrations.

Interview findings

Interviews were conducted with stakeholders from industry such as agencies and NGOs, providing information on environmental concentrations of PFAS. It should be noted that information sources from stakeholders were provided after the drafting of the main body of text for Q2.1. Therefore, the information provided was reviewed in detail to decide whether they would change the outcomes of the answer to research question 2.1. For most of these sources, they did not change the answer to question 2.1.

During the interview with ChemSec and EEB, it was discussed that the EEA and the Forever Pollution Project have published useful data sets. In Sweden (and potentially other countries), there are also national inventories/maps of contaminates sites and groundwater PFAS concentrations. PFAS

exposure from air was confirmed as a data gap when discussed with stakeholders. It was also discussed that the analysis should consider stocks of PFAS in the environment (rather than only annual emissions). The interviewees said they could provide a list of sources with data about contamination and PFAS concentrations, this included the following:

- A database created by the EEA (2019)²⁸² giving an overview of sources which cover PFAS in the environment within Europe. The article itself does not include PFAS values to address Q2.1, but does signpost to several national documents for France, Denmark, Germany, the Netherlands and Sweden which do include values. Several of the links were outdated, although the Netherlands document provided information on concentrations of several PFAS substances around a fluoropolymer manufacturing plant. These values have been included in the tables in Appendix B to Annex A.
- A paper by Brunn et al., (2023)²⁸³ providing Information on levels of PFOS detected in several species and an overview of PFAS In the environment. Sufficient information on PFAS found in these species (bream, herring gull, white-tailed eagle). It should be also noted that the PFOS concentrations were done in ng/g fresh matter (fm). The results included 1 ng/g fm for bream file, 100 ng/g fm for bream liver, 35 ng/g fm for herring gull eggs, 625 ng/g fm for white-tailed eagles, 693 ng/g fm for harbour seal liver and 6182 ng/g fm for otter liver. These samples were taken in biota samples from the German Environmental Specimen bank.
- The PFAS 'forever pollution' map²⁸⁴ which shows where PFAS has been sampled in water and presumptive/known users of PFAS around the EU. As mentioned above, this is a good source of information for PFAS pollution spots within the EU. A summary paragraph can be found at the start of Q2.1.
- A paper from the German Environment Agency (2020)²⁸⁵, which gave infographics of PFAS values in fish livers, top predators, leaves, earthworms and groundwater. The paper is rather generic and gives an overview of PFAS and what it is/some of the areas that it has been found in Germany. It does not provide information to answer Q2.1.
- The Swedish national database²⁸⁶ which contains values of several pollutants that have been monitored in either biota/water samples. Similarly, the map of pollutants within Sweden was also provided²⁸⁷. This is a database which covers several thousand sample points, covering the general category of "environmental toxins" and cannot be easily extracted. The database is also all in Swedish.
- A paper by Joerss et al., (2024)²⁸⁸ covering TFA from pesticide use in Europe and the USA . The data is provided in kg/sq km and the data used is provided in the annex of the paper. This paper does not contribute as significantly for TFA concentrations as the Arp et al., 2024 paper which is covered below.

²⁸² <https://www.eea.europa.eu/en/analysis/publications/emerging-chemical-risks-in-europe>

²⁸³ Brunn, H., Arnold, G., Körner, W. et al. 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 (2023). <https://doi.org/10.1186/s12302-023-00721-8>

²⁸⁴ https://www.lemonde.fr/en/les-decodeurs/article/2023/02/23/forever-pollution-explore-the-map-of-europe-s-pfas-contamination_6016905_8.html

²⁸⁵ https://www.umweltbundesamt.de/sites/default/files/medien/2546/publikationen/200922_uba_sp_1-2020_eng-web_0.pdf

²⁸⁶ <https://www.sgu.se/produkter-och-tjanster/nationella-datavardskap/datavardskap-for-miljogifter/rapporterad-data-till-datavardskap-for-miljogifter/>

²⁸⁷ <https://ext-geoportal.lansstyrelsen.se/standard/?appid=ed0d3fde3cc9479f9688c2b2969fd38c>

²⁸⁸ Hanna Joerss, Finnian Freeling, Stefan van Leeuwen, Juliane Hollender, Xingang Liu, Karsten Nödler, Zhanyun Wang, Bochi Yu, Daniel Zahn, Gabriel Sigmund, Pesticides can be a substantial source of trifluoroacetate (TFA) to water resources, *Environment International*, Volume 193, 2024, 109061, ISSN 0160-4120, <https://doi.org/10.1016/j.envint.2024.109061>.

- Finally, a paper from Sha et al., (2022)²⁸⁹ which covered PFAA samples from sea spray in two sample sites (pg m^{-3}) for outdoor air samples. The paper predicts different tonnes per year of PFOA and PFOS transport based on two sources. One having a low of 258 tonnes per year and a high of 686 tonnes per year (median of 442 tonnes per year) for PFOA and a low of 56 tonnes per year, a high of 149 tonnes per year (median of 96 tonnes per year) for PFOS. The other source having a low of 258 tonnes per year and a high of 468 tonnes per year (median of 352 tonnes per year) for PFOA and a low of 56 tonnes per year, a high of 102 tonnes per year (median of 77 tonnes per year) for PFOS.

A PFAS expert from ETH Zurich also highlighted the Forever Pollution Project, as well as research on certain pollution hotspots (Veneto, Lyon, etc). In terms of extrapolating information from specific sites, the interviewee noted two global studies on background concentrations and drinking water concentrations²⁹⁰.

Representatives of the Forever Pollution Project were also interviewed. Details about the approach, uncertainties and gaps were discussed, notably around industrial sites, illegal waste dumps, and former landfills. Some details can also be found on the project website and a peer-reviewed article²⁹¹ published about the project. The data has been passed on to the CNRS (French national research centre), which have improved the data and created the PFAS data hub²⁹². The dataset is discussed earlier in this section, but the data itself could not be presented in this report due to the size of the dataset.

A discussion with two environmental economists from RIVM gave further information on PFAS pollution in the environment. Discussions took place around the best sources of information for environmental contamination. The stakeholders recommended looking at Dr. Juliane Glüge's work as they are best placed for environmental contamination. The team screened Dr. Glüge's articles since 2020 (as listed on her university's website²⁹³) and identified two relevant papers:

- Dalmijn et al. 2024²⁹⁴: This study contains an inventory of emissions of PFAS from fluoropolymer production sites in Europe using available emission databases and permits. The study provides data on emissions of F-gases to air and fluorosurfactants to air and water, but notes large uncertainties regarding the emissions of other PFAS that are neither fluorinated gases nor fluorosurfactants, such as polymerization by-products, chain transfer agents and fluorinated solvents. No data on resulting concentrations in the environment is provided.
- Arp et al., 2024²⁹⁵: This was also proposed by another stakeholder (PAN Europe) and is discussed as part of their input below.

The stakeholder also mentioned a document which looked at national government's target levels of PFAS in soils (ARAGON).²⁹⁶ The stakeholders also suggested that there would more research and information on PFOA due to the regulation in place.

²⁸⁹ Sha B, Johansson JH, Tunved P, Bohlin-Nizzetto P, Cousins IT, Salter ME. Sea Spray Aerosol (SSA) as a Source of Perfluoroalkyl Acids (PFAAs) to the Atmosphere: Field Evidence from Long-Term Air Monitoring. *Environ Sci Technol*. 2022 Jan 4;56(1):228-238. doi: 10.1021/acs.est.1c04277. Epub 2021 Dec 15. PMID: 34907779; PMCID: PMC8733926. <https://pubs.acs.org/doi/10.1021/acs.est.1c04277>

²⁹⁰ <https://pubmed.ncbi.nlm.nih.gov/30336434/> and <https://www.nature.com/articles/s41561-024-01402-8>

²⁹¹ <https://pubs.acs.org/doi/10.1021/acs.est.3c09746>

²⁹² <https://pdh.cnrs.fr/en/>

²⁹³ <https://emeritus.setg.ethz.ch/people/senior-scientists/gluege--juliane.html>

²⁹⁴ Dalmijn et al. (2024). Emission inventory of PFASs and other fluorinated organic substances for the fluoropolymer production industry in Europe. Available at: <https://pubs.rsc.org/en/content/articlelanding/2024/em/d3em00426k>

²⁹⁵ Arp et al., (2024) The Global Threat from the Irreversible Accumulation of Trifluoroacetic Acid (TFA). *Environmental Science & Technology*. 58(45). Available at: <https://pubs.acs.org/doi/10.1021/acs.est.4c06189>

²⁹⁶ The respondent stated that this document would be shared if it was in the public domain. No further information was received on the initiative.

PAN Europe, a stakeholder focused on pesticides in the European environment, provided three literature sources focusing on TFA in the environment (a breakdown product of active PFAS substances used in PFAS). These include:

- A paper by Arp et al., 2024²⁹⁷ which include a large dataset on TFA monitoring data in several environmental compartments. This data has been included in Appendix B to Annex A (tables used for Q2.1) to add data on TFA.
- A paper from Adlunger et al., 2022²⁹⁸ including an overview of how TFA moves around environmental compartments and the range of concentrations that TFA has been found at in several environmental compartments (including the marine environment, rivers, lakes, estuaries, groundwater and soil). This does not add any further information on TFA concentrations to build on the information used in the Arp et al., 2024 paper.
- A paper from Sturn et al., 2023²⁹⁹ assesses TFA in both surface water and groundwater monitoring, with infographics showing the distribution of sampling and the concentration ranges of TFA across Germany. Similarly, this does not build on the Arp et al paper values and therefore has not been included as a literature source.

3.2.2. Q2.2 What are the environmental effects on aquatic and terrestrial species and populations?

There is a growing body of evidence that some PFAS have the potential to harm aquatic and terrestrial animals and plants. Key literature on the environmental risks from PFAS has been reviewed and summarised by Ankley et al. (2020)³⁰⁰ and Banyoi et al. (2022)³⁰¹. Several hundreds of new scientific publications in the field of PFAS ecotoxicology are published each year.³⁰² Studies have revealed both mechanistic effects of PFAS (e.g. oxidative stress, immunotoxicity, liver toxicity, and genotoxicity) and effects on entire organisms (e.g. developmental effects, effects on reproduction, and behavioural effects). Reproductive and developmental effects are frequently described in the literature and may be of particular interest to this study as they have the potential to affect ecosystem services and biodiversity loss. Despite the growing body of evidence, most studies conclude that PFAS have the potential to cause harm but do not conclude on the *extent* of harm to different species and populations. Some key evidence is summarised in the text below, followed by an overview of the key limitations in the state of the evidence/understanding and a comparison of the state of evidence for different PFAS substances.

Reproductive effects

Ankley et al. (2020) describe several field studies that looked at the possible effects of PFAS on the hatchling success of birds. In tree swallows (a species of birds), negative effects associated with PFOS were observed in two studies (at 150 ng/g ww in eggs), however, a different study on the same species observed no effects at a much higher concentration (600 ng/g). In great tits, a negative association was observed between PFOS exposure and hatchling success. Similarly, in kittiwakes, a negative association was observed between PFDa and hatchling success. This effect (if realised) is likely to be

²⁹⁷ Han et al., (2024) *The Global Threat from the Irreversible Accumulation of Trifluoroacetic Acid (TFA)*. *Environmental Science & Technology*. 58(45). Available at: <https://pubs.acs.org/doi/10.1021/acs.est.4c06189>

²⁹⁸ Adlunger et al., (2020). *Reducing the input of chemicals into waters: trifluoroacetate (TFA) as a persistent and mobile substance with many sources*. Available at: <https://www.umweltbundesamt.de/en/publikationen/reducing-the-input-of-chemicals-into-waters>

²⁹⁹ Sturm et al., 2023. *Trifluoroacetate (TFA): Laying the foundations for effective mitigation*. Available at: <https://www.umweltbundesamt.de/en/publikationen/trifluoroacetate-tfa-laying-the-foundations-for>

³⁰⁰ Ankley et al. (2020) *Assessing the Ecological Risks of Per- and Polyfluoroalkyl Substances: Current State-of-the Science and a Proposed Path Forward*. Available at: <https://setac.onlinelibrary.wiley.com/doi/epdf/10.1002/etc.4869>

³⁰¹ Banyoi et al. (2022) *The effects of exposure to environmentally relevant PFAS concentrations for aquatic organisms at different consumer trophic levels: Systematic review and meta-analyses*. Available at: <https://www.sciencedirect.com/science/article/pii/S0269749122016360>

³⁰² BAuA et al. (ECHA) (2023) *Annex XV Restriction report proposal for a restriction of PFASs (Appendix B)*

relevant at a population level because hatchling success rate influences the rate of population growth / decline, and have consequential effects for ecosystems, and ecosystem stability. In laboratory studies, negative effects have also been observed in fish and invertebrates.

Developmental effects

Developmental effects have been observed in various species. In a systematic review, Banyoi et al. (2022) concluded that PFOS, PFOA, PFNA, and PFBS show negative effects on several aquatic organisms in terms of weight and length, especially for female individuals. The same review identified that reduced growth in microalgae has been associated with exposure to Cl-PFAES at concentrations as low as 10 ng/L. In terrestrial organisms, Peden-Adams et al. (2009)³⁰³ exposed chicken eggs with three different concentrations of PFOS solution (1, 2.5, and 5mg/kg egg wt). In all exposed samples, chicks developed shorter right wings. At the two higher concentrations, an increase in body length was observed. Possible developmental effects have also been observed in terrapins based on field studies monitoring PFOS, PFNA, and PFHxS. In brown anoles (reptiles), exposure to 3 mg/kg body weight/day for 35 days resulted in decreased growth of juveniles, and exposure to PFHxS resulted in decreased egg viability in female anoles. Effects in invertebrates have been documented for several PFAS (PFOS, PFOA, henicosafuoroundecanoic acid, FTOH, PFHpA, PFHxS, PFBS, and 6:2 fluorotelomer sulfonate).

Behavioural effects

Behavioural effects have been observed in fish, e.g. effects on swimming distance, however, these have been observed when fish were exposed to relatively high PFAS concentrations which are unlikely to occur in the environment (Banyoi et al., 2022). Behavioural effects in other organisms were not identified in the literature.

Neurological effects

Pedersen et al. (2015) identified significant correlations between PFSA and PFCA concentrations in the brains of polar bears and changes in enzymes important for the neurological system.³⁰⁴ The average PFSA concentration was 25 ng/g wet weight (91% of which was PFOS) and the average PFCA concentration was 88 ng/g wet weight (79% of which was PFUnDA, PFDoDA and PFTrDA). Molecular effects in fish brain samples have also been identified (Banyoi et al. 2022). This indicates that some PFAS have the capacity to interact with the biological functioning of organisms, however, it does not tell us the nature and extent of ecological effects and it is based on a sample size of only nine polar bears.

General/other toxicity

Various laboratory studies have looked at concentrations of PFAS exposure associated with lethal outcomes (not specific hazard endpoints). For example, Ankley et al. (2020) noted that LC50 values for earthworms fell within the range of 373 – 760 mg/kg soil for PFOS, FPPPs (fluorinated plant protection products³⁰⁵), and PFOA after 14-day exposure). No Observed Effect Concentration (NOEC) values for some PFAS after 3-4 week exposure in earthworms were 1 mg/kg soil.³⁰⁶ For marine shrimp, a 14-day LC50 of 0.0001 mg/L was observed for hexaflumuron. In honeybees, Ankley et al. (2020) highlighted an observed LD50 (72-h) of 0.40 mg PFOS per bee.

³⁰³ Peden-Adams et al. (2009) *Developmental toxicity in white leghorn chickens following in ovo exposure to perfluorooctane sulfonate (PFOS)*. Available at: <https://pubmed.ncbi.nlm.nih.gov/19071210/>

³⁰⁴ Pedersen et al. (2015) *Brain region-specific perfluoroalkylated sulfonate (PFSA) and carboxylic acid (PFCA) accumulation and neurochemical biomarker responses in east Greenland polar bears (Ursus maritimus)*. Available at: <https://pubmed.ncbi.nlm.nih.gov/25682255/>

³⁰⁵ The specific FPPPs were not named in the study, but could include a range of substances (e.g. Ogawa et al. (2020) noted that their database includes 424 fluorinated agrochemicals).

³⁰⁶ PFHxS, PFOS, PFHpA, PFNA, PFOA

Evidence of the following mechanistic effects is also described by Ankley et al. (2020) based on field studies: PFCAs and PFSA and liver toxicity in cetaceans; general PFAS and immunotoxicity in marine mammals (walruses, dolphins, and sea otters); PFOS and immunotoxicity in turtles; and immunotoxicity and liver effects in fish.

Most of the available evidence focuses on animals and algae. Plant toxicity has been investigated to a lesser degree, but generally, the evidence of biochemical and cellular effects suggests that PFAS have the potential to be toxic to plants³⁰⁷. Effects have been observed at concentrations higher than those which are expected to occur in the environment, although bioaccumulation has also been observed which may mean that internal exposure to organisms is higher than expected from environmental concentrations (see the limitations section below).

Quantified effect levels

Most studies indicate in a binary way whether effects may be expected or not (e.g. those which use NOEC values), whereas some studies indicate the extent of damage (e.g. an LD50 value could be used to estimate that 50% of organisms exposed at this concentration are expected to die). Effect levels are highlighted in the table below to exemplify some of the ecotoxicological effects of PFAS, however, due to the large volume of literature (primary studies, rather than review studies), differences between species, PFAS substances, and types of studies, a full list of accurate exposure thresholds is not feasible to generate in this study. Moreover, the limitations noted in the section below mean that it is unlikely to be feasible to use these effect thresholds in this study to estimate the potential for environmental impacts.

Table 3-15 Example quantitative thresholds for PFAS effects in different types of organisms (identified by Ankley et al., 2020)

Type of organism	PFAS substances	Example thresholds	Effect level
Fish	PFOS	9.4 mg/kg (wet weight of fish tissue)	95% protection value (i.e. 5% of species may be adversely affected at this level)
Amphibians	PFOA PFOS PFDA PFUnDA	377 mg/L 48 mg/L 76 mg/L 78 mg/L	LC50 (i.e. 50% of exposed organisms are expected to die)
Birds	PFOS	283 ng/g (egg)	20% decrease in hatchling success
Terrestrial invertebrates	PFOS PFOA FPPPs	373 mg/kg soil dry weight 760 mg/kg soil dry weight 374 – 400 mg/kg soil dry weight	LC50 (i.e. 50% of exposed organisms are expected to die)
Marine invertebrates	PFCAs, PFSA, fluorocyclohexanes, FASAs, FPPPs	0.03 – 100 mg/L	LC50 (i.e. 50% of exposed organisms are expected to die)

³⁰⁷ Li et al. (2022) Exposure routes, bioaccumulation and toxic effects of per- and polyfluoroalkyl substances (PFASs) on plants: A critical review. Available at: <https://pubmed.ncbi.nlm.nih.gov/34592655/>

The example values above are included as they were identified by Ankley et al. (2020). Further examples are provided in Appendix B to Annex A (Table 23) based on an extraction of data from the US EPA ECOTOX Knowledgebase. The database was filtered to the named PFAS in scope of the project, looking at the reported exposure levels where: a) 50% of individuals in a target population may be expected to experience effects (ED50 and EC50); and b) 50% of individuals in a target population may be expected to die (LD50 and LC50). These endpoints were selected as there may be potential to use them to estimate ecological effects, e.g. Fantke et al. (2018) describe how species sensitivity distributions may be applied based on EC50 thresholds to model potential damage to ecosystems.³⁰⁸ At the same time, it is important to note that modelling ecosystem damage has limitations as it is based on extrapolations and does not imply actual species loss in a particular environment (as explained by Fantke et al.). This will be further explored in Task 2.

Overall, the US EPA ECOTOX Knowledgebase shows that there are data gaps for many PFAS, particularly in the terrestrial environment. A wide variety of units and target species are included in the database which limits comparability of the data. The quality of the studies included in the database has not been reviewed by the project team due to the large number of them.

Limitations

The main limitation to research questions 2.2 – 2.4 is that most data related to the environmental effects of PFAS is from laboratory studies or controlled exposure studies. While this data is indicative of probable environmental effects, it does not directly indicate what the expected ecological effects of PFAS are at the ecosystem level. Most available data on the environmental effects of PFAS has the following characteristics:

- a) It indicates whether effects are expected or not (in a binary way), rather than identifying the scale and nature of effects (important for the cost assessment)
- b) It is substance-specific, species-specific, concentration-specific, and hazard/effect-specific (therefore only reveals a small part of the overall picture of the potential ecological effects of PFAS)
- c) It does not take into account co-exposure of multiple PFAS substances (explained in more detail below), i.e., mixture effects.
- d) It does not take into account exposure over prolonged periods of time (as expected in the environment)
- e) It does not take into account uncontrolled environmental variables (which may mitigate or exacerbate the effects of PFAS)
- f) It is based on PFAS concentration levels that are higher than those relevant in the European environment

Even where field studies have been undertaken, many share the first three limitations mentioned above, and even where there are correlations, it is difficult to conclude on causality of effects because of the uncontrolled environmental factors that could influence the results unknowingly.

Mixtures toxicity

Point c) and d) mentioned above are critical to consider in this study as they mean that environmental risks from PFAS could be underestimated based on some available data. Point c) means that most studies do not take into account the reality that PFAS co-occur in **mixtures** in the environment. There is growing evidence that substances, particularly those within the same type of chemical group / with

³⁰⁸ Fantke et al. (2018) *Toward harmonizing ecotoxicity characterization in life cycle impact assessment*. Available at: <https://core.ac.uk/download/pdf/388644844.pdf>

similar toxicity pathways, have additive (and potentially cumulative) effects.³⁰⁹ This means that concentrations of individual PFAS substances thought to be safe / below effect thresholds may still lead to environmental harm if there are other co-occurring PFAS (which is likely). Ankley et al. (2020) highlight a couple of cases where evidence points towards the additivity of PFAS effects. This includes one study looking at PFOA and PFOS toxicity to amphibians and one study looking at reproductive effects in birds.

Bioaccumulation, chronic effects, and persistence

Regarding point d), the lack of studies on exposure over prolonged periods of time is a limiting factor because effect thresholds based on short term exposure to PFAS do not account for: 1) chronic effects that may materialise over time; 2) long term internal exposure caused by the **bioaccumulation potential** of some PFAS in the environment; and 3) the extreme persistence of some PFAS in the environment. For bioaccumulative substances, environmental concentrations (e.g. in surface water, air, and soil) may be lower than derived effect thresholds based on acute toxicity studies, however, the actual (internal) exposure to organisms is likely to be higher due to absorption and retention of the substances over time. Similarly, exposure can be prolonged for persistent substances that do not degrade or volatilise in the environment. This means that effects are possible at concentrations below those identified in controlled exposure and laboratory studies and is an important consideration given that PFAS concentrations are often lower than effect concentrations (observed by Sinclair et al. (2020), based mainly on PFOA and PFOS).³¹⁰ The importance of considering persistence when evaluating the environmental impacts of PFAS was highlighted by Arp et al. (2024).³¹¹ Despite significant gaps in evidence on the (eco)toxicity of TFA, the authors conclude that, given its persistence, exposure to TFA should be considered chronic and lifelong to all species. However, these considerations have not been made in all studies, e.g. those which have concluded that the risk of TFA to the environment (and human health) is negligible.³¹²

Comparison between PFAS substances

The volume and type of data and conclusions vary between PFAS substances. Most ecotoxicity studies on aquatic organisms have been on PFOS, PFOA, PFNA and PFBS (Banyoi et al., 2022). Ankley et al. (2020) noted that for aquatic and terrestrial invertebrate studies, 95% of the available data (based on the Ecotox Knowledgebase at the time) was for PFCAs (30%), PFSA (47%), and FPPPs (fluorinated plant protection products) (18%).

The availability of data for short-chain PFAS, such as TFA, is more limited (as is the case for human health impacts).³¹³ Moreover, for some PFAS, the evidence on toxicity concerns is not consistent between studies. For example, Garavagno et al. (2024) describe the uncertainties on whether TFA is bioaccumulative and whether its toxicity to organisms is of concern. On the other hand, Arp et al. (2024) note that due to its persistence and the available (eco)toxicity data, exposure to TFA should be considered chronic and lifelong to all species.³¹⁴

Fluoropolymers represent another PFAS class where there are diverging stakeholder views on environmental (and human health) impacts. It has previously been claimed that fluoropolymers

³⁰⁹ Martin et al. (2021) *Ten years of research on synergisms and antagonisms in chemical mixtures: A systematic review and quantitative reappraisal of mixture studies*. <https://www.sciencedirect.com/science/article/pii/S0160412020321619>

³¹⁰ Sinclair et al. (2020) *What are the effects of PFAS exposure at environmentally relevant concentrations?* Available at: <https://www.sciencedirect.com/science/article/abs/pii/S0045653520315332>

³¹¹ Arp et al. (2024) *The global threat from the irreversible accumulation of trifluoroacetic acid (TFA)*. Available at: <https://chemrxiv.org/engage/chemrxiv/article-details/670852dd51558a15efbbae16>

³¹² Hanson et al. (2024), *Trifluoroacetic Acid in the Environment: Consensus, Gaps, and Next Steps*. Available at: https://www.researchgate.net/publication/382693185_Trifluoroacetic_Acid_in_the_Environment_Consensus_Gaps_and_Next_Steps

³¹³ Garavagno et al. (2024) *Trifluoroacetic Acid: Toxicity, Sources, Sinks and Future Prospects*. Available at: <https://www.mdpi.com/2071-1050/16/6/2382#B41-sustainability-16-02382>

³¹⁴ Arp et al. (2024) *The Global Threat from the Irreversible Accumulation of Trifluoroacetic Acid (TFA)*. Available at: <https://pubs.acs.org/doi/full/10.1021/acs.est.4c06189>

should be considered as polymers of low concern in terms of environmental and human health impacts.³¹⁵ However, Lohmann et al. (2021) concluded that this should be assessed on a case-by-case basis.³¹⁶ There is uncertainty on the extent to which the chemical and biological stability, as well as the lack of bioaccumulation potential, of most fluoropolymers limits their ability to interact with organisms and pose risks to health and the environment. However, fluoropolymers may have more complicated pathways to health and environmental harm. While there is a general lack of literature on the topic, sources indicate that these pathways may include:³¹⁷

- By-product emissions of other PFAS during fluoropolymer manufacturing
- Emissions of microplastics formed by physical degradation of fluoropolymers during the use phase
- Leaching of PFAS formed from physical degradation of fluoropolymers in waste disposed of in landfill
- Formation (and potential emissions) of smaller PFAS during chemical recycling of fluoropolymers
- Emissions of TFA from the treatment of fluoropolymer waste through incineration (including at high temperatures of 1,100 °C)

The toxicity of fluoropolymers directly is not as well-studied as certain other PFAS. It has previously been argued that the high molecular weight of fluoropolymers means that they are too large to enter biological cells and cause effects, however, Lohmann et al. (2021) demonstrated that this premise is not substantiated by the available scientific evidence. The authors note several examples where high molecular weight polymers have been evidenced to enter biological cells. It may also be noteworthy that other polymers have been linked to significant health and environmental impacts, for example, microplastics have been associated with cancer, cardiovascular disorders, respiratory problems, birth defects, obesity, and neurological disorders.³¹⁸

Ultimately there are many gaps in knowledge on the impacts of fluoropolymers, limiting the ability to draw any conclusions on the nature and scale of impacts in this study, however, the potential of fluoropolymers to cause negative effects should not be overlooked and warrants further research.

In addition to differences in the availability of information on different PFAS, some trends in the toxicity of PFAS substances have been observed in the literature. Ankley et al. (2020) commented that that sulfonates were typically more acutely toxic to fish than carboxylates at the C8 length. For acute toxicity in birds, the authors also found that sulfonates were more toxic than carboxylates. They found that PFOS (a sulfonate) was more toxic than PFOA (a carboxylate), which was more toxic than PFBS (a sulfonate).

Ankley et al. (2020) also noted that toxicity in the same PFAS class tends to increase with increased fluorocarbon chain length. In rodents and birds, C8 compounds were more acutely toxic than shorter chain PFAS. For neurotoxicity in mammals, the greatest toxicity was observed for C8 to C12 compounds (compared to PFCAs <C6 (least toxic) and C14 perfluorotetradecanoic acid).

Ankley et al. (2020) noted that for fluorotelemers, there is a vast range in fluorochains and functional groups that could greatly influence their persistence, bioaccumulation, and toxicity. Studies with 6:2 and 8:2 FTOHs resulted in less toxicity than other C6 PFAS compounds.

³¹⁵ Henry et al. (2018) *A Critical Review of the Application of Polymer of Low Concern and Regulatory Criteria to Fluoropolymers*. Available at: <https://setac.onlinelibrary.wiley.com/doi/10.1002/ieam.4035>

³¹⁶

³¹⁷ Wahlström et al. (2021) *Fluorinated polymers in a low carbon, circular and toxic-free economy*. Available at: [http://youthstudies.co/pdf/eea%20task%20on%20fluoropolymers_full%20report_december%2014%202021%20\(1\).pdf](http://youthstudies.co/pdf/eea%20task%20on%20fluoropolymers_full%20report_december%2014%202021%20(1).pdf)

³¹⁸ Megha et al. (2024) *Environmental impact of microplastics and potential health hazards*, Available at: <https://www.tandfonline.com/doi/abs/10.1080/07388551.2024.2344572>

Relative potency factors (RPFs) can be applied to quantitatively estimate the differences in toxicity between chemicals with similar effects, based on a defined reference point. For PFAAs, RPFs are noted in the annexes to the 2022 proposal for an amendment to the Water Framework Directive and Groundwater Directive (COM(2022) 540 final)³¹⁹. In this instance, the RPF reference point is the toxicity of PFOA, which is therefore given an RPF of 1, and other RPFs indicate the multiplier by which other chemicals are more or less toxic. It is not known whether these values are based on aquatic toxicity, terrestrial toxicity, and/or human health toxicity data. The RPFs of the PFAAs in the scope for this project³²⁰ are as follows (from high to low):

- PFNA – RPF 10
- PFDA – RPF 7
- PFUnDA (PFUnA) – RPF 4
- PFDoDA (PFDoA) – RPF 3
- PFOS – RPF 2
- PFDS – RPF 2
- PFTTrDA – RPF 1.65
- PFHpS – RPF 1.3
- PFOA – RPF 1
- PFHxS – RPF 0.6
- PFHpA – RPF 0.505
- PFTeDA – RPF 0.3
- PFPeA – RPF 0.03
- PFHxA – RPF 0.01
- PFBS – RPF 0.001

Other sources have also highlighted the large degree of differences in toxicity of different PFAS, even within PFAS subgroups. Wang et al. (2024) reported freshwater PNECs for that ranged from 4.8 to 2000 µg/L for PFCAs and 0.4 to 8.9 µg/L for PFSA.³²¹

Conclusions

Laboratory and field studies suggest that various PFAS may have effects on certain species, however, there are many uncertainties and gaps in evidence to conclusively determine the specific environmental effects of environmentally relevant concentrations of PFAS. The lack of quantified estimates of the extent of damage to species caused by PFAS exposure presents a significant challenge to this cost assessment. Other challenges relate to the lack of recent review studies on the ecological risks and effects from PFAS, the focus of the literature on a limited number of PFAS substances, and gaps in evidence for different species.

³¹⁹

³²⁰ Those not in scope for this project include: PFPeS (RPF 0.3005), C6O4 (RPF 0.06), HFPO-DA (GenX) (RPF 0.06), 8:2 FTOH (RPF 0.04), ADONA (RPF 0.03), PFHxDA (RPF 0.02), PFBA (RPF 0.05), PFODA (RPF 0.02), 6:2 FTOH (RPF 0.02),

³²¹ Wang et al. (2024) Critical Evaluation and Meta-Analysis of Ecotoxicological Data on Per- and Polyfluoroalkyl Substances (PFAS) in Freshwater Species. https://www.researchgate.net/publication/384291329_Critical_Evaluation_and_Meta-Analysis_of_Ecotoxicological_Data_on_Per-and-Polyfluoroalkyl_Substances_PFAS_in_Freshwater_Species

3.2.3. Q2.3 What are the ecosystem-level effects? / Q2.4 What are the effects on biodiversity?

The section above provides an overview of evidence on the environmental risks from PFAS. This is indicative of the potential of PFAS to cause environmental harm but does not imply actual damage. Unfortunately, the literature on ecosystem-level effects from PFAS is sparse. As concluded by Banyoi et al. (2022) in the context of aquatic ecosystems: "*field-based studies and controlled studies in combination with uptake and accumulation studies are needed to better understand the population effects and in the long run the ecological effects.*" This is also applicable to terrestrial populations as they have been studied even less than aquatic ecosystems in terms of PFAS effects. More widely, it is acknowledged by the scientific community that there is a general need for improved methods to better understand the impacts of chemicals (including PFAS and beyond) on ecological systems.³²² This moves away from traditional chemical risk assessment which focuses on a low number of test species and focuses on effects on individuals rather than populations and ecological communities.³²³ It has also been observed that chemical pollution has received relatively low attention in research on biodiversity loss.³²⁴

Banyoi et al. (2022) describe some of the potential ecosystem-level effects of PFAS exposure (albeit based on scientific logic rather than observational evidence), for example, they note that the sensitivity of microalgae to PFAS (described in the section on developmental effects, and also noted by Arp et al. (2024) for TFA) could result in wider ecological implications as microalgae are at the bottom of the food web in marine ecosystems, and changes in their population level can cause rapid and serious effects on higher trophic levels. The same could be applicable for other primary producers for which effects are described in the section above, e.g. earth worms and marine shrimp.

In one field study in Italy, possible ecological effects were observed based on invertebrate populations in surface water.³²⁵ The authors observed the presence of more sensitive taxa upstream of a fluorotelomer plant compared with downstream locations, however, no significant differences were observed when overall health of the aquatic ecosystem was analysed. Another field study by Byns et al. (2024) also investigated risks from PFAS to aquatic invertebrates.³²⁶ The authors investigated macroinvertebrate community structure in 30 streams across Flanders (Belgium) and calculated 'safe threshold body burdens' for 28 PFAS substances. The thresholds ranged from 0.5 ng/g wet weight (for PFTDA) to 644 ng/g wet weight (for PFOS). No information on the extent of ecological damage was identified.

The US EPA AQUATOX model has the potential to model ecological risks from chemicals.³²⁷ Ma et al. (2024) applied the model to a lake in China contaminated with 21.7-25.4 ng/L of PFOA and 9.7 – 26.5 ng/L PFOS.³²⁸ In the lake sediment, the concentrations were 0.16 – 0.69 and 0.15 – 0.82 ng/g respectively. The authors modelled fish biomass over time and did not identify major threats, but they did comment that the biomass of some species, e.g. carp, could be affected by PFAS.

³²² Fantke et al. (2018) Toward harmonizing ecotoxicity characterization in life cycle impact assessment. Available at: <https://core.ac.uk/download/pdf/388644844.pdf>

³²³ Galic et al. (2019). Predicting impacts of chemicals from organisms to ecosystem service delivery: A case study of insecticide impacts on a freshwater lake. Available at: <https://digitalcommons.unl.edu/cgi/viewcontent.cgi?article=1232&context=mathfacpub>

³²⁴ Sigmund et al. (2023) Addressing chemical pollution in biodiversity research

³²⁵ Rusconi et al. (2015) Evaluating the impact of a fluoropolymer plant on a river macrobenthic community by a combined chemical, ecological and genetic approach. Available at: <https://pubmed.ncbi.nlm.nih.gov/26327633/>

³²⁶ Byns et al. (2024) Aquatic macroinvertebrate community responses to pollution of perfluoroalkyl substances (PFAS): Can we define threshold body burdens? Available at: <https://www.sciencedirect.com/science/article/pii/S0048969724007496>

³²⁷ <https://www.epa.gov/hydrowq/aquatox-32-download-page>

³²⁸ Ma et al. (2024) Trend of PFAS concentrations and prediction of potential risks in Taihu Lake of China by AQUATOX. Available at: https://www.researchgate.net/publication/379020767_Trend_of_PFAS_concentrations_and_prediction_of_potential_risks_in_Taihu_Lake_of_China_by_AQUATOX

Despite general gaps in the scientific literature, ecological limits have been derived in a regulatory context, which could be used to approximate the level of ecological harm caused by PFAS. Ankley et al. (2020) include a table (Table 1 of the source) of regulatory limits in different jurisdictions with different meanings. For example, in Canada the federal environmental quality guideline for PFOS is 6.8 µg/L. This is a 95% protection value based on a species sensitivity distribution model using 20 different species.

In the EU, environmental quality standards for the sum of 24 PFAS were proposed in 2022.³²⁹ In surface water and groundwater the proposed cumulative limit is 4.4 ng/L and in biota in surface water the proposed cumulative limit is 77 ng/kg wet weight. Both of these limits are proposed as 'PFOA equivalents', meaning the RPFs (noted in section 3.2.2) of the PFAS present should be taken into account.

Overall, there are gaps in the evidence of ecosystem-level effects of PFAS which could potentially in the future be addressed by approaches such as ecosurveillance.³³⁰

Interview findings

A PFAS expert from the US EPA and author of one of the key review papers in this field³³¹ explained that a large number of additional studies on environmental impacts of PFAS have been published since their paper was written, but there have not been many review papers summarizing this work yet. They recommended to use the US EPA's *Ecotox Knowledgebase*³³², the most comprehensive searchable collection of relevant data to their knowledge. This database presents ecotoxicity effect thresholds reported in the scientific literature for a wide range of substances. The database can be filtered to individual substances or substance groups, for example, filtering the results to PFAS as a substance group returns over 30,000 values for different effect thresholds, including over 14,000 NOECs, 9,000 LOECs, 800 LC50s, and others. These span across different types of animals and plants in both aquatic and terrestrial environments. Data for certain thresholds of the PFAS in scope of this project has been analysed in Appendix B to Annex A.

They also explained that proving ecosystem effects of any contaminant (not just PFAS) is generally challenging. Only few successful ecotoxicology papers have managed to link exposure in the field to observed ecosystem effects, due to challenges such as uncontrolled conditions. Furthermore, effects can vary considerably between animal species, PFAS species, and ecosystems. Research in this field is therefore often relying on lab studies to study effects under controlled conditions and then modelling ecosystem effects and/or linking the lab results to observations in the field.

To address a lack of evidence regarding the extent of ecosystem impacts at environmentally relevant concentrations, the interviewee suggested to consider "benchmark values", i.e. limits of environmental concentrations that are considered unsafe (such as environmental quality standards – EQS). The interviewee also recommends the consideration of bioaccumulation, because many environmental (and human) effects are likely from diet rather than direct environmental exposure. This has been reflected in section 3.2.4 below in terms of food provisioning as an ecosystem service.

In another interview, with EEB and ChemSec, it was discussed that some of the same limitations of the research on health effects also apply to environmental effects, such as a lack of research focusing on non-standard endpoints and tests (e.g. long-term exposure, unusual species, mixture effects).

³²⁹ European Commission (2022). Proposal for a Directive amending the Water Framework Directive, the Groundwater Directive and the Environmental Quality Standards Directive. Available at: https://environment.ec.europa.eu/publications/proposal-amending-water-directives_en#:~:text=On%2026%20October%202022,%20the%20Commission%20adopted%20a%20proposal%20for

³³⁰ Beale et al. (2022) Omics-based ecosurveillance for the assessment of ecosystem function, health, and resilience. Available at: <https://portlandpress.com/emergtoplifesci/article/6/2/185/231127/Omics-based-ecosurveillance-for-the-assessment-of>

³³¹ Ankley et al. (2020) Assessing the Ecological Risks of Per- and Polyfluoroalkyl Substances: Current State-of-the Science and a Proposed Path Forward. Available at: <https://setac.onlinelibrary.wiley.com/doi/epdf/10.1002/etc.4869>

³³² <https://cfpub.epa.gov/ecotox/>

A PFAS expert from ETH Zurich noted that multigenerational tests are required to understand ecosystem impacts.

3.2.4. Q2.5 What are the monetised ecosystem service costs associated with impacts on species, ecosystems and biodiversity?

Overview of key ecosystem services in the EU

Table 11 from a Eurostat 2021³³³ publication shows the estimated ecosystem service values associated with the ecosystem types in the EU in 2021. The values in this table are not related to the ecosystem services costs as a result of PFAS pollution specifically. It is estimated that in 2012 the ecosystem services were €172 billion and spread the costs to the nine ecosystems (shown in the table below) based on the total supply the ecosystem contributes (i.e., forests account for 47.5%).³³³

Table 3-16. Economic value provided by ecosystem services in the EU (EU28, 2012, million EURO).³³³

	Urban	Cropland	Grassland	Woodland and forest	Wetland	Heathland and shrub	Sparsely vegetated land	Rivers and lakes	Marine inlets and transitional waters
Crop provision	0	20795	0	0	0	0	0	0	0
Timber provision	0	0	0	14739	0	0	0	0	0
Crop pollination	:	4517	:	:	0	:	0	0	0
Carbon sequestration	0	0	0	9189	0	0	0	:	:
Flood control	89	1015	3128	11388	333	357	1	:	:
Water purification	1105	31041	4128	15374	330	312	170	3114	:
Nature-based reaction	77	4073	7482	30.723	2296	3097	1351	1015	279

In an interview, attention was drawn to the Ecosystem Services Valuation Database (ESVD) hosted by the Foundation for Sustainable Development.³³⁴ This database provides values for ecosystem services per hectare per year, filterable by biome / ecozone, country, location, protection status, and classification (based on the TEEB, CICES, and SEEA frameworks).

Ecosystem services with potential to be affected by PFAS

Section 3.2.2 and 3.2.3 highlight many gaps in terms of the state of knowledge on the specific environmental effects of PFAS, including their resulting impacts on ecosystems and biodiversity. Similarly, ecosystem service assessments of the impacts of PFAS are generally lacking. Challenges and opportunities in assessing chemical impacts in terms of ecosystem service delivery have been

³³³ European Commission (2021). Accounting for ecosystems and their services in the European Union. <https://ec.europa.eu/eurostat/web/products-statistical-reports/-/ks-ft-20-002>

³³⁴ <https://www.esvd.net/>

explored by Maltby et al. (2021)³³⁵ and Faber et al. (2019)³³⁶ and will be further considered in Task 2. This section describes the available evidence from the scientific literature related to PFAS and ecosystem services, and also draws on scientific logic and reasoning to explore the plausibility that PFAS have the potential to disrupt ecosystem service provisioning.

Overall, PFAS have the potential to affect ecosystem service provisioning through two key mechanisms: 1) through direct harm to the abiotic and biotic factors involved in providing ecosystem services; and 2) through loss in value of ecosystem services due to measures to avoid human health risks from PFAS. The two mechanisms are closely interlinked and described in more details below. The second type is notably closely interlinked with research question 1, which will be considered in Task 2.

In terms of the first mechanism, there is a general lack of information in the literature, but the plausibility of certain effects can be commented on. For example, the documented effects on honeybees (section 3.2.2) may result in costs to ecosystem service provisioning, in terms of pollination.

The possible effects on microalgae may also be relevant to ecosystem service provisioning. Microalgae play an important role in climate regulation, which may be hampered if PFAS lead to reduced growth. Moreover, as algae are primary producers, any effects of PFAS could have cascade effects on food webs in ecosystems, leading to a variety of ecological effects aquatic ecosystems, related to a potentially wide range of ecosystem service impacts. This applies to other primary producers which might be affected by PFAS, e.g. plants (noting that there are significant data gaps).

A second relevant ecosystem service in this context is food provisioning. For example, developmental effects and effects on the reproductive success of species involved in crop, livestock, and fish production may lead to societal costs in terms of lost food production and reduced profits for farms. This is mentioned only briefly in the literature, for example, Li et al. (2022) conclude that PFAS toxicity to plants could result in profound impacts on crops, although there remain many uncertainties.³³⁷ As discussed in section 3.2.2 above, there are gaps in the evidence on specific effects of PFAS on species, which is probably why the literature does not present information on the expected likelihood or scale of this type of ecosystem service cost.

Food provisioning may also be affected through the second type of mechanism mentioned above. It is possible that even where agricultural productivity is not reduced due to (eco)toxic effects on organisms involved in food provisioning, productivity may be reduced due to measures to protect humans from exposure to PFAS via diet. Commission Regulation 2022/2388/EU sets maximum levels for PFAS (PFOS, PFOA, PFNA, PFHxS, individually and as a cumulative sum) in certain foodstuffs (eggs, seafood, and livestock produce).³³⁸ The limits range from 0.2 to 50 µg/kg wet weight.

In Belgium, at least one livestock farm is expected to face productivity losses due to PFAS contamination of meat. Testing by Belgian authorities has revealed PFAS contamination in cattle on the farm, resulting in an obligation to test meat for PFAS before it can be sold.³³⁹ Similarly, in another contaminated region of Belgium, residents were advised to avoid the consumption of eggs.³⁴⁰ It should be considered how these costs interplay with human health costs when the Task 2 method is

³³⁵ Maltby et al. (2021) *Assessing chemical risk within an ecosystem services framework: Implementation and added value*. Available at: <https://www.sciencedirect.com/science/article/pii/S0048969721037037>

³³⁶ Faber et al. (2019) *Priorities and opportunities in the application of the ecosystem services concept in risk assessment for chemicals in the environment*. Available at: <https://www.sciencedirect.com/science/article/pii/S0048969718336544#bb0300>

³³⁷ Li et al. (2022) *Exposure routes, bioaccumulation and toxic effects of per- and polyfluoroalkyl substances (PFASs) on plants: A critical review*. Available at: <https://pubmed.ncbi.nlm.nih.gov/34592655/>

³³⁸ Commission Regulation 2022/2388/EU on maximum levels of PFAS in certain foodstuffs. Available at: <https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32022R2388>

³³⁹ La Libre (2024) *PFAS pollution: Meat production at Stabroek farm restricted after PFAS discovery*. Available at: <https://www.lalibre.be/planete/sante/2024/05/02/pollution-aux-pfas-la-production-de-viande-dune-ferme-de-stabroek-restreinte-apres-la-decouverte-de-pfas-2RGJKA4KFREWZETY2LGPDYZWCE/>

³⁴⁰ RTBF Actus (2021) *Flanders shaken by an environmental scandal that concerns us all*. Available at: <https://www.rtbf.be/article/la-flandre-secouee-par-un-scandale-environnemental-qui-nous-concerne-tous-10781726>

developed under this project. The Nordic (2019) study also cited a US study which estimated a WTP of €14 – €33 to avoid fishing in PFOS contaminated surface waters. It is not clear if this referred to commercial fishing or recreational fishing (mentioned below as a different type of ecosystem service).

Water purification is an ecosystem service provided by freshwater that maintains sufficient water quality for drinking and domestic use (due to the ability of freshwater plants and ecosystems to trap, breakdown, process and transform pollutants, toxins and heavy metals present in water).³⁴¹ PFAS have the potential to disrupt this service for several reasons, for example, there is potential for persistent PFAS to resist the (bio)degradation processes involved in water purification. PFAS may also be toxic to organisms involved in the purification process (e.g. microalgae), reducing their effectiveness in purification. While the extent of ecosystem service disruption caused by PFAS has not yet been quantified, one identified study looked at the willingness-to-pay (WTP) of consumers for improved drinking water quality in a PFAS contaminated area.³⁴² The author used a benefit transfer method to estimate an annual WTP of € 250.80 per household for improved drinking water quality.

Other ecosystem services disrupted through the second type of mechanism could include economic activities reliant on land use which may not be able to take place if land is contaminated with PFAS. This could include residential or commercial developments and agriculture. Cultural services could also be disrupted through this mechanism, for example, PFAS contaminated water bodies could be unsuitable for recreational bathing or fishing.

PFAS contamination may cause broader societal issues in terms of desirability of an area, which is likely to be connected to a range of ecosystem services and their disruption. The authors of the 2019 Nordic study cite a study from the US which identified a decline in house value by 7.3% in areas most affected by PFAS contamination. The average lost value per home was €12,657 in the most affected areas and €10,184 in other affected areas.

In practice, there are knowledge gaps on the levels of PFAS in soil and water across Europe, which may prevent people from being able to choose to avoid PFAS exposure, meaning the costs may not be realised. This could change in the future, depending on improvements in water quality monitoring and contaminated site identification and risk assessment.

Ecosystem service impacts from other chemicals

Given the scarcity of available data on the ecosystem service impacts of PFAS, evidence of ecosystem service impacts of other chemicals was reviewed to better understand the available methods and whether any proxies could be used in our assessment.

The 2019 Nordic Council study on costs of PFAS mentions WTP estimates to avoid risks from PBT and vPvB substances based on a small survey related to siloxanes D4 and D5. The estimated WTP for superior personal care products with reduced emissions of PBT/vPvB substances to the aquatic environment was EUR 5 per person per year. This is useful to infer that people place a value on a clean environment, however, it does not indicate the actual costs from the presence of contaminants in the environment.

Galic et al. (2019) predicted ecosystem service impacts from pesticide exposure to a freshwater lake using the AQUATOX ecosystem model tool to simulate how exposure to a hypothetical insecticide in different exposure management scenarios could affect species populations and environmental properties.³⁴³ The authors estimated costs in terms of lost value for wading and swimming based on a water clarity valuation model (which may not be applicable for PFAS as evidence on PFAS affecting

³⁴¹ Freshwater Information System. How multiple stressors affect rivers, lakes and estuaries.

<http://fis.freshwatertools.eu/index.php/infolib/ecoservices/regulating-services.html>

³⁴² Pintus (2024). Valuing drinking water quality after a PFAS contamination event: Results from a meta-analysis benefit transfer. Available at: <https://www.sciencedirect.com/science/article/pii/S0301479724011290>

³⁴³ Galic et al. (2019). Predicting impacts of chemicals from organisms to ecosystem service delivery: A case study of insecticide impacts on a freshwater lake. Available at: <https://digitalcommons.unl.edu/cgi/viewcontent.cgi?article=1232&context=mathfacpub>

the clarity of water was not identified). However, the estimates related to abundance of game fish may be relevant. WTP estimates of anglers to have fish of higher biomass was taken from the literature, at 1.55 – 4.03 USD / kg/ha increase in biomass of a specific fish species. The AQUATOX model was used to estimate fish biomass in each pesticide pollution scenario. For the bluegill and largemouth bass, the median value for biomass was higher in lower exposure scenarios. For the catfish, the trend was reversed. There was substantial overlap in data for each scenario for all species. Overall, the variety of trends per species indicate that interspecies differences are key to consider. This could include differences in sensitivity to the relevant pollutant(s) and differences in ecological interactions, which could make it difficult to apply a similar approach or use any proxies for PFAS.

Impacts of other chemicals on ecosystem services have been estimated where there are fewer uncertainties on the ecological impacts of chemicals (relative to PFAS). For example, tributyltin has an immediate and pronounced effect on aquatic organisms which was easily detectable and had a clear dose-response relationship. Loss of production of oysters in the Atlantic French coast between 1979 and 1983 was estimated to result in a loss in market value of €130 million.³⁴⁴

Overall, the knowledge gaps and specific challenges related to PFAS are likely to mean that estimates of ecosystem service impacts from other chemicals, and the methods used to derive them, are not applicable to PFAS, however, this will be further explored in Task 2.

Interview findings

A PFAS expert from ETH Zurich agreed that ecosystem service costs are currently not well studied but noted that studies by Jorge Numata (BfR Germany) on bioaccumulation of PFAS in farm animals could potentially be used to estimate economic losses if exposure levels lead to exceedances of limit values in meat.

3.2.5. Q2.6 What are the environmental clean-up costs (soil and water remediation/treatment costs) and litigation costs?

There are significant costs related to litigation and clean-up with relation to PFAS. ChemSec has estimated that nearly €16 trillion (or 1.6% of global GDP) is associated with the remediation and increased healthcare costs due to PFAS worldwide.³⁴⁵ Another study done by Ling estimates that removing PFAS from the environment at the rate we are adding it would cost more than the global GDP.^{345, 346} It is estimated that chemical companies could incur \$65-248 billion in clean-up costs in the US alone (equivalent to €60-229 billion³⁴⁷).³⁴⁵ A 2020 report by Wood et al.³⁴⁸ reports the costs of remediation by compartment within the EU. The report estimates that soil remediation costs are around €0.5-4.5 million per site, while ground water and drinking water remediation could cost over €30 million per site if remediation is undertaken over the course of 30 years.³⁴⁸ The costs of cleaning up PFAS contamination typically falls to public utilities, government, and taxpayers upfront rather than to the polluter.³⁴⁹ The Forever Pollution Project estimates costs of €95 billion over the next 20

³⁴⁴ RPA and BRE Environment (2003). *The Impact of the New Chemicals Policy on Health and the Environment. A report for the European Commission DG Environment.*

³⁴⁵ ChemSec (2024). *A Profitable Detox - Why safer chemistry makes financial sense.*
https://chemsec.org/app/uploads/2024/09/ChemSec_A-Profitable-Detox_241007.pdf

³⁴⁶ Ling, A.L. (2024). *Estimated scale of costs to remove PFAS from the environment at current emission rates.*
<https://doi.org/10.1016/j.scitotenv.2024.170647>

³⁴⁷ Converted based on an exchange rate of €1 = US\$1.0824 (2024 annual average exchange rate according to the European Central Bank, available at
https://www.ecb.europa.eu/stats/policy_and_exchange_rates/euro_reference_exchange_rates/html/eurofxref-graph-usd.en.html).

³⁴⁸ Wood et al. (2020). *The use of PFAS and fluorine-free alternatives in fire-fighting foams. Report produced for European Commission DG Environment / European Chemicals Agency (ECHA).*
https://echa.europa.eu/documents/10162/6755610/pfas_flourine-free_alternatives_fire_fighting_en.pdf/d5b24e2a-d027-0168-cdd8-f723c675fa98

³⁴⁹ Cordner, A. et al. (2021). *The true cost of PFAS and the benefits of acting now.* <https://doi.org/10.1021/acs.est.1c03565>

years for remediation of legacy PFAS.³⁵⁰ The project estimates that cleaning up the most concentrated sources of long-chain PFAS in Europe alone will be €4.8 billion per year.³⁵⁰ To remediate all PFAS over the next 20 years, the cost is estimated to be close to €2 trillion.

There have been more than 2000 PFAS litigations in 2023. 3M has had multiple payouts due to PFAS litigation, including \$850 million with the State of Minnesota (2018) (equivalent to €785 million³⁵¹) €571 million with the Flemish government (2022), and most recently a \$10.3 billion settlement with a group of US public water suppliers (2023) (equivalent to €9.5 billion³⁵²).³⁴⁵ Similarly, Chemours, DuPont, and Corteva have agreed to pay \$1.2 billion in 2023 (equivalent to €1.1 billion³⁵³) and BASF \$316.5 million in 2024 (equivalent to €292 million³⁵⁴) to resolve several pollution claims in the US alone. Future litigation costs are expected to be taken on by the individual companies. The State of New Jersey recently announced a settlement of \$393.8 million to cover drinking water remediation and environmental damages associated with PFAS (equivalent to €364 million³⁵⁵).³⁵⁶

The State of New Hampshire process sludge into compost, earning roughly \$400,000 annually (equivalent to €370,000³⁵⁷). If there is PFAS contamination in this sludge or resultant compost, the state will not only lose their annual earnings but also face upwards of \$2.4 million in landfill charges (equivalent to €2.2 million³⁵⁸).³⁴⁹

A 2019 report focused on the environmental remediation costs of the five Nordic countries estimates that over the next 20 years, €46 million – 11 billion will be spend on non-health costs (Table below).³⁵⁹ The column labelled 'Health assessment' is the environmental health, not human health.

Table 17. Detailed breakdown of ranges in quantified non-health costs for the Nordic countries.³⁵⁹

N people affected (3%)	Screening and monitoring	Health assessment	Upgrade treatment works and maintenance	Soil remediation	Total

³⁵⁰ Forever Pollution Project (2025). *Unaffordable - The absurd cost of 'PFAS as usual'*

³⁵¹ Converted based on an exchange rate of €1 = US\$1.0824 (2024 annual average exchange rate according to the European Central Bank, available at https://www.ecb.europa.eu/stats/policy_and_exchange_rates/euro_reference_exchange_rates/html/eurofxref-graph-usd.en.html).

³⁵² Converted based on an exchange rate of €1 = US\$1.0824 (2024 annual average exchange rate according to the European Central Bank, available at https://www.ecb.europa.eu/stats/policy_and_exchange_rates/euro_reference_exchange_rates/html/eurofxref-graph-usd.en.html).

³⁵³ Converted based on an exchange rate of €1 = US\$1.0824 (2024 annual average exchange rate according to the European Central Bank, available at https://www.ecb.europa.eu/stats/policy_and_exchange_rates/euro_reference_exchange_rates/html/eurofxref-graph-usd.en.html).

³⁵⁴ Converted based on an exchange rate of €1 = US\$1.0824 (2024 annual average exchange rate according to the European Central Bank, available at https://www.ecb.europa.eu/stats/policy_and_exchange_rates/euro_reference_exchange_rates/html/eurofxref-graph-usd.en.html).

³⁵⁵ Converted based on an exchange rate of €1 = US\$1.0824 (2024 annual average exchange rate according to the European Central Bank, available at https://www.ecb.europa.eu/stats/policy_and_exchange_rates/euro_reference_exchange_rates/html/eurofxref-graph-usd.en.html).

³⁵⁶ Despotaki et al. (2024). PFAS Litigation Could Generate Billions in Ground-Up Losses. Here's How. <https://core.verisk.com/Insights/Emerging-Issues/Articles/2024/April/Week-1/PFAS-Litigation-Could-Generate-Billions-in-Ground-Up-Losses>.

³⁵⁷ Converted based on an exchange rate of €1 = US\$1.0824 (2024 annual average exchange rate according to the European Central Bank, available at https://www.ecb.europa.eu/stats/policy_and_exchange_rates/euro_reference_exchange_rates/html/eurofxref-graph-usd.en.html).

³⁵⁸ Converted based on an exchange rate of €1 = US\$1.0824 (2024 annual average exchange rate according to the European Central Bank, available at https://www.ecb.europa.eu/stats/policy_and_exchange_rates/euro_reference_exchange_rates/html/eurofxref-graph-usd.en.html).

³⁵⁹ Goldenman et al. (2019). The cost of inaction: A socioeconomic analysis of environmental and health impacts linked to exposure to PFAS. <https://www.norden.org/en/publication/cost-inaction-0>

Denmark	169,791	€70,000-8.3 mil	€280,000-27 mil	€ 7.4 mil- 274 mil	€0- 798 mil	€8 mil-1.1 bil
Finland	164,153	€250,000-22 mil	€270,000-26 mil	€7.2 mil-265 mil	€2.2 mil-2.1 bil	€10 mil-2.4 bil
Iceland	10,102	€10,000-900,000	€20,000-1.6 mil	€400,000-1.6 mil	€100,000-86 mil	€1 mil-105 mil
Norway	154,995	€170,000-20 mil	€260,000-25 mil	€6.8 mil-250 mil	€1.6 mil-1.9 bil	€9 mil-2.2 bil
Sweden	292,421	€480,000-47 mil	€490,46 mil	€13 mil-472 mil	€4.3 mil-4.5 bil	€18 mil-5.1 bil
Nordic total	791,462					€46 mil-11 bil

Goldenman et al. (2019) also estimated the non-health costs for environmental remediation within the 31 EEA member states and found it to be €821 million – 170 billion.³⁵⁹

The information presented here is a snapshot of the litigation and remediation costs, with significant uncertainties and limitations. In terms of litigations, the above studies focus on settlement numbers that have been published in the public domain. These publications do not take into account private settlements or the cause of those settlements. Along with the potential private nature of settlements, it is also important to note that the available data may be skewed by the nature of the population in the areas of litigation. Some societies are more likely to undertake litigation and push for higher settlements based on societal norms. In terms of remediation costs, it should be noted that such costs can vary substantially depending on site-specific criteria, and that in the absence of detailed site-specific assessments, there is significant uncertainty about the number of sites and extent of remediation that would be required on a national or international level, so any extrapolation to national or international totals is highly challenging.

Interview findings

ChemSec/EEB recommended to consider the ongoing work by the OECD on the valuation of environmental effects from chemicals, and water treatment cost estimates by EurEau and Svenskt Vatten.

Representatives of the Forever Pollution Project highlighted that at the time of the interview, they were working on a follow-up project estimating the remediation costs to address the polluted sites identified in the original project. The results have since been scheduled and have been presented earlier in this section.

A representative of the Global PFAS Science Panel confirmed Ling (2024) as a key source.

3.2.6. Q2.7 What are the geographical and temporal trends in environmental costs?

For PFAS across ecosystems, biological time series data suggests that there are variable temporal changes.³⁶⁰ Data shows that legacy PFAS are declining in the environment, however new PFAS and the metabolites of legacy PFAS are still present in the environment, resulting in changing costs as

³⁶⁰ De Silva et al. (2020). *PFAS Exposure Pathways for Humans and Wildlife: A Synthesis of Current Knowledge and Key Gaps in Understanding*, Environmental Toxicology and Chemistry, 40, 631. Available at: <https://doi.org/10.1002/etc.4935>

different remediation is necessary. As different geographies experience contamination from different PFAS, it is difficult to estimate overarching trends in environmental costs.

Interview findings

Representatives of the Forever Pollution Project confirmed that temporal trends are difficult to determine because analytical capabilities are still emerging (e.g. additional PFAS species that were not tested in the past). However, recent evidence³⁶¹ suggests that TFA is now an orders of magnitude higher than other PFAS species, due to it being a transformation product of f-gases, pesticides, pharmaceuticals and industrial chemicals etc (not to mention the general production of TFA).

3.3. Overall societal costs from PFAS (Q3)

3.3.1. Q3.1 What are the methods to calculate societal costs from PFAS pollution?

The calculation of societal costs of PFAS pollution depends on the quantification of human health and environmental impacts, which were discussed in the previous sections. This section provides an overview of the methods employed to monetise the health and environmental costs of PFAS pollution. Note that there are different types of costs of PFAS pollution, which were identified and are discussed further in Section 3.3.2. Note also that the present section is intended as an initial overview, as a more detailed review and evaluation of methodologies is in the scope of Task 2.

Monetisation of health costs

Human health impacts associated with PFAS can be 'monetised', that is, their monetary value can be estimated using tried and tested, best-practice valuation technique (e.g., in line with the Commission's Better Regulation Toolbox, Tool #63). An initial list of valuation methods identified in the literature review so far is provided below, and these will be further reviewed and considered under Task 2.

- **Market-based methods** use market data to value health impacts. This includes methods such as the cost of illness (COI) method, human capital approach and the present value of lifetime earnings (PVLE).
 - *COI method* measures the economic burden of a disease or condition on society by considering its economic impact, including direct (medical and non-medical) and indirect (loss of productivity) costs.
 - *Human capital approach* is used to estimate the economic value of human life by considering the potential future earnings of individuals, taking into consideration other aspects of human capital such as education, skills and experience.
 - *PVLE* is used to estimate the economic value of an individual's future earnings, discounted back to their present value.
- **Avoided damage methods:** Cost-based approach used to estimate the economic value of preventing negative health outcomes, that is, the market and/or non-market costs that would have been incurred if the health damage had not been prevented.
- **Revealed preferences methods** use observed behaviours and market transactions by market actors to estimate the economic value of health outcomes. This includes Hedonic Pricing method, Travel cost method and the averting behaviour method.
 - *Hedonic Pricing method* estimates the value of health risks by analysing how they affect market prices, such as property values or wages, e. g., the wage differential for

³⁶¹ <https://pubs.acs.org/doi/10.1021/acs.est.4c06189>

jobs with varying levels of health risk can reveal the value workers place on reducing those risks.

- *Travel Cost method* uses the costs incurred by individuals to access healthcare services or recreational areas as a proxy for the value they place on these services, e.g., the travel expenses and time spent to visit a healthcare facility can indicate the value of the health benefits provided.
- *Averting behaviour method* examines the expenditures individuals make to avoid health risks, such as purchasing bottled water to avoid contaminated tap water, or expenditures for additional water treatment to remove PFAS from drinking water.
- **Stated preferences methods** are used to estimate the economic value of health outcomes based on individuals' expressed preferences in hypothetical scenarios, generally summarised in terms of their willingness to pay to avoid years of life lived with disability and/or lost. These methods are particularly useful when market data is unavailable or insufficient. This group includes Contingent Valuation (CV), Discrete Choice Experiments (DCE):
 - CV involves presenting respondents with a hypothetical scenario and asking them how much they would be willing to pay for a specific benefit or to avoid a negative outcome. For example, researchers investigate people's willingness to pay to reduce risk of premature death by a small probability and estimate the social 'Value of Statistical Life' (VSL), and/or their willingness to pay for an additional year of life and estimate the 'Value of a Life Year' (VOLY). The VOLY can also be derived from VSL estimates based on considerations of life expectancy.
 - DCE presents individuals with a set of hypothetical scenarios involving different attributes and asks them to choose their preferred option.
- **Benefit Transfer methods** can also be employed, which draw on valuation data gathered in one situation and applying it, with adjustments, in a similar situation to a population with similar attributes and suffering from similar burden of disease. This method is used frequently as it limits the need for primary valuation studies.

There are two main papers which have so far been identified as having monetised the potential human health costs of PFAS, including Goldenman *et al.* (2019) for the Nordic Council of Ministers covering populations in Europe, followed by Obsekov, Kahn and Trasande (2023) focussed on the U.S.

Goldenman *et al.* (2019) use monetise non-market disease burden using CV by drawing on available evidence of the 'Value of a Statistical Life' from ECHA (2016)'s 'Valuing selected health impacts of chemicals: Summary of the results and a critical review of the ECHA study'³⁶² and OECD (2012)'s 'Mortality risk valuation in environment, health and transport policies'³⁶³. To do this, Goldenman *et al.* (2019) also draws on a case study approach, for example, of populations living near contaminated areas in Minnesota, U.S.; West Virginia, U.S.; Dordrecht, Netherlands; Ronneby, Sweden; and Veneto Region, Italy; to quantify, extrapolate and monetise impacts across larger populations.

Obsekov, Kahn and Trasande (2023) draw on market-based methods, such as the cost of illness approach to develop estimates of medical costs and productivity losses, primarily, and non-market (CV) methods to quantify and monetise disease burden.

³⁶² Note that a more recent study was published by ECHA in 2023 of "Reference willingness-to-pay values for monetising chemicals health impacts". Available at:

https://echa.europa.eu/documents/10162/17229/seac_reference_wtp_values_en.pdf/403429a1-b45f-4122-ba34-77b71ee9f7c9

³⁶³ Note that we will also consider more up-to-date evidence from the OECD's work on Surveys on Willingness-to-Pay to Avoid Negative Chemicals-Related Health Effects. Available at: <https://www.oecd.org/en/topics/sub-issues/risk-management-risk-reduction-and-sustainable-chemistry/the-costs-and-benefits-of-regulating-chemicals.html>

Monetisation of environmental costs

In previous efforts to calculate societal impacts of PFAS pollution (e.g. the 2019 Nordic Council 'cost of inaction' report³⁶⁴ and ChemSec, 2024³⁶⁵), the main approach of monetising environmental impacts has involved extrapolating the cost of remediation and water treatment from PFAS pollution (see also Section 3.2.5). This approach is referred to as **avoided damage cost** (averting expenditure approach and avoided treatment costs approach) and **substitute cost methods**, which reflect the costs of mitigating against the negative impacts of environmental degradation.

Stated preference methods (e.g. contingent valuation, choice experiment) elicit people's WTP for specific environmental changes and have been applied to PFAS water pollution in a few studies (e.g. Pintus, 2024³⁶⁶ and Lemos Jr et al., 2024³⁶⁷). WTP methods are used to estimate the value society places on avoiding negative effects including on environmental effects from chemicals and have been used extensively to value impacts on biodiversity and ecosystem services.

The **hedonic price method** has been applied to property values affected by PFAS contamination (e.g. Marcus and Mueller, 2024³⁶⁸). This method uses changes in land or house prices to value different environmental attributes such as local water quality, land or air pollution, and different environmental amenities such as recreation and aesthetic. This method is one approach of the wider group of **revealed preference methods**, which use observed behaviour by market actors to value environmental effects. This group also includes the travel cost method, which uses travel costs as a proxy for the value of recreational sites by correlating the cost of travel with the decision to visit environmental sites such as woodlands, wetlands, rivers and lakes and coastal areas. This method is typically used to value recreational values of natural environment, but no examples of applying this method to PFAS impacts have been identified.

It would not be feasible to conduct primary stated preference or revealed preference studies. To avoid the need to carry out primary valuation studies, the **benefit transfer (BT) method** is frequently used in policy appraisals. It uses environmental valuation data gathered in one situation and applies it in at a similar site for similar environmental attribute(s). The approach can transfer a single value, adjusted unit value or demand function. Best practice entails at least an adjustment for socio-economic and demographic variables (e.g. PPP). Ultimately, the use of BT method depends on availability, quality and similarity of original valuation studies. BT was applied to PFAS contamination for example by Pintus (2024)³⁶⁹.

Lastly, **direct market-based methods** use market price data to value environmental impacts on production of commercial goods (e.g. fishery and agricultural products). To date, no examples of applying this method to impacts of PFAS pollution have been identified.

3.3.2. Q3.2 What are the direct and indirect, market and non-market, one-off and recurring costs of PFAS pollution?

The following table summarises the costs that have been identified in the literature and categorises them according to human health vs environmental, direct vs indirect, market vs not-market, and one-

³⁶⁴ Goldenman et al. (2019). *The cost of inaction: A socioeconomic analysis of environmental and health impacts linked to exposure to PFAS*. Available at: [THE COST OF INACTION](#)

³⁶⁵ ChemSec: *A Profitable Detox - Why safer chemistry makes financial sense*. Available at: https://chemsec.org/app/uploads/2024/09/ChemSec_A-Profitable-Detox_241007.pdf

³⁶⁶ Pintus (2024). *Valuing drinking water quality after a PFAS contamination event: Results from a meta-analysis benefit transfer*. Available at: <https://www.sciencedirect.com/science/article/pii/S0301479724011290>

³⁶⁷ Lemos Jr, Price, and Halstead (2024): *Economic Valuation of PFAS Remediation in New Hampshire Municipal Drinking Water Systems: A Contingent Valuation Approach*. Available at: <https://ascelibrary.org/doi/10.1061/JWRMD5.WRENG-5998>

³⁶⁸ Marcus and Mueller (2024): *Unregulated contaminants in drinking water: Evidence from PFAS and housing prices*. Available at: <https://www.sciencedirect.com/science/article/pii/S0095069624000615>

³⁶⁹ Pintus (2024). *Valuing drinking water quality after a PFAS contamination event: Results from a meta-analysis benefit transfer*. Available at: <https://www.sciencedirect.com/science/article/pii/S0301479724011290>

off vs recurring costs. Please note that this table captures a comprehensive list of health and environmental cost categories that, even if interrelated, are separate, in their own right, and can be incurred by the same and/or different stakeholders in the EU. It is acknowledged that, often, and especially due to a lack of evidence, some of these costs, especially market costs such as healthcare or remediation costs, might also be used to approximate the scale of other potential costs of pollution, such as the overall health or environmental burden. The interrelationships and potential overlaps between these cost categories will be considered in depth as part of the specification of our methodology (Task 2).

Table 3-18 Typology of identified costs of PFAS pollution

Cost category	Main types of costs identified	Direct (D) or Indirect (I),	Market (M), or Non-Market (NM)	One-Off (OC), or Recurring Costs (RC)	Description	Sources
Human health costs of pollution	Health and wellbeing losses (Disability-Adjusted Life Years)	D	NM	OC, RC	Loss of both quality of life (also referred to as 'Years Lived with Disability') and quantity of life (also referred to as 'Years of Life Lost') due to illness or disability from pollution.	See Sections 3.1.3 and 3.1.4
	Demographic impacts (birth rate and birth outcomes, etc.)	I	NM	RC	Adverse impacts on birth rates and birth outcomes, potentially including birth defects or low birth weights.	See Sections 3.1.3 and 3.1.4
	Healthcare demand increased	I	M	RC	Increased need for medical services due to pollution-related health conditions, leading to higher healthcare costs.	See Sections 3.1.3 and 3.1.4
	Social care/ care services demand increased	I	M, NM	RC	Increased need for care services due to pollution-related health conditions, which might include services provided in the market economy or outside of it.	See Section 3.1.4
	Economic productivity losses	I	M	RC	Sickness absence/ absenteeism, presenteeism.	See Sections 3.1.3 and 3.1.4

Cost category	Main types of costs identified	Direct (D) or Indirect (I),	Market (M), or Non-Market (NM)	One-Off (OC), or Recurring Costs (RC)	Description	Sources
Environmental costs of pollution	Environmental health	D	NM	OC, RC	Harm to species populations; Impacts on ecosystem services; Loss of biodiversity	See Sections 3.2.2 and 3.2.3
	Economic value-added losses	I	M	RC	Loss of profits from fisheries and agriculture. Note that these may overlap with ecosystem services in the previous row above.	Cordner et al. (2021) ³⁷⁰ , UPFAS restriction proposal ³⁷¹ , interview input
Indirect market costs (not attributable to only health or environmental impacts)	Clean up / remediation / treatment	I	M	OC	Soil remediation, water treatment	See Section 3.2.5
	Litigation	I	M	OC	Legal costs associated with environmental and health damage claims and liability cases due to pollution impacts.	See Section 3.2.5
	Wealth / asset damage	I	M	OC, RC	Loss of property values, higher costs for drinking water due to contamination of less costly sources of water	Cordner et al. (2021) ³⁷² , interview input
	Administrative effort	I	M	RC	Costs of administering the response to PFAS pollution, such as testing, monitoring, developing and enforcing regulation, legal expenses, etc.	Cordner et al. (2021) ³⁷³ , interview input

³⁷⁰ Cordner A., Goldenman G., Birnbaum L., Brown P., Miller M., Mueller R., Patton S., Salvatore D., Transande L. (2021): *The true cost of PFAS and the benefits of acting now*. Available at: <https://doi.org/10.1021/acs.est.1c03565>

³⁷¹ BAUA, RIVM, KEMI, Norwegian EA, Danish EPA (published by ECHA) (2023): *Proposal for a restriction of per- and polyfluoroalkyl substances (PFASs)*. Available at: <https://echa.europa.eu/restrictions-under-consideration/-/substance-rev/72301/term>

³⁷² Cordner A., Goldenman G., Birnbaum L., Brown P., Miller M., Mueller R., Patton S., Salvatore D., Transande L. (2021): *The true cost of PFAS and the benefits of acting now*. Available at: <https://doi.org/10.1021/acs.est.1c03565>

³⁷³ Cordner A., Goldenman G., Birnbaum L., Brown P., Miller M., Mueller R., Patton S., Salvatore D., Transande L. (2021): *The true cost of PFAS and the benefits of acting now*. Available at: <https://doi.org/10.1021/acs.est.1c03565>

3.4. Gaps and uncertainties

The main data gaps and uncertainties are discussed for each research question in the previous sections. These are not repeated here, but there are a number of overarching observations across research questions, which are summarised below:

- **Non-legacy PFAS:** 'Legacy' PFAS (i.e., regulated PFAS species such as PFOA, PFOS, PFNA, PFHxS) are generally well studied, whereas much less information is available on other PFAS species (including polymeric PFAS and F-gases), although monitoring and research into the effects of non-legacy PFAS have increased in recent years.
- **Causation:** The identified evidence often shows potential correlation with more or less confidence between exposure to PFAS and adverse human health outcomes. However, from our research so far, causation remains uncertain in many cases as it is difficult or not always possible to study empirically.
- **Mixture effects:** There are significant uncertainties and data gaps related to the health and environmental effects of exposure to mixtures of different PFAS species or mixtures between PFAS and other substances (e.g. microplastics).
- **Environmental effects:** Previous attempts to determine the societal costs of PFAS have largely focused on health impacts, remediation costs and litigation costs, due to significant uncertainties and data gaps associated with other environmental effects of PFAS. Most data related to the environmental effects of PFAS is from laboratory studies. While this data is indicative of probable environmental effects, there are many challenges which make it difficult to estimate the ecological effects of PFAS. Most data only covers certain effects of certain substances at specific concentrations to certain species, but data is lacking for ecosystem-level impacts of a wide range of PFAS at environmentally relevant concentrations, and extrapolation is challenging. Most data also indicates whether effects are expected or not (in a binary way), rather than identifying the scale of effects that would be expected. Most data do not consider uncontrolled environmental variables. Most data is also not based on environmentally relevant concentrations of PFAS. Some field studies have been identified that can help to understand the disruption of species populations and wider ecosystems, we still find that there is limited evidence on the *extent* of disruption caused by PFAS.

These gaps (except the bullet titled "causation") are likely to lead to underestimation of the societal costs of PFAS pollution.

3.5. Conclusions and next steps

Recent (2019-2024) human biomonitoring studies find a broad range of PFAS in the blood serum of different groups of the EU population that can be attributed to different routes of exposure. Several comprehensive meta-analyses and primary research studies suggest that there are eight health risks across five categories confidently associated with PFAS exposure: namely, respiratory infections, autoimmune thyroid disease, liver disease and non-alcoholic fatty liver disease, low sperm count and mobility, gestational hypertension, decreased foetal growth, and lower birth weight and small for gestational age. These health risks are sufficiently evidenced to consider in an assessment of human health costs of PFAS pollution.

However, links of PFAS exposures to other health risks (e.g., cancers, diabetes, ulcerative colitis) have lower levels of confidence and/or remain more suggestive or speculative. In addition, there are several health risks associated with PFAS exposure in the literature which do not have (or for which we have not found) quantified risk relationships. Methodologies are available to monetise health impacts, and a couple of studies have been found to apply these to estimate the monetary burden of disease attributable to PFAS, using contingent valuation methods, and the associated healthcare costs.

Monitoring studies find a broad range of PFAS species in different environmental compartments (soil, water, air, and biota) in the EU, and PFAS contamination hotspots in Europe have been identified and thoroughly studied. There is a growing body of evidence that some PFAS have the potential to harm aquatic and terrestrial animals and plants. Studies have revealed both mechanistic effects of PFAS (e.g. oxidative stress, immunotoxicity, liver toxicity, and genotoxicity) and effects on entire organisms (e.g. developmental effects, effects on reproduction, and behavioural effects). However, most studies conclude that PFAS have the potential to cause harm but do not conclude on the *extent* of harm to different species and populations.

Furthermore, there are many uncertainties and gaps in evidence to conclusively determine the specific environmental effects of environmentally relevant concentrations of PFAS. The lack of quantified estimates of the extent of damage to species caused by PFAS exposure presents a significant challenge to this cost assessment. Other challenges relate to the lack of recent review studies on the ecological risks and effects from PFAS, the focus of the literature on a limited number of PFAS substances, and gaps in evidence for different species. There is a distinct lack of data on ecosystem-level effects and effects on biodiversity, which would make it difficult to estimate and monetise ecosystem service costs.

Many case studies and some societal estimates of environmental clean-up costs (soil and water remediation/treatment costs) and litigation costs have been identified, although it should be noted that clean-up costs can vary significantly on a case-by-case basis, and litigation is more prevalent in the United States than in the EU. Some additional types of costs of PFAS pollution not included in the health and environmental effects discussed above have also been identified (e.g., impacts on property values, fishing and agriculture), although limited evidence regarding their magnitude has been identified to date.

Based on the available evidence summarised above, Task 2 will specify the approaches and methodologies that are most feasible and appropriate to assess the human health and environmental costs of PFAS pollution. Where appropriate, additional data that was not presented in the present report will be extracted from the literature to better match the needs of the methodology chosen in Task 2. Additional targeted interviews and targeted research will also be conducted to this end.

Appendices to Annex A

A. Literature review screening and analysis

Referen ce ID	Title	Potentially relevant source				PFAS in scope of study	Relevant research sub-questions and summary															Geographic relevance rating	Geography Notes		Thematic relevance Notes		Robustness and limitations Notes		Shortlisting		
		Author	Year	Link			1.1 To what extent are humans exposed to PFAS in the EU?	1.2 What PFAS exposure is associated with human health risks?	1.3 What are the observed risk relationships and/or predicted human health impacts from those risks?	1.4 What are the costs associated with the human health impacts?	1.5 What are the geographical and temporal trends in human health costs?	2.1 To what extent are environmental compartments (soil, water, air, and biota) contaminated with PFAS in the EU?	2.2 What are the environmental effects on aquatic and terrestrial species and populations?	2.3 What are the ecosystem-level effects?	2.4 What are the effects on biodiversity?	2.5 What are the monetised ecosystem service costs associated with impacts on species, ecosystems and biodiversity?	2.6 What are the environmental clean-up costs (soil and water remediation/treatme nt costs) and litigation costs?	2.7 What are the geographical and temporal trends in environmental costs?	3.1 What are the methods to calculate the societal costs from PFAS?	3.2 What are the indirect and direct, market and non-market, and one-off and recurring costs of PFAS pollution?	Thematic relevance rating (research questions, inclusion criteria, and scope boundaries)		Robustness rating (source credible, method robust and transparent, significance of limitations)	Score	Justification / explanation for shortlisting or not	Will this source be taken forward for data extraction?					
1	The true cost of PFAS and the benefits of acting now	Cordner A., Goldenman G., Birnbaum L, Brown P., Miller M., Mueller R., Patton S., Salvatore D., Trasande L.	2021	https://doi.org/10.1021/aocs.est.1c03665		x		x							US examples of treatment costs and legal costs, and identifies other costs such as testing and monitoring, reduction of property values, impacts on agriculture, governance and research expenses.			x		Very high - relevant to EU as a whole or large parts of EU	Medium - Answers at least one research question, but does not conform with inclusion criteria for that question, or is not within scope boundaries	High - no doubts about the credibility of the source (e.g. peer-reviewed study or renowned institution), robustness and transparency of method, or limitations affecting the validity of results	5	Already covered in Nordic Council (2019) study	No						
2	Economic Analysis for the Proposed Per-and Polyfluoroalkyl Substances National Primary Drinking Water Regulation	US EPA	2023	https://nepis.epa.gov/ExeZyPDF.cgi/P1017QH0.PDF?Dockey=P1017QH0.PDF			x	x												Medium - not directly relevant to EU, but likely transferrable	High - Answers at least one research question, conforms with inclusion criteria for that question, within scope boundaries	High - no doubts about the credibility of the source (e.g. peer-reviewed study or renowned institution), robustness and transparency of method, or limitations affecting the validity of results	5	Superseded by reference 3	No						
3	Economic Analysis for the Final Per-and Polyfluoroalkyl Substances National Primary Drinking Water Regulation	US EPA	2024	https://shorturl.at/tw2RY			x	x												Medium - not directly relevant to EU, but likely transferrable	High - Answers at least one research question, conforms with inclusion criteria for that question, within scope boundaries	High - no doubts about the credibility of the source (e.g. peer-reviewed study or renowned institution), robustness and transparency of method, or limitations affecting the validity of results	5	ERFs for CVD and RCC extracted. Costs not relevant	Yes						
4	Leveraging Systematic Reviews to Explore Disease Burden and Costs of Per-and Polyfluoroalkyl Substance Exposures in the United States	Obsekov V., Kahn L.G., Trasande L.	2022	https://pmc.ncbi.nlm.nih.gov/articles/PMC10198842/pdf/12403_2022_Article_496.pdf			x	x												Medium - not directly relevant to EU, but likely transferrable	High - Answers at least one research question, conforms with inclusion criteria for that question, within scope boundaries	High - no doubts about the credibility of the source (e.g. peer-reviewed study or renowned institution), robustness and transparency of method, or limitations affecting the validity of results	5	Relevant for methodology, recommended by Goldenman	Yes						
5	Per- and Polyfluoroalkyl Substances (PFAS) in United States Tapwater: Comparison of Underserved Private-Well and Public-Supply Exposures and Associated Health Implications	Smalling K., Romanok K., Bradley P., Morris M., Gray J., Kanagy L., Gordon S., Williams B., Breitmeyer S., Jones D., DeCicco L., Smith C., Wagner T.	2023	https://doi.org/10.1016/j.envint.2023.108033	x														Low - not relevant to EU and likely not transferrable	The study very specifically investigates PFAS in the United States. The exact frequency of detection and concentrations are likely not directly transferrable. Comment 07/11: Does not look relevant, as it assess benefits and not costs of PFAS (the focus of this study); Assesses the human health BENEFITS of PFAS when used as active pharmaceutical ingredients as well as process chemicals and equipment in the pharma industry.	Medium - Answers at least one research question, but as does not conform with inclusion criteria for that question, or is not within scope boundaries	High - no doubts about the credibility of the source (e.g. peer-reviewed study or renowned institution), robustness and transparency of method, or limitations affecting the validity of results	3	Geographical scope not applicable	No						
6	Socio-Economic analysis of the potential restriction of the per- and polyfluoroalkyl substances (PFAS) used in the production, packaging and delivery of human medicinal products	EPPA	2023	https://www.efpia.eu/media/52ipvg/finanex-1-efpia_soa_pfas_final.pdf															Very high - relevant to EU as a whole or large parts of EU	The study very specifically investigates PFAS in the United States. The exact frequency of detection and concentrations are likely not directly transferrable. Comment 07/11: Does not look relevant, as it assess benefits and not costs of PFAS (the focus of this study); Assesses the human health BENEFITS of PFAS when used as active pharmaceutical ingredients as well as process chemicals and equipment in the pharma industry.	Low - Does not answer research questions	Analyses benefits of PFAS use, which I don't think is in scope of our study, despite covering health impacts in this case	Commissioned by industry association with vested interest	3	Analyses benefits of PFAS use, which I don't think is in scope of our study, despite covering health impacts in this case	No					
7	Estimated scale of costs to remove PFAS from the environment at current emission rates	Ling A.L.	2024	https://doi.org/10.1016/j.scitotenv.2024.170847											This article is specifically about the environmental costs of remediation. The compartments studied are not listed in the abstract, rather the abstract is generic to treatment.		Article is about the scale of costs, snippet suggests there is information regarding the calculations of these costs.		Medium - not directly relevant to EU, but likely transferrable	The geographic scope is global, but definitely transferrable to EU	High - Answers at least one research question, conforms with inclusion criteria for that question, within scope boundaries	Analyses benefits of PFAS use, which I don't think is in scope of our study, despite covering health impacts in this case	Commissioned by industry association with vested interest	5	Highly relevant for a number of research questions	Yes					
8	A Profitable Detox - Why safer chemistry makes financial sense	ChemSec	2024	https://chemsec.org/app/uploads/2024/09/ChemSec-A-Profitable-Detox_241007.pdf											Quotes three studies estimating societal costs of PFAS pollution, one covering disease burden and related economic costs in the US, one covering remediation costs and healthcare costs globally, and one covering remediation costs globally.			High - relevant to some EU countries	Mostly global perspective, so that includes the EU but is not necessarily specific to the EU	High - Answers at least one research question, conforms with inclusion criteria for that question, within scope boundaries	Only small parts of the report are relevant and there is not a lot of detail, but it provides a good overview of some key studies and litigation cases.	Medium - doubts about one of the credibility of the source (e.g. peer-reviewed study or renowned institution), robustness and transparency of method, or limitations affecting the validity of results	Does not provide details of analysis itself, only references other studies and cases, so it depends on those references.	4.5	Focus only on section 2 (persistent chemicals), which has a useful overview of some key studies and litigation cases.	Yes					
9	Human exposure pathways to poly- and perfluoroalkyl substances (PFAS) from indoor media: A systematic review protocol	DeLuca et al.	2021	https://www.sciencedirect.com/science/article/pii/S1604129220000752															High - relevant to some EU countries	The study reports results for North America and Europe, and provides a comparative assessment between the two geographies. The results are slightly more weighted towards North America.	High - Answers at least one research question, conforms with inclusion criteria for that question, within scope boundaries	Relevant to Q1.1 and Q1.5	High - no doubts about the credibility of the source (e.g. peer-reviewed study or renowned institution), robustness and transparency of method, or limitations affecting the validity of results	Robust methodologies presented	5.5	Contains information on PFAS exposures in Europe, for both exposure routes and quantified	Yes				
10	PFAS levels and exposure determinants in sensitive population groups	Fábelová et al.	2023	https://www.sciencedirect.com/science/article/pii/S0456535220402311															Very high - relevant to EU as a whole or large parts of EU	Key study following HBM4EU, scope of nine European birth cohorts (5 countries)	High - Answers at least one research question, conforms with inclusion criteria for that question, within scope boundaries	Relevant to Q1.1 and Q1.5	High - no doubts about the credibility of the source (e.g. peer-reviewed study or renowned institution), robustness and transparency of method, or limitations affecting the validity of results	Peer-reviewed study based on extensive HBM data	6	Used as part of the response for sub-populations	Yes				

Reference ID	Title	Potentially relevant source				PFAS in scope of study	Relevant research sub-questions and summary															Geography		Thematic relevance		Robustness and limitations		Shortlisting	
		Author	Year	Link			1.1 To what extent are humans exposed to PFAS in the EU?	1.2 What PFAS exposure is associated with human health risks?	1.3 What are the observed risk relationships and/or predicted human health impacts from those risks?	1.4 What are the costs associated with the human health impacts?	1.5 What are the geographical and temporal trends in human health costs?	2.1 To what extent are environmental compartments (soil, water, air, and biota) contaminated with PFAS in the EU?	2.2 What are the environmental effects on aquatic and terrestrial species and populations?	2.3 What are the ecosystem-level effects?	2.4 What are the effects on biodiversity?	2.5 What are the monetised ecosystem service costs associated with impacts on species, ecosystems and biodiversity?	2.6 What are the environmental clean-up costs (soil and water remediation/treatment costs) and litigation costs?	2.7 What are the geographical and temporal trends in environmental costs?	3.1 What are the methods to calculate the societal costs from PFAS?	3.2 What are the indirect and direct, market and non-market, and one-off and recurring costs of PFAS pollution?	Geographic relevance rating	Notes	Thematic relevance rating (research questions, inclusion criteria, and scope boundaries)	Notes	Robustness rating (source credibility, method robust and transparent, significance of limitations)	Score	Justification / explanation for shortlisting or not	Will this source be taken forward for data extraction?	
11	Multiple pathways of human exposure to poly- and perfluoroalkyl substances (PFASs): From external exposure to human blood	Poonthong et al.	2019	https://www.sciencedirect.com/science/article/pii/S1564120119320357	18 TFAAs and 12 TFAA precursors	x													High - relevant to some EU countries	Study focuses on Norway only. Relevant to European populations.	Medium - Answers at least one research question, but does not conform with inclusion criteria for that question, or is not within scope boundaries	Explores different routes of PFAS exposure, with a particular focus on dietary exposure.	High - no doubts about the credibility of the source (e.g. peer-reviewed study or renowned institution), robustness and transparency of method, or limitations affecting the validity of results	Peer reviewed study with extensive sampling.	4.5	Relevant to Europe and exposures	Yes		
12	PFASs: What can we learn from the European Human Biomonitoring Initiative HBM4EU	Uhl et al.	2023	https://www.sciencedirect.com/science/article/pii/S1564120123000595	Known and novel PFAS, PFASs inc. PFOA, PFOS, PFNA, PFHxS	x	x			x									Very high - relevant to EU as a whole or large parts of EU	Key HBM4EU study covering a large geographic area - nine European countries	High - Answers at least one research question, conforms with inclusion criteria for that question, within scope boundaries	Provides direct evidence to response to Q1.1	High - no doubts about the credibility of the source (e.g. peer-reviewed study or renowned institution), robustness and transparency of method, or limitations affecting the validity of results	Peer-reviewed study based on extensive HBM data	6	Key study, contains directly relevant information and in the correct metrics (blood serum levels)	Yes		
13	Human exposure to per- and polyfluoroalkyl substances (PFAS) through drinking water: A review of the recent scientific literature	Domingo and Nadal	2019	https://www.sciencedirect.com/science/article/pii/S1564120119320357	PFOS, PFOA	x													Very high - relevant to EU as a whole or large parts of EU	The geographical scope of the study is wider than the EU, but presents comprehensive country-by-country data for the European countries.	High - Answers at least one research question, conforms with inclusion criteria for that question, within scope boundaries	Provides evidence for drinking water exposures, which are a key pathway affecting the validity of results	High - no doubts about the credibility of the source (e.g. peer-reviewed study or renowned institution), robustness and transparency of method, or limitations affecting the validity of results	Peer-reviewed study with extensive data	6	The geographic scope and content are directly relevant to the question	Yes		

Referen ce ID	Title	Potentially relevant source				PFAS in scope of study	Relevant research sub-questions and summary															Geography		Thematic relevance		Robustness and limitations		Shortlisting																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																									
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		Author	Year	Link			1.1 To what extent are humans exposed to PFAS in the EU?	1.2 What PFAS exposure is associated with human health risks?	1.3 What are the observed risk relationships and/or predicted human health impacts from those risks?	1.4 What are the costs associated with the human health impacts?	1.5 What are the geographical and temporal trends in human health costs?	2.1 To what extent are environmental compartments (soil, water, air, and biota) contaminated with PFAS in the EU?	2.2 What are the environmental effects on aquatic and terrestrial species and populations?	2.3 What are the ecosystem-level effects?	2.4 What are the effects on biodiversity?	2.5 What are the monetised ecosystem service costs associated with impacts on species, ecosystems and biodiversity?	2.6 What are the environmental clean- up costs (soil and water remediation/treatme nt costs) and litigation costs?	2.7 What are the geographical and temporal trends in environmental costs?	3.1 What are the methods to calculate the societal costs from PFAS?	3.2 What are the indirect and direct, market and non- market, and one- off and recurring costs of PFAS pollution?									
20	Approaches to mixture risk assessment of PFASs in the European population based on human hazard and biomonitoring data	Bil et al.	2023	https://www.sciencedirect.com/science/article/pii/S1438463922001547?via=ihl	Multiple PFAS		x	x												High - relevant to some EU countries		Medium - Answers at least one research question, but does not conform with inclusion criteria for that question, or is not within scope boundaries	High - no doubts about the credibility of the source (e.g. peer-reviewed study or renowned institution), robustness and transparency of method, or limitations affecting the validity of results	4.5	Generic PFAS risks covered by other papers	No			
21	Risk to human health related to the presence of perfluoroalkyl substances in food	EFSA CONTAM Panel	2020	https://efsa.onlinelibrary.wiley.com/doi/epdf/10.2903/j.efsa.2020.6223?eoft_integrat=acs&src=getft&utm_source=ag			x	x												Very high - relevant to EU as a whole or large parts of EU		High - Answers at least one research question, conforms with inclusion criteria for that question, within scope boundaries	High - no doubts about the credibility of the source (e.g. peer-reviewed study or renowned institution), robustness and transparency of method, or limitations affecting the validity of results	6	Summary of evidence on health risks	Yes			
22	The cost of inaction: A socioeconomic analysis of environmental and health impacts linked to exposure to PFAS	Goldenman et al.	2019	https://www.nord-en.org/en/publications/04-inaction-0	Multiple PFAS				x	x								x		Very high - relevant to EU as a whole or large parts of EU		High - Answers at least one research question, conforms with inclusion criteria for that question, within scope boundaries	High - no doubts about the credibility of the source (e.g. peer-reviewed study or renowned institution), robustness and transparency of method, or limitations affecting the validity of results	6	Key source	Yes			
23	PFAS levels and determinants of variability in exposure in European teenagers – Results from the HBM4EU aligned studies (2014–2021)	Richterová et al.	2023	https://www.sciencedirect.com/science/article/pii/S1438463922001407	PFOS, PFOA, PFHxS, PFNA	x			x	x									Very high - relevant to EU as a whole or large parts of EU	A key HBM4EU covering nine European countries	High - Answers at least one research question, conforms with inclusion criteria for that question, within scope boundaries	Presents exposure levels from nine European countries and is thus directly relevant	Peer reviewed study using comprehensive data sets.	6	Key study that is directly relevant to the scope of Q1.1 and Q1.5	Yes			
24	Changes in plasma levels of per- and polyfluoroalkyl substances (PFAS) are associated with changes in plasma lipids - A longitudinal study over 10 years	Dunder et al.	2022	https://www.sciencedirect.com/science/article/pii/S0160412016302926						x									Very high - relevant to EU as a whole or large parts of EU		High - Answers at least one research question, conforms with inclusion criteria for that question, within scope boundaries	High - no doubts about the credibility of the source (e.g. peer-reviewed study or renowned institution), robustness and transparency of method, or limitations affecting the validity of results	6	Key study that is directly relevant to the scope of Q1.5	Yes				
25	Repeated measurements of per- and polyfluoroalkyl substances (PFASs) from 1979 to 2007 in males from Northern Norway: Assessing time trends, compound correlations and relations to age/birth cohort	Haugdahl Nest	2014	https://www.sciencedirect.com/science/article/pii/S0160412014000610	PFOA, PFNA, PFDA, PFUnDA, PFHxS, PFHpS, PFOS and FOSA						x								Very high - relevant to EU as a whole or large parts of EU		High - Answers at least one research question, conforms with inclusion criteria for that question, within scope boundaries	High - no doubts about the credibility of the source (e.g. peer-reviewed study or renowned institution), robustness and transparency of method, or limitations affecting the validity of results	6	Key study that is directly relevant to the scope of Q1.5	Yes				
26	Global distributions, source-type dependencies, and concentration ranges of per- and polyfluoroalkyl substances in groundwater	Johnson et al.	2022	https://www.sciencedirect.com/science/article/abs/pii/S0048969722003893	PFOS, PFOA									Article is behind a paywall but it covers the global distribution of PFAS in groundwater, it is based on 96 reports from 1999-2021, and looks at the varying concentrations from close to identified sources and further away. The report compare groundwater concentrations to soil, surface waters, marine waters and precipitation concentration							Medium - not directly relevant to EU, but likely transferrable		Medium - Answers at least one research question, but does not conform with inclusion criteria for that question, or is not within scope boundaries	High - no doubts about the credibility of the source (e.g. peer-reviewed study or renowned institution), robustness and transparency of method, or limitations affecting the validity of results	4	This source is behind a paywall and looks at PFAS in groundwater on a global scale (potentially including the EU). I would suggest purchasing only if there are no other open studies on PFAS conc in groundwater, there are no studies which are primarily EU focused.			
27	Spatial Prediction of Concentrations of Per- and Polyfluoroalkyl Substances (PFAS) in European Soils	Moghadasi et al.	2023	https://pubs.acs.org/doi/epdf/10.1021/acs.estlett.3c00633?ref=article_openPDF	PFCA, PFSA, PFOS, PFOA, PFNA and PFHxS mentioned (although study only focuses on general PFAS)									Article on the spacial distribution of PFAS in European Substances. It compares PFAS close to identified sources and the change in concentrations with distance from the source. The source shows a map to highlight this.							Very high - relevant to EU as a whole or large parts of EU		High - Answers at least one research question, conforms with inclusion criteria for that question, within scope boundaries	Medium - doubts about one of credibility of the source (e.g. peer-reviewed study or renowned institution), robustness and transparency of method, or limitations affecting the validity of results	5	Uses the Map of Forever Pollution I Europe to look at PFAS in soil near a presumptive point. It is useful for presumed PFAS concentrations in 5 soil (section 2.1).	Yes		
28	PFAS Exposure Pathways for Humans and Wildlife: A Synthesis of Current Knowledge and Key Gaps in Understanding	De Silva et al.	2020	https://setac.onlinelibrary.wiley.com/doi/10.1002/etc.4935	PFCA, PFSA, FTOH, PFOA, PFOS, PFBA, PFHxA, PFHxS, PFHpA, PFHpS, PFOA, PFNA, PFDA, PFDS, PFUnDA, PFDoDA, PFTrDA	x							The article has an overview of PFAS sources and environmental pathways, mainly from an exposure perspective.							High - relevant to some EU countries		High - Answers at least one research question, conforms with inclusion criteria for that question, within scope boundaries	High - no doubts about the credibility of the source (e.g. peer-reviewed study or renowned institution), robustness and transparency of method, or limitations affecting the validity of results	5.5	Gives an overview of PFAS in humans, and exposure pathways (including values for several PFAS species) and gives information on PFAS exposure in wildlife. Covers the exposure to humans and different terrestrial and aquatic species. The response is mainly covering animal exposure. The source does partially cover PFAS conc. In water	Yes			
29	Current Review of Increasing Animal Health Threat of Per- and Polyfluoroalkyl Substances (PFAS): Harms, Limitations, and Alternatives to Manage Their Toxicity	Peritore et al.	2023	https://www.mdpi.com/1422-0067/24/14/11707	PFOS, PFOA, PFHpA		x						Looks at the exposure pathways through water soil etc and their impact on animal health.	This only really focuses on farm animals and lab animals. Excluded					High - relevant to some EU countries		High - Answers at least one research question, conforms with inclusion criteria for that question, within scope boundaries	Medium - doubts about one of credibility of the source (e.g. peer-reviewed study or renowned institution), robustness and transparency of method, or limitations affecting the validity of results	4.5		Yes				
30	Determination of 56 per- and polyfluoroalkyl substances in top predators and their prey from Northern Europe by LC- MS/MS	Androulakis et al.	2022	https://www.sciencedirect.com/science/article/abs/pii/S0045653521022475	56 PFAS species								Behind a paywall, but seems to look at the exposure pathways for top predators in Northern Europe for 56 PFAS species.							High - relevant to some EU countries		High - Answers at least one research question, conforms with inclusion criteria for that question, within scope boundaries	High - no doubts about the credibility of the source (e.g. peer-reviewed study or renowned institution), robustness and transparency of method, or limitations affecting the validity of results	5.5	Gives a good overview of PFAS accumulation in top predators within Northern Europe. However, it is behind a paywall, suggest only purchasing if no other source provides information on PFAS bioaccumulation in predators in Europe.				

Referen ce ID	Potentially relevant source				PFAS in scope of study	Relevant research sub-questions and summary															Geography		Thematic relevance		Robustness and limitations		Shortlisting		
	Title	Author	Year	Link		1.1 To what extent are humans exposed to PFAS in the EU?	1.2 What PFAS exposure is associated with human health risks?	1.3 What are the observed risk relationships and/or predicted human health impacts from those risks?	1.4 What are the costs associated with the human health impacts?	1.5 What are the geographical and temporal trends in human health costs?	2.1 To what extent are environmental compartments (soil, water, air, and biota) contaminated with PFAS in the EU?	2.2 What are the environmental effects on aquatic and terrestrial species and populations?	2.3 What are the ecosystem-level effects?	2.4 What are the effects on biodiversity?	2.5 What are the monetised ecosystem service costs associated with impacts on species, ecosystems and biodiversity?	2.6 What are the environmental clean- up costs (soil and water remediation/treatme nt costs) and litigation costs?	2.7 What are the geographical and temporal trends in environmental costs?	3.1 What are the methods to calculate the societal costs from PFAS?	3.2 What are the indirect and direct, market and non- market, and one- off and recurring costs of PFAS pollution?	Geographic relevance rating	Notes	Thematic relevance rating (research questions, inclusion criteria, and scope boundaries)	Notes	Robustness rating (source credible, method robust and transparent, significance of limitations)	Notes	Score	Justification / explanation for shortlisting or not	Will this source be taken forward for data extraction?	
31	The effects of exposure to environmentally relevant PFAS concentrations for aquatic organisms at different consumer trophic levels: Systematic review and meta-analyses	Banyoi et al.	2022	https://www.sciencedirect.com/science/article/pii/S0269749122016363							Looks at exposure of aquatic species to several PFAS variants. This is from a lab-based perspective, but has been completed based on an extensive literature review.								Medium - not directly relevant to EU, but likely transferrable		High - Answers at least one research question, conforms with inclusion criteria for that question, within scope boundaries		High - no doubts about the credibility of the source (e.g. peer-reviewed study or renowned institution), robustness and transparency of method, or limitations affecting the validity of results		Information should be quick and easy to extract to show exposure in labs and effects to the 5 aquatic organisms	Yes			
32	Assessing the Ecological Risks of Per- and Polyfluoroalkyl Substances: Current State-of-the Science and a Proposed Path Forward	Ankley et al.	2020	https://setac.onlinelibrary.wiley.com/doi/epdf/10.1002/etc.4869							Gives an overview of bioaccumulation and bioactivity estimates of PFAS. Also provides a toxicity overview for several species groups.	Gives an up to date review of the current knowledge on ecological exposures to PFAS and the risk to the ecosystems, mainly through toxicological assessments to species groups and providing field-based effect studies in wildlife.			Also provides assessment activities for PFAS and their ecological risk.				Medium - not directly relevant to EU, but likely transferrable		High - Answers at least one research question, conforms with inclusion criteria for that question, within scope boundaries		High - no doubts about the credibility of the source (e.g. peer-reviewed study or renowned institution), robustness and transparency of method, or limitations affecting the validity of results		Gives a very good overview of ecological risk of PFAS, and the effects on different 5 specie groups.	Yes			
33	PFAS: Ecological Implications, Remedial Actions and Ethical Considerations	Awolesi et al.	2023	https://www.researchgate.net/publication/373543188_PFAS_Ecological_Implications_Remedial_Actions_and_Ethical_Considerationslink/64f1ea52827074313fed8527d0wnload?_tp=eyJlb250ZXh0lp7lmZpcnN0UGFnZSI6InB1YmxpY2F0aW9uIlwic3FnZSI6InB1YmxpY2F0aW9uIn19							Discusses the impacts on aquatic organisms, and the health effects PFAS has. Table 2 shows different effects of PFAS on organisms of several PFAS species.	Discuss the distribution and adverse impacts of PFAS on the environment including water systems, soils and plants.							Medium - not directly relevant to EU, but likely transferrable		High - Answers at least one research question, conforms with inclusion criteria for that question, within scope boundaries		High - no doubts about the credibility of the source (e.g. peer-reviewed study or renowned institution), robustness and transparency of method, or limitations affecting the validity of results		Answers several research questions and provides some useful infographics 5 and tables.	Yes			
34	Effects of perfluoroalkyl and polyfluoroalkyl substances (PFAS) on soil structure and function	Xu et al.	2022	https://www.researchgate.net/publication/361300727_Effects_of_perfluoroalkyl_and_polyfluoroalkyl_substances_PFAS_on_soil_structure_and_functionlink/62ac3471a920e8693efb1682d0wnload?_tp=eyJlb250ZXh0lp7lmZpcnN0UGFnZSI6InB1YmxpY2F0aW9uIlwic3FnZSI6InB1YmxpY2F0aW9uIn19															Medium - not directly relevant to EU, but likely transferrable	The scope is the arctic, and the ecosystem there is highly unique. It is possible that there are areas within the EU/EEA that are similar enough geography can be transferred.	High - Answers at least one research question, conforms with inclusion criteria for that question, within scope boundaries		High - no doubts about the credibility of the source (e.g. peer-reviewed study or renowned institution), robustness and transparency of method, or limitations affecting the validity of results		Gives a good overview of the effects that PFAS has on soil structure and functions 5	Yes			
35	Pollution in the Arctic Ocean: An overview of multiple pressures and implications for ecosystem services	Townhill et al.	2022	https://link.springer.com/article/10.1007/s13280-021-01657-0							Article is specific to the marine environment when understanding how the pressures from pollutants can be modeled in arctic ecosystems								Medium - not directly relevant to EU, but likely transferrable		Answers at least one research question, but does not conform with inclusion criteria for that question, or is not within scope boundaries	Answers research questions 2.1-2.4	High - no doubts about the credibility of the source (e.g. peer-reviewed study or renowned institution), robustness and transparency of method, or limitations affecting the validity of results	Peer reviewed study in journal	4 across	Should be taken forward as it is relevant to a number of research questions under subject 2. While the geography may be specific to the arctic, some similarities may be able to be drawn	Yes		
36	Comparison of PFAS soil remediation alternatives at a civilian airport using cost-benefit analysis	Drenning et al.	2023	https://www.sciencedirect.com/science/article/pii/S048969723022842							Soil contamination is the focus of this work, there may be information in the introduction/background that provides information on the soil contamination in the study area	Abstract alludes to external cost/benefits alongside remediation. Possible there is more information regarding ecosystem services as well	Focused on a cost benefit analysis for evaluating PFAS remediation methods within soils.		Has direct information about how the calculations for this work have been done				High - relevant to some EU countries	Study based in Sweden	High - Answers at least one research question, conforms with inclusion criteria for that question, within scope boundaries	Provides CBA for PFAS remediation	High - no doubts about the credibility of the source (e.g. peer-reviewed study or renowned institution), robustness and transparency of method, or limitations affecting the validity of results	Peer reviewed study in journal	Highly relevant for a number of research questions 5.5	Yes			

Reference ID	Title	Potentially relevant source				PFAS in scope of study	Relevant research sub-questions and summary												Geography		Thematic relevance		Robustness and limitations		Shortlisting		
		Author	Year	Link			1.1 To what extent are humans exposed to PFAS in the EU?	1.2 What PFAS exposure is associated with human health risks?	1.3 What are the observed risk relationships and/or predicted human health impacts from those risks?	1.4 What are the costs associated with the human health impacts?	1.5 What are the geographical and temporal trends in human health costs?	2.1 To what extent are environmental compartments (soil, water, air, and biota) contaminated with PFAS in the EU?	2.2 What are the environmental effects on aquatic and terrestrial species and populations?	2.3 What are the ecosystem-level effects?	2.4 What are the effects on biodiversity?	2.5 What are the monetised ecosystem service costs associated with impacts on species, ecosystems and biodiversity?	2.6 What are the environmental clean-up costs (soil and water remediation/treatment costs) and litigation costs?	2.7 What are the geographical and temporal trends in environmental costs?	3.1 What are the methods to calculate the societal costs from PFAS?	3.2 What are the indirect and direct, market and non-market, and one-off and recurring costs of PFAS pollution?	Geographic relevance rating	Notes	Thematic relevance rating (research questions, inclusion criteria, and scope boundaries)	Notes	Robustness rating (source credible, method robust and transparent, significance of limitations)	Notes	Score
37	Cost scenarios for small drinking water treatment technologies	Dore et al.	2013	https://www.sciencedirect.com/science/article/pii/S1944398624187346	Does not specify														Medium - not directly relevant to EU, but likely transferrable	Study appears to be based in US/North America	Low - Does not answer research questions	Focused on remediation, not on costs	High - no doubts about the credibility of the source (e.g. peer-reviewed study or renowned institution), robustness and transparency of method, or limitations affecting the validity of results	Peer reviewed study in journal	3	Not relevant to the study, focused on the techniques but does not specify for what kinds of chemicals/pollutant	No
38	Evaluation and prediction of anthropogenic impacts on long-term multimedia fate and health risks of PFOS and PFOA in the Elbe River Basin	Zhu et al.	2024	https://www.sciencedirect.com/science/article/abs/pii/S0043135424005761	PFOS and PFOA					Study is focused on water contamination and level of PFOS/PFOA concentrations	Article is specifically about aquatic effects	Some information on human health risks/bans on fish predation to mitigate risks	Study provides information on fish hazard which can be related to biodiversity			Some long term modelling regarding concentrations has been done			High - relevant to some EU countries	Study is based in Europe	Medium - Answers at least one research question, but does not conform with inclusion criteria for that question, or is not within scope boundaries	Focused on 2.1-2.4	High - no doubts about the credibility of the source (e.g. peer-reviewed study or renowned institution), robustness and transparency of method, or limitations affecting the validity of results	Peer reviewed study in journal	4.5	Should be taken forward for RQ 2.1-2.4	Yes
39	Modeling Water Treatment Performance and Costs for Removal of PFAS from Drinking Water	Burkhardt et al.	2021	https://www.taylorfrancis.com/chapters/edit/10.1201/9781003024521-18/modeling-water-treatment-performance-costs-removal-pfas-drinking-water-jonathan-burkhardt-richard-anderson-rajiv-khera-levi-haupt-patrick-ransom-david-wahman-page-jordan-jonathan-pressman-marc-mills-thomas-speth	PFAS																				Not yet rated	Cannot access abstract to screen	
40	Predicting impacts of chemicals from organisms to ecosystem service delivery: A case study of endocrine disruptor effects on trout	Forbes et al.	2019	https://www.sciencedirect.com/science/article/abs/pii/S0048969718333151	n/a														Medium - not directly relevant to EU, but likely transferrable		Low - Does not answer research questions		High - no doubts about the credibility of the source (e.g. peer-reviewed study or renowned institution), robustness and transparency of method, or limitations affecting the validity of results		3	Behind a paywall, but it does not really seem to be about PFAS but just 'chemicals' which are not listed in detail in the abstract.	No
41	Universal PFAS restriction proposal	BAUA, RIVM, KEMI, Norwegian EA, Danish EPA (published by ECHA)	2023	https://echa.europa.eu/restrictions-under-consideration/-/substance-rev72301/term-attached-to it	All PFAS: "Any substance that contains at least one fully fluorinated methyl (CF3-) or methylene (-CF2-) carbon atom (without any H/C/Br/I attached to it)."	Section 1.1.5.8. summarises the human exposure assessment. More detail in Annex B, section B.9.21.	See Q1.3 in next column	Section 1.1.4.9. summarizes literature on effects on human health by PFAS group. More detail in Annex B, Section B.5.		Section 1.1.5.7. summarises literature on environmental monitoring data. More detail in Annex B, Sections B.4.2.		Short summary of ecotoxicity and endocrine activity/disruption in Sections 1.1.4.7 and 1.1.4.8. More detailed summary of literature for various species in Annex B, Section B.7.			Two paragraphs with a few examples of remediation and water purification costs in Section 2.4.4. Annex B, Section B.4.5 also lists and describes available treatment techniques, but not cost data is provided (note there is a reference here to more case studies and costs in Annex E, but I could not find any such information in Annex E).			There is not a detailed assessment here, but Section 2.4.4 mentions health and healthcare costs, remediation and purification costs, and decrease in fishing grounds.	Very high - relevant to EU as a whole or large parts of EU		High - Answers at least one research question, conforms with inclusion criteria for that question, within scope boundaries		High - no doubts about the credibility of the source (e.g. peer-reviewed study or renowned institution), robustness and transparency of method, or limitations affecting the validity of results		6		Yes

Reference ID	Potentially relevant source				PFAS in scope of study	Relevant research sub-questions and summary															Geography		Thematic relevance		Robustness and limitations		Shortlisting	
	Title	Author	Year	Link		1.1 To what extent are humans exposed to PFAS in the EU?	1.2 What PFAS exposure is associated with human health risks?	1.3 What are the observed risk relationships and/or predicted human health impacts from those risks?	1.4 What are the costs associated with the human health impacts?	1.5 What are the geographical and temporal trends in human health costs?	2.1 To what extent are environmental compartments (soil, water, air, and biota) contaminated with PFAS in the EU?	2.2 What are the environmental effects on aquatic and terrestrial species and populations?	2.3 What are the ecosystem-level effects?	2.4 What are the effects on biodiversity?	2.5 What are the monetised ecosystem service costs associated with impacts on species, ecosystems and biodiversity?	2.6 What are the environmental clean-up costs (soil and water remediation/treatment costs) and litigation costs?	2.7 What are the geographical and temporal trends in environmental costs?	3.1 What are the methods to calculate the societal costs from PFAS?	3.2 What are the indirect and direct, market and non-market, and one-off and recurring costs of PFAS pollution?	Geographic relevance rating	Notes	Thematic relevance rating (research questions, inclusion criteria, and scope boundaries)	Notes	Robustness rating (source credible, method robust and transparent, significance of limitations)	Score	Justification / explanation for shortlisting or not	Will this source be taken forward for data extraction?	
42	Estimating the burden of disease due to lead, PFAS, phthalates, cadmium, pyrethroids and bisphenol A using HBM4EU data – test of feasibility and first results for selected 42 countries.	Plass et al.	2023	https://www.eionet.europa.eu/etcs/etc/he/products/etc/he-reports/etc/he-report-2023-13-estimating-the-burden-of-disease-due-to-lead-pfas-phthalates-cadmium-pyrethroids-and-bisphenol-a-using-hbm4eu-data-2013-test-of-feasibility-and-first-results-for-selected-countries/@@doxload/file/ETC-HE-2023-13-EIONET-REPORT-3-2-6-3-ERO-chemicals-FINAL.pdf	Focus on PFOS, PFOA	x	x	x	x	x									Very high - relevant to EU as a whole or large parts of EU		High - Answers at least one research question, conforms with inclusion criteria for that question, within scope boundaries		High - no doubts about the credibility of the source (e.g. peer-reviewed study or renowned institution), robustness and transparency of method, or limitations affecting the validity of results	6	Key source	Yes		
43	Association between prenatal exposure to perfluorinated compounds and symptoms of infections at age1–4years among 359 children in the Odense Child Cohort.	Dalsager L et al	2016	https://www.sciencedirect.com/science/article/pii/S0160412016303245#~:text=We%20found%20a%20positive%20association%20between%20in%20uteroinfections%20as%20a%20possible%20consequence%20of%20immune%20toxic%20effects.	PFOS , PFOA, PFHxS, PFDA, PFNA													Medium - not directly relevant to EU, but likely transferrable		Medium - Answers at least one research question, but does not conform with inclusion criteria for that question, or is not within scope boundaries		Medium - doubts about one of credibility of the source (e.g. peer-reviewed study or renowned institution), robustness and transparency of method, or limitations affecting the validity of results	Covered in Nordic 3 Council study	No				
44	POLICY BRIEFING: Toxic tide rising: time to tackle PFAS - National approaches to address PFAS in drinking water across Europe	EEB	2023	https://eeb.org/wp-content/uploads/2023/10/PFAS-in-drinking-water-briefing-final-1.pdf	Generic PFAS	x										x		Very high - relevant to EU as a whole or large parts of EU	This is a briefing on European PFAS policy	Medium - Answers at least one research question, but this has largely been identified through other sources (HBM4EU studies)		High - no doubts about the credibility of the source (e.g. peer-reviewed study or renowned institution), robustness and transparency of method, or limitations affecting the validity of results	Policy document using reputable evidential sources	The relevant information included has been identified through other sources. The policy information is not directly relevant to Q1.1/1.2	No			
45	Risks of PFAS for human health in Europe (Signal)	EEA	2024	https://www.eea.europa.eu/en/european-zero-pollution-dashboards/indicators/risk-of-pfas-in-humans?activeTab=76005f3434f		x	x			x								Very high - relevant to EU as a whole or large parts of EU		High - Answers at least one research question, conforms with inclusion criteria for that question, within scope boundaries		High - no doubts about the credibility of the source (e.g. peer-reviewed study or renowned institution), robustness and transparency of method, or limitations affecting the validity of results	Summary of evidence on health 6 risks	Yes				

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		Author	Year	Link			1.1 To what extent are humans exposed to PFAS in the EU?	1.2 What PFAS exposure is associated with human health risks?	1.3 What are the observed risk relationships and/or predicted human health impacts from those risks?	1.4 What are the costs associated with the human health impacts?	1.5 What are the geographical and temporal trends in human health costs?	2.1 To what extent are environmental compartments (soil, water, air, and biota) contaminated with PFAS in the EU?	2.2 What are the environmental effects on aquatic and terrestrial species and populations?	2.3 What are the ecosystem-level effects?	2.4 What are the effects on biodiversity?	2.5 What are the monetised ecosystem service costs associated with impacts on species, ecosystems and biodiversity?	2.6 What are the environmental clean-up costs (soil and water remediation/treatment costs) and litigation costs?	2.7 What are the geographical and temporal trends in environmental costs?	3.1 What are the methods to calculate the societal costs from PFAS?	3.2 What are the indirect and direct, market and non-market, and one-off and recurring costs of PFAS pollution?	Geographic relevance rating	Notes	Thematic relevance rating (research questions, inclusion criteria, and scope boundaries)	Notes	Robustness rating (source credible, method robust and transparent, significance of limitations)	Notes	Score	Justification / explanation for shortlisting or not	Will this source be taken forward for data extraction?
46	Cohort mortality study of workers exposed to perfluorooctanoic acid.	Steenland K and Woskie S	2012	https://pubmed.ncbi.nlm.nih.gov/23079607/	Paywall. PFOA.			x												Medium - not directly relevant to EU, but likely transferrable		Medium - Answers at least one research question, but does not conform with inclusion criteria for that question, or is not within scope boundaries		Medium - doubts about one of credibility of the source (e.g. peer-reviewed study or renowned institution), robustness and transparency of method, or limitations affecting the validity of results High - no doubts about the credibility of the source (e.g. peer-reviewed study or renowned institution), robustness and transparency of method, or limitations affecting the validity of results		Covered in Nordic 3 Council study	No		
47	Cross-cutting story 3: PFAS	EEA	2023	https://www.eea.europa.eu/publications/zero-pollution/cross-cutting-stories/pfas	PFOS and PFOA		x													Very high - relevant to EU as a whole or large parts of EU	Directly relevant to the EU, based on findings from HBM4EU study	Medium - Answers at least one research question, but does not conform with inclusion criteria for that question, or is not within scope boundaries	The information included is relevant but has been obtained from other primary sources	This is a government agency output that draws upon robust sources	The relevant information included is duplicative and has been obtained from other primary sources.	No			
48	Drinking water contamination from perfluoroalkyl substances (PFAS): an ecological mortality study in the Veneto Region, Italy.	Mastrantonio M et al.	2017	https://academic.oup.com/europub/article/28/1/180/3652033	PFAS	x	x	x		x										Medium - not directly relevant to EU, but likely transferrable		High - Answers at least one research question, conforms with inclusion criteria for that question, within scope boundaries		High - no doubts about the credibility of the source (e.g. peer-reviewed study or renowned institution), robustness and transparency of method, or limitations affecting the validity of results Medium - doubts about one of credibility of the source (e.g. peer-reviewed study or renowned institution), robustness and transparency of method, or limitations affecting the validity of results	Information used in support of key exposure discussions, where more recent isolated case studies are not available	5 available	Yes		
49	Unregulated contaminants in drinking water: Evidence from PFAS and housing prices	Marcus and Mueller	2024	https://www.sciencedirect.com/science/article/pii/S095006624000615	Generic PFAS													x		Low - not relevant to EU and likely not transferrable	Examines US house prices in PFAS contaminated areas	Low - Does not answer research questions	House prices are not in scope.	Some limitations to the methodology in attributing house prices to PFAS exposure	1 question	No			
50	HBM platform			https://hbm.vito.be/eu-hbm-dashboard; https://www.hbm4eu.eu/what-we-do/european-hbm-platform/eu-hbm-dashboard/	All PFAS					x										Very high - relevant to EU as a whole or large parts of EU	Contains information from all European PFAS monitoring activities	High - Answers at least one research question, conforms with inclusion criteria for that question, within scope boundaries	Information can be extracted and compiled to directly support Q1.1	High - no doubts about the credibility of the source (e.g. peer-reviewed study or renowned institution), robustness and transparency of method, or limitations affecting the validity of results High - no doubts about the credibility of the source (e.g. peer-reviewed study or renowned institution), robustness and transparency of method, or limitations affecting the validity of results	Primary monitoring data	The study team contacted Vito for information stratified by PFAS type, age and geography and this was compiled in support of Q1.1	Yes		
51	Economic Valuation of PFAS Remediation in New Hampshire Municipal Drinking Water Systems: A Contingent Valuation Approach	Lemos Jr et al.	2024	https://ascellibrary.org/doi/10.1061/JWRMD5.WRE.NG-5998	PFAS													x		Low - not relevant to EU and likely not transferrable	Study is based in a specific part of the US, the financial conditions of residents may not be transferable	Medium - Answers at least one research question, but does not conform with inclusion criteria for that question, or is not within scope boundaries	Focused on how much residents would pay for clean water, which could be a method for societal costs	Peer reviewed study in journal	Does not answer research questions and is not geographically relevant	No			
52	Background Document to the Opinion on the Annex XV dossier proposing restrictions on Octamethylcyclotetrasiloxane (D4) and Decamethylcyclotetrasiloxane (D5)	ECHA	2016	https://echa.europa.eu/documents/10162/efaa3a2-ftcd-4b74-4ec8-3c869d4dae7	Siloxanes, not PFAS															Very high - relevant to EU as a whole or large parts of EU	Relevant to whole EU, background for an EU wide restriction	Low - Does not answer research questions	Not about PFAS, about siloxanes	From ECHA	Siloxanes, not about PFAS	No			
53	Two-year follow-up biomonitoring pilot study of residents' and controls' PFC plasma levels after PFOA reduction in public water system in Arnsberg	Brede E et al.	2010	https://www.sciencedirect.com/science/article/pii/S1438463910000416	PFOA		x													High - relevant to some EU countries	Germany only and specific to contaminated areas	High - Answers at least one research question, conforms with inclusion criteria for that question, within scope boundaries	Information directly relevant to the population sub-group 'people living near contaminated sites'	High - no doubts about the credibility of the source (e.g. peer-reviewed study or renowned institution), robustness and transparency of method, or limitations affecting the validity of results	Comprehensive monitoring data	Directly supports a sub-group in scope of this study, though note that this study is from 2010	Yes		
54	Diet, nutrition, physical activity and cancer	World Cancer Research Fund International	2018	https://www.wcrf.org/wp-content/uploads/2021/02/Summary-of-Third-Expert-Report-2018.pdf	None mentioned			x												Medium - not directly relevant to EU, but likely transferrable	Some geographic relevance (a global report)	Low - Does not answer research questions	Does not include information on PFAS	Comprehensive study produced by the World Cancer Research Fund / American Institute for Cancer Research	Not relevant to 3 PFAS exposures	No			
55	Cost-Benefit Analysis of the Swiss National Policy on Reducing Micropollutants in Treated Wastewater	Logar et al.	2014	https://pubs.acs.org/doi/10.1021/es502338j	Micropollutants, not specifically PFAS															High - relevant to some EU countries	Switzerland	Low - Does not answer research questions	Survey focuses on how much people will pay to upgrade their sewage treatment	Peer reviewed study in journal	Does not answer 3.5 research questions	No			
56	Association of Perfluoroalkyl Substances, Bone Mineral Density, and Osteoporosis in the U.S. Population in NHANES 2009-2010	Khalil, N., Chen, A., Lee, M., Czerwinski, S. A., Ebert, J. R., DeWitt, J. C., & Kannan, K.	2016	https://doi.org/10.1289/ehp.130790	PFOA, PFHxS, PFNA			x												Medium - not directly relevant to EU, but likely transferrable		Medium - Answers at least one research question, but does not conform with inclusion criteria for that question, or is not within scope boundaries		Medium - doubts about one of credibility of the source (e.g. peer-reviewed study or renowned institution), robustness and transparency of method, or limitations affecting the validity of results	ERF for 3 osteoporosis	Yes			

Reference ID	Potentially relevant source				PFAS in scope of study	Relevant research sub-questions and summary															Geography		Thematic relevance		Robustness and limitations		Shortlisting		
	Title	Author	Year	Link		1.1 To what extent are humans exposed to PFAS in the EU?	1.2 What PFAS exposure is associated with human health risks?	1.3 What are the observed risk relationships and/or predicted human health impacts from those risks?	1.4 What are the costs associated with the human health impacts?	1.5 What are the geographical and temporal trends in human health costs?	2.1 To what extent are environmental compartments (soil, water, air, and biota) contaminated with PFAS in the EU?	2.2 What are the environmental effects on aquatic and terrestrial species and populations?	2.3 What are the ecosystem-level effects?	2.4 What are the effects on biodiversity?	2.5 What are the monetised ecosystem service costs associated with impacts on species, ecosystems and biodiversity?	2.6 What are the environmental clean-up costs (soil and water remediation/treatment costs) and litigation costs?	2.7 What are the geographical and temporal trends in environmental costs?	3.1 What are the methods to calculate the societal costs from PFAS?	3.2 What are the indirect and direct, market and non-market, and one-off and recurring costs of PFAS pollution?	Geographic relevance rating	Notes	Thematic relevance rating (research questions, inclusion criteria, and scope boundaries)	Notes	Robustness rating (source credible, method robust and transparent, significance of limitations)	Notes	Score	Justification / explanation for shortlisting or not	Will this source be taken forward for data extraction?	
57	Mixture Exposure to PFAS: A relative potency factor approach	M.J. Zeilmaker et al.	2018	https://www.rivm.nl/bibliotheek/rapporten/2018-0070.pdf	Generic PFAS		x												Very high - relevant to EU as a whole or large parts of EU	European study	Medium - Answers at least one research question, but does not conform with inclusion criteria for that question, or is not within scope boundaries	Discusses risks from PFAS, which are relevant, but not in terms of human health endpoints	Medium - doubts about one of credibility of the source (e.g. peer-reviewed study or renowned institution), robustness and transparency of method, or limitations affecting the validity of results	Some limitations to the methodology	Does not focus on 4 specific endpoints	No			
58	Perfluorooctanoic acid exposure is associated with elevated homocysteine and hypertension in US adults.	Min et al.	2012	https://pmc.ncbi.nlm.nih.gov/articles/PMC3426376/	PFOA		x	x											Medium - not directly relevant to EU, but likely transferrable		High - Answers at least one research question, conforms with inclusion criteria for that question, within scope boundaries		High - no doubts about the credibility of the source (e.g. peer-reviewed study or renowned institution), robustness and transparency of method, or limitations affecting the validity of results		Covered in Nordic Council study and 5 EEA Study	No			
59	The relationship between perfluoroalkyl substances and hypertension: A systematic review and meta-analysis	Pan et al.	2023	https://www.sciencedirect.com/science/article/pii/S0139331223011460	PFNA, PFOA, PFOS, PFHxS, PFDA, PFUnDA		x	x											Medium - not directly relevant to EU, but likely transferrable		High - Answers at least one research question, conforms with inclusion criteria for that question, within scope boundaries		High - no doubts about the credibility of the source (e.g. peer-reviewed study or renowned institution), robustness and transparency of method, or limitations affecting the validity of results		ERF for 5 hypertension	Yes			
60	Surveys of willingness-to-pay to avoid negative chemicals-related health effects (SWACHE)	OECD		https://www.oecd.org/content/dam/oecd/en/topics/policy-issue-focus/swache/Brochure-Surveys-of-willingness-to-pay-to-avoid-negative-chemicals-related-health-effects-SWACHE.pdf	Methodology for costing					x									Medium - not directly relevant to EU, but likely transferrable		Medium - Answers at least one research question, but does not conform with inclusion criteria for that question, or is not within scope boundaries		High - no doubts about the credibility of the source (e.g. peer-reviewed study or renowned institution), robustness and transparency of method, or limitations affecting the validity of results		Being considered for methodological 4 aspects	Yes			
61	Willingness to pay to avoid certain health impacts	ECHA		https://echa.europa.eu/support/scio-economic-analysis-in-reach/willingness-to-pay-to-avoid-certain-health-impacts	Methodology for costing					x									High - relevant to some EU countries		Medium - Answers at least one research question, but does not conform with inclusion criteria for that question, or is not within scope boundaries		High - no doubts about the credibility of the source (e.g. peer-reviewed study or renowned institution), robustness and transparency of method, or limitations affecting the validity of results		Being considered for methodological 4.5 aspects	Yes			
62	Stated-preference study to examine the economic value of benefits of avoiding selected adverse human health outcomes due to exposure to chemicals in the European Union	ECHA	2014	https://echa.europa.eu/documents/10162/17228/study_economic_benefits_avoiding_adverse_health_outcomes_1_en.pdf/5c884e27-8ce7-4ffd-97dc-5e7875ee67e0	Methodology for costing								x						High - relevant to some EU countries		Medium - Answers at least one research question, but does not conform with inclusion criteria for that question, or is not within scope boundaries		High - no doubts about the credibility of the source (e.g. peer-reviewed study or renowned institution), robustness and transparency of method, or limitations affecting the validity of results		Being considered for methodological 4.5 aspects	Yes			
63	High willingness to pay more to avoid PFAS in everyday products	Luleå University of Technology	2023	https://www.ltu.se/en/latest-news/news/news/2023-10-05-high-willingness-to-pay-more-to-avoid-pfas-in-everyday-products	Methodology for costing							x							High - relevant to some EU countries		Medium - Answers at least one research question, but does not conform with inclusion criteria for that question, or is not within scope boundaries		High - no doubts about the credibility of the source (e.g. peer-reviewed study or renowned institution), robustness and transparency of method, or limitations affecting the validity of results		Being considered for methodological 4.5 aspects	Yes			

Reference ID	Potentially relevant source				PFAS in scope of study	Relevant research sub-questions and summary														Geography		Thematic relevance		Robustness and limitations		Shortlisting		
	Title	Author	Year	Link		1.1 To what extent are humans exposed to PFAS in the EU?	1.2 What PFAS exposure is associated with human health risks?	1.3 What are the observed risk relationships and/or predicted human health impacts from those risks?	1.4 What are the costs associated with the human health impacts?	1.5 What are the geographical and temporal trends in human health costs?	2.1 To what extent are environmental compartments (soil, water, air, and biota) contaminated with PFAS in the EU?	2.2 What are the environmental effects on aquatic and terrestrial species and populations?	2.3 What are the ecosystem-level effects?	2.4 What are the effects on biodiversity?	2.5 What are the monetised ecosystem service costs associated with impacts on species, ecosystems and biodiversity?	2.6 What are the environmental clean-up costs (soil and water remediation/treatment costs) and litigation costs?	2.7 What are the geographical and temporal trends in environmental costs?	3.1 What are the methods to calculate the societal costs from PFAS?	3.2 What are the indirect and direct, market and non-market, and one-off and recurring costs of PFAS pollution?	Geographic relevance rating	Notes	Thematic relevance rating (research questions, inclusion criteria, and scope boundaries)	Notes	Robustness rating (source credible, method robust and transparent, significance of limitations)	Notes	Score	Justification / explanation for shortlisting or not	Will this source be taken forward for data extraction?
64	The use of PFAS and fluorine-free alternatives in fire-fighting foams. Report produced for European Commission DG Environment / European Chemicals Agency (ECHA).	Wood, Ramboll, COWI	2020	https://echa.europa.eu/documents/10162/6755610/pfas-flourine-free-alternatives-fire-fighting-en.pdf/d5b24e2a-d027-0168-cdd8-7723c675fa98	PFAS in fire-fighting foams (s carboxylic/sulfonic short- and long chain PFAS and a variety of fluorotelomers)														Very high - relevant to EU as a whole or large parts of EU	Studied commissioned by ECHA for the EU	High - Answers at least one research question, conforms with inclusion criteria for that question, within scope boundaries	Answers a number of research questions and focuses on costs of remediation and SEA with specific section to environmental impacts	Medium - doubts about one of credibility of the source (e.g. peer-reviewed study or renowned institution), robustness and transparency of method, or limitations affecting the validity of results	WSP has shown credibility in reports, however the report is not peer reviewed	5	Highly relevant for a number of research questions	Yes	
65	Pollution and health: a progress update.	Fuller et al.	2022	https://www.thelancet.com/action/showPdf?pii=S25166528222930080-0	None mentioned		x												High - relevant to some EU countries	Global geographic scope	Low - Does not answer research questions	Discusses health effects of pollution more broadly.	High - no doubts about the credibility of the source (e.g. peer-reviewed study or renowned institution), robustness and transparency of method, or limitations affecting the validity of results	Credible source (the Lancet)	3.5	No reference to PFAS	No	
66	Our Current Understanding of the Human Health and Environmental Risks of PFAS.	US EPA	2024	https://www.epa.gov/pfas/our-current-understanding-human-health-and-environmental-risks-pfas	Generic PFAS			x											Medium - not directly relevant to EU, but likely transferrable	Information is presented the US EPA, but is generic and thus applicable to European populations	Medium - Answers at least one research question, but does not conform with inclusion criteria for that question, or is not within scope boundaries	Provides generic sources of PFAS exposure and health effects, without further details	High - no doubts about the credibility of the source (e.g. peer-reviewed study or renowned institution), robustness and transparency of method, or limitations affecting the validity of results	Regulatory body	4	Not taken forward for full data extraction, but used as supporting evidence where information is generally available from other European sources	No	
67	Changing interpretation of human health risks from perfluorinated compounds.	Grandjean P et al.	2014	https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4187289/				x											Low - not relevant to EU and likely not transferrable	North American data, blood and water PFAS concentrations not directly transferable	Medium - Answers at least one research question, but does not conform with inclusion criteria for that question, or is not within scope boundaries	Provides a response to Q1.1/1.2 but for the incorrect geography	High - no doubts about the credibility of the source (e.g. peer-reviewed study or renowned institution), robustness and transparency of method, or limitations affecting the validity of results	Peer reviewed study	3	Not relevant to European populations.	No	
68	Toxicological profile for Perfluoroalkyls. Atlanta, GA: U.S. Department of Health and Human Services, Public Health Service.	Agency for Toxic Substances and Disease Registry (ATSDR)	2021	https://www.atsdr.cdc.gov/ToxProfiles/n200-p.pdf	Contents page only.			x											Medium - not directly relevant to EU, but likely transferrable	American source, but toxicology information is relevant to Europe	Medium - Answers at least one research question, but does not conform with inclusion criteria for that question, or is not within scope boundaries	Focus appears to be toxicological rather than observed human health endpoints	High - no doubts about the credibility of the source (e.g. peer-reviewed study or renowned institution), robustness and transparency of method, or limitations affecting the validity of results	Published by a government body	4	Only the contents page is available. The scope of Q1.1/1.2 is not comprehensive toxicology data, as appears to be included in this document.	No	
69	Exposure to Perfluoroalkyl Substances and Associations with Pubertal Onset and Serum Reproductive Hormones in a Longitudinal Study of Young Girls in Greater Cincinnati and the San Francisco Bay Area.	Pinney et al.	2023	https://ehp.niehs.nih.gov/dohi/10.1289/EHP1181	PFOA, PFNA, PFDeA, Me-PFOSA-AcOH				x										Medium - not directly relevant to EU, but likely transferrable	American study but findings may apply to European populations (exact quantities will not)	High - Answers at least one research question, conforms with inclusion criteria for that question, within scope boundaries	Supports discussion on reproductive health endpoints in Q1.2	High - no doubts about the credibility of the source (e.g. peer-reviewed study or renowned institution), robustness and transparency of method, or limitations affecting the validity of results	Peer reviewed study	5	Used in support of human health discussions on reproductive endpoints	Yes	
70	Carcinogenicity of perfluorooctanoic acid (PFOA) and perfluorooctanesulfonic acid (PFOS)	Zahn et al.	2023	https://www.thelancet.com/journal/S0147201820452300622-8/fulltext	PFOA, PFOS					x									Very high - relevant to EU as a whole or large parts of EU	Refers to a meeting of an international group including European countries	Medium - Answers at least one research question, but does not conform with inclusion criteria for that question, or is not within scope boundaries	Provides discussion on the carcinogenicity of PFAS	High - no doubts about the credibility of the source (e.g. peer-reviewed study or renowned institution), robustness and transparency of method, or limitations affecting the validity of results	Peer reviewed publication in a credible source	5	Used in support of human health discussions on carcinogenicity	Yes	
71	Emerging chemical risks in Europe — 'PFAS'	EEA	2019	https://www.eea.europa.eu/publications/emerging-chemical-risks-in-europe	PFOA, PFOS, generic PFAS	x		x											Very high - relevant to EU as a whole or large parts of EU	Outputs from HBM4EU study, and focused on European countries/populations	High - Answers at least one research question, conforms with inclusion criteria for that question, within scope boundaries	Directly relevant to Q1.1/1.2	Medium - doubts about one of credibility of the source (e.g. peer-reviewed study or renowned institution), robustness and transparency of method, or limitations affecting the validity of results	Discussion based on HBM data	6	Used as a source from early in the time period (2019), and to benchmark any changes in conclusions over time (2019-2024)	Yes	
72	Estimating Consumer Exposure to PFOS and PFOA Risk Analysis.	Trudel D et al.	2008	https://dioxin20xx.com/wp-content/uploads/pdfs/2008/08-309.pdf	PFOS, PFOA								x						High - relevant to some EU countries	Covers North America and Europe	High - Answers at least one research question, conforms with inclusion criteria for that question, within scope boundaries	Relates to overall PFAS exposures.	High - no doubts about the credibility of the source (e.g. peer-reviewed study or renowned institution), robustness and transparency of method, or limitations affecting the validity of results	Validity of results limited due to modelled nature	4.5	Scoped out due to study date (2008) and limitations (modelling) of method	No	

Reference ID	Potentially relevant source				PFAS in scope of study	Relevant research sub-questions and summary															Geography		Thematic relevance		Robustness and limitations		Shortlisting		
	Title	Author	Year	Link		1.1 To what extent are humans exposed to PFAS in the EU?	1.2 What PFAS exposure is associated with human health risks?	1.3 What are the observed risk relationships and/or predicted human health impacts from those risks?	1.4 What are the costs associated with the human health impacts?	1.5 What are the geographical and temporal trends in human health costs?	2.1 To what extent are environmental compartments (soil, water, air, and biota) contaminated with PFAS in the EU?	2.2 What are the environmental effects on aquatic and terrestrial species and populations?	2.3 What are the ecosystem-level effects?	2.4 What are the effects on biodiversity?	2.5 What are the monetised ecosystem service costs associated with impacts on species, ecosystems and biodiversity?	2.6 What are the environmental clean-up costs (soil and water remediation/treatment costs) and litigation costs?	2.7 What are the geographical and temporal trends in environmental costs?	3.1 What are the methods to calculate the societal costs from PFAS?	3.2 What are the indirect and direct, market and non-market, and one-off and recurring costs of PFAS pollution?	Geographic relevance rating	Notes	Thematic relevance rating (research questions, inclusion criteria, and scope boundaries)	Notes	Robustness rating (source credible, method robust and transparent, significance of limitations)	Notes	Score	Justification / explanation for shortlisting or not	Will this source be taken forward for data extraction?	
73	How can I be exposed?	Agency for Toxic Substances and Disease Registry (ATSDR)		https://www.atsdr.cdc.gov/pfas/health-effects/exposure.html	Generic PFAS	x	x													Very high - relevant to EU as a whole or large parts of EU	Generic discussions applicable to EU exposure pathways	High - Answers at least one research question, conforms with inclusion criteria for that question, within scope boundaries	Explains exposure pathways relevant to Q1.1	High - no doubts about the credibility of the source (e.g. peer-reviewed study or renowned institution), robustness and transparency of method, or limitations affecting the validity of results	U.S. regulatory body publication		Not taken forward for extraction as information is generic, but can be used as a supporting reference for generic introductory text	No	
74	Expert Health Panel for Per- and Poly-Fluoroalkyl Substances (PFAS)	Australia Government Department of Health	2018	https://www.sahealth.sa.gov.au/vp/serve/connect/public+content/sa+health+internet/conditions/chemicals+and+contaminants/pfas/per-and+poly-fluoroalkyl+substances+pfas#~:text=The%20Expert%20Health%20Panel%20for%20PFAS%20found%20that%20several%20health%20effects%20are%20linked%20to%20PFAS.															Medium - not directly relevant to EU, but likely transferrable	Regulatory conclusions not applicable to Europe	Medium - Answers at least one research question, but does not conform with inclusion criteria for that question, or is not within scope boundaries	Presents evidence on the human health effects of PFAS	High - no doubts about the credibility of the source (e.g. peer-reviewed study or renowned institution), robustness and transparency of method, or limitations affecting the validity of results	Regulatory body	4	Australian regulatory assessment not considered relevant to this study.	No		
75	Updated draft state of per- and polyfluoroalkyl substances (PFAS) report	Environment and Climate Change Canada, Health Canada	2024	https://www.canada.ca/en/environment-climate-change/services/evaluating-existing-substances/updated-draft-state-of-per-and-polyfluoroalkyl-substances-report.html	Several species.		x												Medium - not directly relevant to EU, but likely transferrable		Medium - Answers at least one research question, but does not conform with inclusion criteria for that question, or is not within scope boundaries		Medium - doubts about one of credibility of the source (e.g. peer-reviewed study or renowned institution), robustness and transparency of method, or limitations affecting the validity of results		3	National doc from Canada. Provides information on bio-monitoring, and the human exposure and health hazards. Also has information on ecotox. Has some answers to some research questions (e.g. 1.1) although not relevant for the EU, some of the information could be transferred however.	Yes		
76	PFAS Litigation Could Generate Billions in Ground-Up Losses. Here's How.	Despotaki, Hang, Braqq	2024	https://core.verisk.com/insights/merging-issues/articles/2024/April/Week-1/PFAS-Litigation-Could-Generate-Billions-in-Ground-Up-Losses										"The model calculates the losses arising from claims seeking compensation for four damage types, including mitigation and remediation costs related to PFAS clean-up; bodily injuries for those individuals who develop cancer because of PFAS-related exposure; property damage to households due to environmental contamination; and medical monitoring costs."	"The model calculates the losses arising from claims seeking compensation for four damage types, including mitigation and remediation costs related to PFAS clean-up; bodily injuries for those individuals who develop cancer because of PFAS-related exposure; property damage to households due to environmental contamination, and medical monitoring costs."			Medium - not directly relevant to EU, but likely transferrable	US focus, but still interesting to consider	Medium - Answers at least one research question, but does not conform with inclusion criteria for that question, or is not within scope boundaries	Only useful in terms of the types of costs considered, and the headline figure for ground-up losses in the U.S. from PFAS-contaminated drinking water and related environmental litigation.	Low - doubts about at least two of credibility of the source (e.g. peer-reviewed study or renowned institution), robustness and transparency of method, or limitations affecting the validity of results	Article by a private company that was not peer reviewed, low transparency about methodology	2	Could quickly extract two useful pieces of information for context (types of costs considered, and the headline figure for ground-up losses in the U.S. from PFAS-contaminated drinking water and related environmental litigation.), although this is not a very strong source.	Yes			
77	Linking ecological data and economics to estimate the total economic value of improving water quality by reducing nutrients	Nelson et al.	2015	https://www.sciencedirect.com/science/article/abs/pii/S092180091500244X	Nutrients, not specifically PFAS														Low - not directly relevant to EU and likely not transferrable	US study, US water is very different than EU. Based specifically in Utah	Low - Does not answer research questions	Focused on nutrients, not on pollutants	High - no doubts about the credibility of the source (e.g. peer-reviewed study or renowned institution), robustness and transparency of method, or limitations affecting the validity of results	Peer reviewed study in journal	2	Does not answer research questions and is not geographically relevant	No		
78	Measuring natural capital value and ecological complexity of lake ecosystems	Grande et al.	2023	https://www.sciencedirect.com/science/article/abs/pii/S0304380023001321	Nutrients, not specifically PFAS														High - relevant to some EU countries	Study in Poland	Medium - Answers at least one research question, but does not conform with inclusion criteria for that question, or is not within scope boundaries	Does provide information about environmental costings, however is not focused on PFAS/effects due to PFAS		Peer reviewed study in journal	4.5	Highly relevant for a number of research questions	Yes		
More generic about natural capital and ecological complexity																													

Reference ID	Potentially relevant source				PFAS in scope of study	Relevant research sub-questions and summary															Geography		Thematic relevance		Robustness and limitations		Shortlisting		
	Title	Author	Year	Link		1.1 To what extent are humans exposed to PFAS in the EU?	1.2 What PFAS exposure is associated with human health risks?	1.3 What are the observed risk relationships and/or predicted human health impacts from those risks?	1.4 What are the costs associated with the human health impacts?	1.5 What are the geographical and temporal trends in human health costs?	2.1 To what extent are environmental compartments (soil, water, air, and biota) contaminated with PFAS in the EU?	2.2 What are the environmental effects on aquatic and terrestrial species and populations?	2.3 What are the ecosystem-level effects?	2.4 What are the effects on biodiversity?	2.5 What are the monetised ecosystem service costs associated with impacts on species, ecosystems and biodiversity?	2.6 What are the environmental clean-up costs (soil and water remediation/treatment costs) and litigation costs?	2.7 What are the geographical and temporal trends in environmental costs?	3.1 What are the methods to calculate the societal costs from PFAS?	3.2 What are the indirect and direct, market and non-market, and one-off and recurring costs of PFAS pollution?	Geographic relevance rating	Notes	Thematic relevance rating (research questions, inclusion criteria, and scope boundaries)	Notes	Robustness rating (source credible, method robust and transparent, significance of limitations)	Notes	Score	Justification / explanation for shortlisting or not	Will this source be taken forward for data extraction?	
79	Accounting for ecosystems and their services in the European Union	European Commission	2021	https://ec.europa.eu/eurostat/web/products-statistical-reports/-/ks-ft-20-002	Does not specify										Generic about the ecosystem accounting used for EU28					Very high - relevant to EU as a whole or large parts of EU	EU focused project	Medium - Answers at least one research question, but does not conform with inclusion criteria for that question, or is not within scope boundaries	Provides information about ecosystem costing, with a focus on EU28	High - no doubts about the credibility of the source (e.g. peer-reviewed study or renowned institution), robustness and transparency of method, or limitations affecting the validity of results		5	Gives a good basis for ecosystem costing and accounting	Yes	
80	Introducing the Adverse Ecosystem Service Pathway as a Tool in Ecological Risk Assessment	Awuah et al.	2020	https://pubs.acs.org/doi/10.1021/acs.est.9b06851	n/a														Medium - not directly relevant to EU, but likely transferrable		Low - Does not answer research questions	Medium - doubts about one of credibility of the source (e.g. peer-reviewed study or renowned institution), robustness and transparency of method, or limitations affecting the validity of results		2	Behind a paywall and does not directly mention PFAS, but looks at the ecosystem services provided by soil. Not sure if it should be taken forward.	No			
81	Status of local soil contamination in Europe: Revision of the indicator "Progress in the management contaminated sites in Europe"	Paya Perez and Rodriguez Eugenio	2018	https://www.eea.europa.eu/data-and-maps/data/external/status-of-local-soil-contamination	PFAS (general)														High - relevant to some EU countries		Low - Does not answer research questions	High - no doubts about the credibility of the source (e.g. peer-reviewed study or renowned institution), robustness and transparency of method, or limitations affecting the validity of results		3.5	Covers soil contamination in Europe, however, fails to really talk about PFAS contamination and the cost of PFAS contamination	No			
82	U.S. EPA Health Assessment Workspace Collaborative (HAWC)	Ng, C., Cousins, I.T., DeWitt, J.C., Gluge, J., Goldenman, G., Herzke, D., Lohmann, R., Miller, M., Patton, S., Scheringer, M., Trier, X., Wang, Z.		https://hawc.epa.gov/summary/visualassessment/100500085/Epidemiological-Studies-and-Study-Confidence/			x												Low - not relevant to EU and likely not transferrable		Medium - Answers at least one research question, but does not conform with inclusion criteria for that question, or is not within scope boundaries	Medium - doubts about one of credibility of the source (e.g. peer-reviewed study or renowned institution), robustness and transparency of method, or limitations affecting the validity of results		2	Summary of ERFs, considered in other sources	No			
83	Addressing urgent questions for PFAS in the 21st century		2021	https://pubs.acs.org/doi/abs/10.1021/acs.est.1c03386	General PFAS		x								Asks what the remediation costs are					High - relevant to some EU countries		High - Answers at least one research question, conforms with inclusion criteria for that question, within scope boundaries	High - no doubts about the credibility of the source (e.g. peer-reviewed study or renowned institution), robustness and transparency of method, or limitations affecting the validity of results		5.5	general but could be highly relevant to a number of questions	Yes		
84	The top 12 PFAS producers in the world and the staggering societal costs of PFAS pollution	ChemSec	2023	https://chemsec.org/reports/the-top-12-pfas-producers-in-the-world-and-the-staggering-societal-costs-of-pfas-pollution/	General PFAS													Lists some key costs from key sources, and extrapolates to global estimates. Only a few paragraphs.		Very high - relevant to EU as a whole or large parts of EU		High - Answers at least one research question, conforms with inclusion criteria for that question, within scope boundaries	Low - doubts about at least two of credibility of the source (e.g. peer-reviewed study or renowned institution), robustness and transparency of method, or limitations affecting the validity of results	I would consider this an "opinion piece" with no real research. Calculations behind estimates are not transparent.	4	Lack of detail on estimates provided	No		
85	PFAS: A Case Study on its Current Costs and How to Regulate Toxic Chemicals in the Future	Serratos, Isaac	2021	https://repository.uclawf.edu/cgi/viewcontent.cgi?article=1604&context=hashtinas_environmental-law-journal											x				Medium - not directly relevant to EU, but likely transferrable	US	High - Answers at least one research question, conforms with inclusion criteria for that question, within scope boundaries	Low - doubts about at least two of credibility of the source (e.g. peer-reviewed study or renowned institution), robustness and transparency of method, or limitations affecting the validity of results	Author is a second year law student, and journal is his university's. Abstract is not very well written which does not inspire confidence.	3	Don't consider the source credible enough, and the relevant data is from the US and somewhat dated.	No			
86	Prenatal Exposure to Perfluoroalkyl Substances and Birth Outcomes; An Updated Analysis from the Danish National Birth Cohort	Meng et al.	2018	https://pmc.ncbi.nlm.nih.gov/articles/PMC6164159/				x											Medium - not directly relevant to EU, but likely transferrable		High - Answers at least one research question, conforms with inclusion criteria for that question, within scope boundaries	High - no doubts about the credibility of the source (e.g. peer-reviewed study or renowned institution), robustness and transparency of method, or limitations affecting the validity of results		5	ERF	Yes			
87	An Overview of Per- and Polyfluoroalkyl Substances (PFAS) in the Environment: Source, Fate, Risk and Regulations	Abunada et al.	2020	https://www.mdpi.com/2073-4441/12/12/3590		Contains PFAS ranges found in soil and landfill													Medium - not directly relevant to EU, but likely transferrable		High - Answers at least one research question, conforms with inclusion criteria for that question, within scope boundaries	High - no doubts about the credibility of the source (e.g. peer-reviewed study or renowned institution), robustness and transparency of method, or limitations affecting the validity of results		5	Gives some information on PFAS sources and how they enter the environment	Yes			
88	PFAS Molecules: A Major Concern for the Human Health and the Environment	Panieri et al.	2022	https://www.mdpi.com/2305-6304/10/2/44		Contains information on PFAS in several species		Talks about the effects of PFAS species on aquatic species												Medium - not directly relevant to EU, but likely transferrable		High - Answers at least one research question, conforms with inclusion criteria for that question, within scope boundaries	High - no doubts about the credibility of the source (e.g. peer-reviewed study or renowned institution), robustness and transparency of method, or limitations affecting the validity of results		5	Answers 2 research questions and gives a good overview of PFAS in the environment	Yes		

Referen ce ID	Title	Potentially relevant source				PFAS in scope of study	Relevant research sub-questions and summary															Geography		Thematic relevance		Robustness and limitations		Shortlisting																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																				
		Author	Year	Link			1.1 To what extent are humans exposed to PFAS in the EU?	1.2 What PFAS exposure is associated with human health risks?	1.3 What are the observed risk relationships and/or predicted human health impacts from those risks?	1.4 What are the costs associated with the human health impacts?	1.5 What are the geographical and temporal trends in human health costs?	2.1 To what extent are environmental compartments (soil, water, air, and biota) contaminated with PFAS in the EU?	2.2 What are the environmental effects on aquatic and terrestrial species and populations?	2.3 What are the ecosystem-level effects?	2.4 What are the effects on biodiversity?	2.5 What are the monetised ecosystem service costs associated with impacts on species, ecosystems and biodiversity?	2.6 What are the environmental clean-up costs (soil and water remediation/treatme nt costs) and litigation costs?	2.7 What are the geographical and temporal trends in environmental costs?	3.1 What are the methods to calculate the societal costs from PFAS?	3.2 What are the indirect and direct, market and non-market, and one-off and recurring costs of PFAS pollution?	Geographic relevance rating	Notes	Thematic relevance rating (research questions, inclusion criteria, and scope boundaries)	Notes	Robustness rating (source credible, method robust and transparent, significance of limitations)	Score	Justification / explanation for shortlisting or not	Will this source be taken forward for data extraction?																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																				
				V2CDmmlaKp00albY2JWHYySbDdd09pRu8eaT6Xv272O5N3DRSKmYFniL3e9pegbNLvYH0Ev2Xr12KvzYZU%2FpwrUzBW02WkbU%2zBXOgeXf%2FF3P-v40Ecdv6KPSHMvYaMKLDstHg7EiqohABWTCBHssd4lPIOmCjexl0q4MfnzURKK90qZfjYrLqJkEXLGyAkqVuWK3RHgmc8uC9RpMhMTpmp7A7Av%2BoT8QMyymm99D9%2BNKH5p2kWDz5k4oLRLK6tc9b04DIZlDz%2FTCX71INUUcmoP46WncLpibhF11Tz1mdJfgcqt7phwOYMieKOHGkVq%2BxIOecS4%2FvRXADot6bqJU0slpg6%2BNnzE4zo8lq%2BGpeJfb1oGHawVzproF1m.%2B%2zFKbmeIFrudwgcwblqgh%2FIVzahFIMN397kGOtEB1mc%2FyIHn8TsfZWf%2BAelXzmm%2Fqz3wzzokltGatl8mYQvaqC9%2BICpYY%2BISsnBRtTEI66%2BinOXYEzxl917dSPyq9ODU9H1pDn7a0YXlUb%2FvDJsvWVCBQ4TK5noI8lzSc1UgZULyJPS6elB3AN0S796muN1czslmIHmnzuwueXNWGNXxUS4LVJPSrqaoQnckGdZwl9jIkNecdnGGAEyJxJAO4GIUyQx%2FoRTRdQa&X-Amz-Algorithm=AWS4-HMAC-SHA256&X-Amz-Date=20241120T153659Z&X-Amz-Signed-Headers=host&X-Amz-Expires=300&X-Amz-Credential=ASIAQ3PHCVTY553EX5LO%2F20241120%2Fus-east-1%2F53%2Faws4_request&X-Amz-Signature=a83aa1fa1739c47ecc883e8f609e9e90446af8826816f0db9e07d4c546b11bd8hash=9a59b134603285f6ff7bd8796438df1e51a4f0d5b992716171cd5b2b4ecfe8638host=68042c943591013ac2b2430a89b270f6af2c76d8df086a07176afe7c76c2e61&pii=S004896972301444&tid=spdf-712406f0-bc7a-4776-ae10-210766b51193&sid=7a74c10b363c55417f581297234e2afb9d8e9prqb&type=client&soh=d3d3LnNjaVVuY2VkaXJlY3QuY298&ua=01025e01535b5751005b&r=9e5984c8be619401&cc=gb																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																												

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Referen ce ID	Potentially relevant source				PFAS in scope of study	Relevant research sub-questions and summary															Geography		Thematic relevance		Robustness and limitations		Shortlisting	
	Title	Author	Year	Link		1.1 To what extent are humans exposed to PFAS in the EU?	1.2 What PFAS exposure is associated with human health risks?	1.3 What are the observed risk relationships and/or predicted human health impacts from those risks?	1.4 What are the costs associated with the human health impacts?	1.5 What are the geographical and temporal trends in human health costs?	2.1 To what extent are environmental compartments (soil, water, air, and biota) contaminated with PFAS in the EU?	2.2 What are the environmental effects on aquatic and terrestrial species and populations?	2.3 What are the ecosystem-level effects?	2.4 What are the effects on biodiversity?	2.5 What are the monetised ecosystem service costs associated with impacts on species, ecosystems and biodiversity?	2.6 What are the environmental clean-up costs (soil and water remediation/treatment costs) and litigation costs?	2.7 What are the geographical and temporal trends in environmental costs?	3.1 What are the methods to calculate the societal costs from PFAS?	3.2 What are the indirect and direct, market and non-market, and one-off and recurring costs of PFAS pollution?	Geographic relevance rating	Notes	Thematic relevance rating (research questions, inclusion criteria, and scope boundaries)	Notes	Robustness rating (source credible, method robust and transparent, significance of limitations)	Score	Justification / explanation for shortlisting or not	Will this source be taken forward for data extraction?	
97	The HBM4EU chromatex study – Outcomes and impacts on EU policies and occupational health practices	Santonen et al	2023	https://www.sciencedirect.com/science/article/pii/S1438463922001821	Generic PFAS	x	x												Very high - relevant to EU as a whole or large parts of EU	Linked to HBM	Low - Does not answer research questions	Describes policy outcomes	High - no doubts about the credibility of the source (e.g. peer-reviewed study or renowned institution), robustness and transparency of method, or limitations affecting the validity of results		Refers to policy 4 discussions	No		
98	Firefighters' exposure to per-and polyfluoroalkyl substances (PFAS) as an occupational hazard: A review	Mazumder et al	2023	https://www.frontiersin.org/journals/materials/articles/10.3389/fmats.2023.1143411/full	Generic PFAS	x	x												Medium - not directly relevant to EU, but likely transferrable	U.S. blood serum levels	Medium - Answers at least one research question, but does not conform with inclusion criteria for that question, or is not within scope boundaries	Relates to PFAS blood serum levels	High - no doubts about the credibility of the source (e.g. peer-reviewed study or renowned institution), robustness and transparency of method, or limitations affecting the validity of results	Meta analysis	Focus of Q1.1 is European levels 4 only	No		
99	Higher serum concentrations of PFAS among pesticide exposed female greenhouse workers	Andersen et al	2024	https://www.sciencedirect.com/science/article/pii/S1438463923001839	PFOS, PFHxS, PFOA, PFNA, PFDA, FOSA, N-MeFOSAA, N-EFOSAA	x												High - relevant to some EU countries	Results from Denmark only	High - Answers at least one research question, conforms with inclusion criteria for that question, within scope boundaries		High - no doubts about the credibility of the source (e.g. peer-reviewed study or renowned institution), robustness and transparency of method, or limitations affecting the validity of results		Contributes to a sub-group 5.5 population for Q1.1	Yes			
100	Environmental contamination and human exposure to PFASs near a fluorocemical production plant: Review of historic and current PFOA and GenX contamination	Gebbink et al	2020	https://ehp.niehs.nih.gov/doi/full/10.1289/EHP5337	PFOA, PFHxS, PFOS													High - relevant to some EU countries	Italy	High - Answers at least one research question, conforms with inclusion criteria for that question, within scope boundaries	Relates to a population sub-group	High - no doubts about the credibility of the source (e.g. peer-reviewed study or renowned institution), robustness and transparency of method, or limitations affecting the validity of results	Longitudinal monitoring study	Provides up to date results from a key contamination study 5.5 in Europe	Yes			
101	Environmental Substances Associated with Osteoporosis–A Scoping Review	Elonheimo et al	2021	https://www.sciencedirect.com/science/article/pii/S1604120193380010	PFOA, GenX	x												High - relevant to some EU countries	Netherlands	High - Answers at least one research question, conforms with inclusion criteria for that question, within scope boundaries		High - no doubts about the credibility of the source (e.g. peer-reviewed study or renowned institution), robustness and transparency of method, or limitations affecting the validity of results		All studies relate to exposures dating to 5.5 pre-2019	No			
102	Perfluoroalkyl substances in drinking water is associated with increased risk of osteoporotic fractures – A cohort study from Ronneby, Sweden	Xu et al.	2023	https://www.sciencedirect.com/science/article/pii/S0139351220212301	PFOS, PFHxS		x											High - relevant to some EU countries	Sweden	High - Answers at least one research question, conforms with inclusion criteria for that question, within scope boundaries	Osteoporosis	High - no doubts about the credibility of the source (e.g. peer-reviewed study or renowned institution), robustness and transparency of method, or limitations affecting the validity of results		Includes population relevant info on an endpoint and captures the nuance regarding the certainty of the 5.5 endpoint	Yes			
103	Environmental Substances Associated with Osteoporosis–A Scoping Review	Elonheimo et al	2021	https://www.mdpi.com/1660-4601/18/2/738	Generic PFAS													Medium - not directly relevant to EU, but likely transferrable	Global geographic scope	High - Answers at least one research question, conforms with inclusion criteria for that question, within scope boundaries		High - no doubts about the credibility of the source (e.g. peer-reviewed study or renowned institution), robustness and transparency of method, or limitations affecting the validity of results		Provides some information on strength of osteoporosis as an 5 endpoint	Yes			
104	Perfluoroalkyl substances and bone health in young men: a pilot study	DiNisio et al	2019	https://link.springer.com/article/10.1007/s12020-019-02094-4	Generic PFAS			x										Medium - not directly relevant to EU, but likely transferrable	Human health data may be transferable	Medium - Answers at least one research question, but does not conform with inclusion criteria for that question, or is not within scope boundaries		robustness and transparency of method, or limitations affecting the validity of results	Study setup (small sample size, white men) reduces applicability of results	Useful information on mode of action of PFAS 3 and osteoporosis	Yes			
105	Prenatal and postnatal exposure to PFAS and cardiometabolic factors and inflammation status in children from six European cohorts	Papadopoulou et al	2021	https://www.sciencedirect.com/science/article/pii/S1604120210047815	PFOS, PFOA, PFHxS, PFNA, PFUnDA	x												Very high - relevant to EU as a whole or large parts of EU	Relevant to children in Europe	High - Answers at least one research question, conforms with inclusion criteria for that question, within scope boundaries		High - no doubts about the credibility of the source (e.g. peer-reviewed study or renowned institution), robustness and transparency of method, or limitations affecting the validity of results		Used to fill data gap on exposure levels 6 in children	Yes			
106	Limited reproductive impairment in a passerine bird species exposed along a perfluoroalkyl acid (PFAA) pollution gradient	Groffen et al.	2019	https://medialibrary.uantwerpen.be/oldcontent/content/20200507files/Groffen%20et%20al%20202019%20-%20Reproductive%20gradient.pdf	PFAA								x													Not yet rated		
107	Chronic Reproductive Toxicity Thresholds for Northern Bobwhite Quail (Colinus virginianus) Exposed to Perfluorohexanoic Acid (PFHxA) and a Mixture of Perfluorooctane Sulfonic Acid (PFOS) and PFHxA	Dennis et al.	2021	https://pubmed.ncbi.nlm.nih.gov/34102702/	PFHxA, PFOS								x													Not yet rated		
108	Exposure to perfluoroalkyl substances during fetal life and hospitalization for infectious disease in childhood: A study among 1,503 children from the Odense Child Cohort. Environment international, 149, 106395	Dalsager L et al	2021	https://doi.org/10.1016/j.envint.2021.106395	PFOA, PFOS														Medium - not directly relevant to EU, but likely transferrable		High - Answers at least one research question, conforms with inclusion criteria for that question, within scope boundaries		Medium - doubts about one of credibility of the source (e.g. peer-reviewed study or renowned institution), robustness and transparency of method, or limitations affecting the validity of results		4 ERF in EEA paper	Yes		
109	Maternal levels of perfluoroalkyl substances (PFASs) during pregnancy and childhood allergy	Impinen et al.	2019	https://doi.org/10.1016/j.envint.2018.12.041	PFOA, PFOS								x						Medium - not directly relevant to EU, but likely transferrable		High - Answers at least one research question, conforms with inclusion criteria for that question, within scope boundaries		Medium - doubts about one of credibility of the source (e.g. peer-reviewed study or renowned institution), robustness and transparency of method, or		ERF in Obsekov 4 paper	Yes		

Reference ID	Potentially relevant source				PFAS in scope of study	Relevant research sub-questions and summary													Geography		Thematic relevance		Robustness and limitations		Shortlisting	
	Title	Author	Year	Link		1.1 To what extent are humans exposed to PFAS in the EU?	1.2 What PFAS exposure is associated with human health risks?	1.3 What are the observed risk relationships and/or predicted human health impacts from those risks?	1.4 What are the costs associated with the human health impacts?	1.5 What are the geographical and temporal trends in human health costs?	2.1 To what extent are environmental compartments (soil, water, air, and biota) contaminated with PFAS in the EU?	2.2 What are the environmental effects on aquatic and terrestrial species and populations?	2.3 What are the ecosystem-level effects?	2.4 What are the effects on biodiversity?	2.5 What are the monetised ecosystem service costs associated with impacts on species, ecosystems and biodiversity?	2.6 What are the environmental clean-up costs (soil and water remediation/treatment costs) and litigation costs?	2.7 What are the geographical and temporal trends in environmental costs?	3.1 What are the methods to calculate the societal costs from PFAS?	3.2 What are the indirect and direct, market and non-market, and one-off and recurring costs of PFAS pollution?	Geographic relevance	Notes	Thematic relevance rating (research questions, inclusion criteria, and scope boundaries)	Notes	Robustness rating (source credibility, method robust and transparent, significance of limitations)	Score	Justification / explanation for shortlisting or not
111	Effects of perfluoroalkyl and polyfluoroalkyl substances (PFAS) on soil structure and function	Xu et al.	2022	7d3bf437af2e44a43158a5212536fad8f5a57584a14b&hash=5cf53ce96f9638c676a8d84fd0c5464664fbc45089a1cd05eda6abbd11dea5&host=68042c943591013ac2b2430a89a270f6a2c76d8df086a07176afe7c76c2c61&pi=S2666765722000564&id=spdf-89b4bce8-c8ac-4295-b8d2-7f0c70ad5c52&si-d=dc1672c37fc8040fc687c927d8812d0ed61gxrqb&type=client&ts-oh=3a3LnNjaWVUY2VkaXJY3QvY29t&ua=01025e0102045f5c5a53&r=8edf0990aaaeed5b&cc=gbhttps://link.springer.com/article/10.1007/s42832-1007-s42832-022-0143-5	PFOS, PFBS, PFOA																			Not yet rated		
112	Association between serum perfluorinated chemicals and thyroid function in U.S. adults: the National Health and Nutrition Examination Survey 2007-2010	Wen et al.	2013	https://doi.org/10.1210/jc.2013-1282	PFOA, PFOS			x											Medium - not directly relevant to EU, but likely transferrable	High - Answers at least one research question, conforms with inclusion criteria for that question, within scope boundaries		Medium - doubts about one of credibility of the source (e.g. peer-reviewed study or renowned institution), robustness and transparency of method, or limitations affecting the validity of results		ERF in Obsekov 4 paper	Yes	
113	Investigation among U.S. Women Perfluorooctanoic Acid (PFOA) Exposure in Early Life Increases Risk of Childhood Adiposity: A Meta-Analysis of Prospective Cohort Studies	Sun et al.	2018	https://doi.org/10.1289/EHP2619	PFOA				x										Medium - not directly relevant to EU, but likely transferrable	High - Answers at least one research question, conforms with inclusion criteria for that question, within scope boundaries		Medium - doubts about one of credibility of the source (e.g. peer-reviewed study or renowned institution), robustness and transparency of method, or limitations affecting the validity of results		ERF in Obsekov 4 paper	Yes	
114	Prenatal exposure to persistent organic pollutants and child overweight/obesity at 5-year follow-up: a prospective cohort study	Liu et al.	2018	https://doi.org/10.3390/ijerph15102070	PFOA				x										Medium - not directly relevant to EU, but likely transferrable	High - Answers at least one research question, conforms with inclusion criteria for that question, within scope boundaries		Medium - doubts about one of credibility of the source (e.g. peer-reviewed study or renowned institution), robustness and transparency of method, or limitations affecting the validity of results		ERF in Obsekov 4 paper	Yes	
115	Perfluoroalkyl substances and changes in body weight and resting metabolic rate in response to weight-loss diets: A prospective study	Lauritzen et al.	2018	https://doi.org/10.1186/s12940-017-0338-x	PFOS				x										Medium - not directly relevant to EU, but likely transferrable	High - Answers at least one research question, conforms with inclusion criteria for that question, within scope boundaries		Medium - doubts about one of credibility of the source (e.g. peer-reviewed study or renowned institution), robustness and transparency of method, or limitations affecting the validity of results		ERF in Obsekov 4 paper	Yes	
116	Perfluoroalkyl substances and changes in body weight and resting metabolic rate in response to weight-loss diets: A prospective study	Liu et al.	2018	https://doi.org/10.1186/s12940-017-0338-x	PFOA, PFOS					x									Medium - not directly relevant to EU, but likely transferrable	High - Answers at least one research question, conforms with inclusion criteria for that question, within scope boundaries		Medium - doubts about one of credibility of the source (e.g. peer-reviewed study or renowned institution), robustness and transparency of method, or limitations affecting the validity of results		ERF in Obsekov 4 paper	Yes	
117	Perfluoroalkyl chemicals and chronic kidney disease in US adults	Shankar et al.	2011	https://doi.org/10.1093/aje/kwr171	PFOA, PFOS			x											Medium - not directly relevant to EU, but likely transferrable	High - Answers at least one research question, conforms with inclusion criteria for that question, within scope boundaries		High - no doubts about the credibility of the source (e.g. peer-reviewed study or renowned institution), robustness and transparency of method, or limitations affecting the validity of results		ERF in Obsekov 5 paper	Yes	
118	Association between plasma PFOA and PFOS levels and total cholesterol in a middle-aged Danish population	Eriksen et al.	2013	https://doi.org/10.1371/journal.pone.0056969	PFOA, PFOS				x										Medium - not directly relevant to EU, but likely transferrable	High - Answers at least one research question, conforms with inclusion criteria for that question, within scope boundaries		High - no doubts about the credibility of the source (e.g. peer-reviewed study or renowned institution), robustness and transparency of method, or limitations affecting the validity of results		ERF in Obsekov 5 paper	Yes	
119	Exposure to per- and Polyfluoroalkyl Substances and Markers of Liver Injury: A Systematic Review and Meta-Analysis	Costello et al.	2022	https://doi.org/10.1289/EHP10092	PFOA, PFOS, PFNA					x									Medium - not directly relevant to EU, but likely transferrable	High - Answers at least one research question, conforms with inclusion criteria for that question, within scope boundaries		High - no doubts about the credibility of the source (e.g. peer-reviewed study or renowned institution), robustness and transparency of method, or limitations affecting the validity of results		ERF in Obsekov 5 paper	Yes	
120	Association of per- and polyfluoroalkyl substance exposure with fatty liver disease risk in US adults. JHEP reports : innovation in hepatology	Zhang et al.	2023	https://doi.org/10.1016/j.jhepr.2023.100694	PFHxS					x									Medium - not directly relevant to EU, but likely transferrable	High - Answers at least one research question, conforms with inclusion criteria for that question, within scope boundaries		High - no doubts about the credibility of the source (e.g. peer-reviewed study or renowned institution), robustness and transparency of method, or limitations affecting the validity of results		ERF in Obsekov 5 paper	Yes	
121	Critical review on PFOA, kidney cancer, and testicular cancer	Bartell and Vieira	2021	https://doi.org/10.1080/10962247.2021.1909668	PFOA			x											Medium - not directly relevant to EU, but likely transferrable	High - Answers at least one research question, conforms with inclusion criteria for that question, within scope boundaries		High - no doubts about the credibility of the source (e.g. peer-reviewed study or renowned institution), robustness and transparency of method, or limitations affecting the validity of results		ERF in Obsekov 5 paper	Yes	
122	Perfluorochemicals and endometriosis: the ENDO study	Buck Louis et al.	2012	https://doi.org/10.1097/EDE.0b013e31826cc0cf	PFOA					x									Medium - not directly relevant to EU, but likely transferrable	High - Answers at least one research question, conforms with inclusion criteria for that question, within scope boundaries		High - no doubts about the credibility of the source (e.g. peer-reviewed study or renowned institution), robustness and transparency of method, or limitations affecting the validity of results		ERF in Obsekov 5 paper	Yes	
123	Exploring the potential association between brominated diphenyl ethers, polychlorinated biphenyls, organochlorine pesticides, perfluorinated compounds, phthalates, and bisphenol A in polycystic ovary syndrome: a case-control study	Vagi et al.	2014	https://doi.org/10.1186/1472-6823-14-86	PFOA, PFOS						x								Medium - not directly relevant to EU, but likely transferrable	High - Answers at least one research question, conforms with inclusion criteria for that question, within scope boundaries		High - no doubts about the credibility of the source (e.g. peer-reviewed study or renowned institution), robustness and transparency of method, or limitations affecting the validity of results		ERF in Obsekov 5 paper	Yes	
124	Perfluorinated compounds and subfecundity in pregnant women	Whitworth et al.	2012	https://doi.org/10.1097/EDE.0b013e31826cc0cf	PFOA, PFOS					x									Medium - not directly relevant to EU, but likely transferrable	High - Answers at least one research question, conforms with inclusion criteria for that question, within scope boundaries		High - no doubts about the credibility of the source (e.g. peer-reviewed study or renowned institution), robustness and transparency of method, or limitations affecting the validity of results		ERF in Obsekov 5 paper	Yes	
125	Association of perfluoroalkyl substances with	Borghese et al.	2020	0.105789	PFOA, PFOS, PFHxS						x								Medium - not directly relevant to EU, but likely transferrable	High - Answers at least one research question, conforms with inclusion criteria for that question, within scope boundaries		High - no doubts about the credibility of the source (e.g. peer-reviewed study or renowned institution), robustness and transparency of method, or limitations affecting the validity of results		ERF in Obsekov 5 paper	Yes	

Reference ID	Potentially relevant source				PFAS in scope of study	Relevant research sub-questions and summary															Geography relevance rating	Notes	Thematic relevance rating (research questions, inclusion criteria, and scope boundaries)	Robustness and limitations rating (source credible, method robust and transparent, significance of limitations)	Shortlisting	
	Title	Author	Year	Link		1.1 To what extent are humans exposed to PFAS in the EU?	1.2 What PFAS exposure is associated with human health risks?	1.3 What are the observed risk relationships and/or predicted human health impacts from those risks?	1.4 What are the costs associated with the human health impacts?	1.5 What are the geographical and temporal trends in human health costs?	2.1 To what extent are environmental compartments (soil, water, air, and biota) contaminated with PFAS in the EU?	2.2 What are the environmental effects on aquatic and terrestrial species and populations?	2.3 What are the ecosystem-level effects?	2.4 What are the effects on biodiversity?	2.5 What are the monetised ecosystem service costs associated with impacts on species, ecosystems and biodiversity?	2.6 What are the environmental clean- up costs (soil and water remediation/treatme nt costs) and litigation costs?	2.7 What are the geographical and temporal trends in environmental costs?	3.1 What are the methods to calculate the societal costs from PFAS?	3.2 What are the indirect and direct, market and non- market, and one- off and recurring costs of PFAS pollution?	Score					Justification / explanation for shortlisting or not	Will this source be taken forward for data extraction?
126	gestational hypertension and preeclampsia in the MIREC study Perfluoroalkyl and polyfluoroalkyl substances and hypertensive disorders of pregnancy: A systematic review and meta-analysis	Hu et al.	2023	https://doi.org/10.1016/j.envres.2023.116064	PFOA, PFOS, PFHxS			x											Medium - not directly relevant to EU, but likely transferrable	question, within scope boundaries High - Answers at least one research question, conforms with inclusion criteria for that question, within scope boundaries	institution), robustness and transparency of method, or limitations affecting the validity of results High - no doubts about the credibility of the source (e.g. peer-reviewed study or renowned institution), robustness and transparency of method, or limitations affecting the validity of results	5	ERF in Obsekov paper	Yes		
127	Gestational hypertension, preeclampsia, and gestational diabetes mellitus after high exposure to perfluoroalkyl substances from drinking water in Rönneby, Sweden	Ebel et al.	2023	https://doi.org/10.1016/j.envres.2023.117316	PFAS			x											Medium - not directly relevant to EU, but likely transferrable	High - Answers at least one research question, conforms with inclusion criteria for that question, within scope boundaries	High - no doubts about the credibility of the source (e.g. peer-reviewed study or renowned institution), robustness and transparency of method, or limitations affecting the validity of results	5	ERF in Obsekov paper	Yes		
128	Prenatal exposure to endocrine disrupting chemicals and risk of being born small for gestational age: Pooled analysis of seven European birth cohorts	Govarts et al.	2018	https://doi.org/10.1016/j.envint.2018.03.017	PFOA				x										Medium - not directly relevant to EU, but likely transferrable	High - Answers at least one research question, conforms with inclusion criteria for that question, within scope boundaries	High - no doubts about the credibility of the source (e.g. peer-reviewed study or renowned institution), robustness and transparency of method, or limitations affecting the validity of results	5	ERF in EEA paper	Yes		
129	The Navigation Guide - evidence-based medicine meets environmental health: systematic review of human evidence for PFOA effects on fetal growth	Johnson et al.	2014	https://doi.org/10.1289/ehp.130789	PFOA			x											Medium - not directly relevant to EU, but likely transferrable	High - Answers at least one research question, conforms with inclusion criteria for that question, within scope boundaries	High - no doubts about the credibility of the source (e.g. peer-reviewed study or renowned institution), robustness and transparency of method, or limitations affecting the validity of results	5	ERF in Obsekov paper	Yes		
130	Serum Perfluorooctanoic Acid and Birthweight: An Updated Meta-analysis With Bias Analysis	Steenland et al.	2018	https://doi.org/10.1097/EDE.0000000000000903	PFOA				x										Medium - not directly relevant to EU, but likely transferrable	High - Answers at least one research question, conforms with inclusion criteria for that question, within scope boundaries	High - no doubts about the credibility of the source (e.g. peer-reviewed study or renowned institution), robustness and transparency of method, or limitations affecting the validity of results	5	ERF in Obsekov paper	Yes		
131	Small for gestational age-cognitive performance from infancy to adulthood: an observational study. BJOG : an international journal of obstetrics and gynaecology	Eves et al.	2020	https://doi.org/10.1111/1471-0528.16341	N/A - IQ loss associated with SGA					x									Medium - not directly relevant to EU, but likely transferrable	High - Answers at least one research question, conforms with inclusion criteria for that question, within scope boundaries	High - no doubts about the credibility of the source (e.g. peer-reviewed study or renowned institution), robustness and transparency of method, or limitations affecting the validity of results	5	ERF in EEA paper	Yes		
132	HBMAEU results support the Chemicals' Strategy for Sustainability and the Zero-Pollution Action Plan	Vicente et al	2023	https://doi.org/10.1016/j.jiheh.2023.114111	Generic PFAS	x													Very high - relevant to EU as a whole or large parts of EU	Medium - Answers at least one research question, but does not conform with inclusion criteria for that question, or is not within scope boundaries	High - no doubts about the credibility of the source (e.g. peer-reviewed study or renowned institution), robustness and transparency of method, or limitations affecting the validity of results		Contains supporting information relevant to policy context	Yes		
133	Blood and exhaled air can be used for biomonitoring of hydrofluorocarbon exposure	Ernstgard et al	2014	https://www.sciencedirect.com/science/article/pii/S037842741301432X	Hydrofluorocarbons (F-gases)	x													Very high - relevant to EU as a whole or large parts of EU	Medium - Answers at least one research question, but does not conform with inclusion criteria for that question, or is not within scope boundaries	High - no doubts about the credibility of the source (e.g. peer-reviewed study or renowned institution), robustness and transparency of method, or limitations affecting the validity of results	5	Provides evidence of HFC metabolism and that they are below detectable levels after 22 hours	Yes		
134	Disposal methods, health effects and emission regulations for sulfur hexafluoride and its by-products	Parthiban et al	2021	https://www.sciencedirect.com/science/article/pii/S0304389421010712	SF6		x												High - relevant to some EU countries	Medium - Answers at least one research question, but does not conform with inclusion criteria for that question, or is not within scope boundaries	High - no doubts about the credibility of the source (e.g. peer-reviewed study or renowned institution), robustness and transparency of method, or limitations affecting the validity of results	4.5	Summary of SF6 health effects (minimal)	Yes		
135	An overview of environmental hazards and exposure risk of hydrofluorocarbons (HFCs)	Wen-Tien Tsai	2005	https://www.sciencedirect.com/science/article/pii/S0945653505000500	HFCs			x											Medium - not directly relevant to EU, but likely transferrable	Medium - Answers at least one research question, but does not conform with inclusion criteria for that question, or is not within scope boundaries	High - no doubts about the credibility of the source (e.g. peer-reviewed study or renowned institution), robustness and transparency of method, or limitations affecting the validity of results	4	HFCs hazards	Yes		
136	Reproductive and developmental toxicity of hydrofluorocarbons used as refrigerants	Ema et al	2010	https://www.sciencedirect.com/science/article/pii/S0890623809003232?ref=pdf_download&fr=RR-7&rn=966662ab5f81e90b	HFCs				x										High - relevant to some EU countries	Medium - Answers at least one research question, but does not conform with inclusion criteria for that question, or is not within scope boundaries	High - no doubts about the credibility of the source (e.g. peer-reviewed study or renowned institution), robustness and transparency of method, or limitations affecting the validity of results	4.5	HFCs hazards	Yes		
137	Toxicokinetics of 1,1,1,2-tetrafluoroethane (HFC-134a) in male volunteers after experimental exposure	Gunnare et al	2006	https://www.sciencedirect.com/science/article/pii/S0378427406012501	HFCs			x											High - relevant to some EU countries	Medium - Answers at least one research question, but does not conform with inclusion criteria for that question, or is not within scope boundaries	High - no doubts about the credibility of the source (e.g. peer-reviewed study or renowned institution), robustness and transparency of method, or limitations affecting the validity of results	4.5	HFCs hazards	Yes		
138	Human Safety and Pharmacokinetics of the CFC Alternative Propellants HFC-134a (1,1,1,2-Tetrafluoroethane) and HFC 227 (1,1,1,2,3,3,3-Heptafluoropropane) Following Whole-Body Exposure	Emmen et al	2000	https://www.sciencedirect.com/science/article/pii/S02732323000091402	HFCs				x										High - relevant to some EU countries	Medium - Answers at least one research question, but does not conform with inclusion criteria for that question, or is not within scope boundaries	Medium - doubts about one of credibility of the source (e.g. peer-reviewed study or renowned institution), robustness and transparency of method, or limitations affecting the validity of results	3.5	HFCs hazards	Yes		

Reference ID	Title	Potentially relevant source				PFAS in scope of study	Relevant research sub-questions and summary															Geography		Thematic relevance		Robustness and limitations		Shortlisting		
		Author	Year	Link			1.1 To what extent are humans exposed to PFAS in the EU?	1.2 What PFAS exposure is associated with human health risks?	1.3 What are the observed risk relationships and/or predicted human health impacts from those risks?	1.4 What are the costs associated with the human health impacts?	1.5 What are the geographical and temporal trends in human health costs?	2.1 To what extent are environmental compartments (soil, water, air, and biota) contaminated with PFAS in the EU?	2.2 What are the environmental effects on aquatic and terrestrial species and populations?	2.3 What are the ecosystem-level effects?	2.4 What are the effects on biodiversity?	2.5 What are the monetised ecosystem service costs associated with impacts on species, ecosystems and biodiversity?	2.6 What are the environmental clean-up costs (soil and water remediation/treatment costs) and litigation costs?	2.7 What are the geographical and temporal trends in environmental costs?	3.1 What are the methods to calculate the societal costs from PFAS?	3.2 What are the indirect and direct, market and non-market, and one-off and recurring costs of PFAS pollution?	Geographic relevance rating	Notes	Thematic relevance rating (research questions, inclusion criteria, and scope boundaries)	Notes	Robustness rating (source credible, method robust and transparent, significance of limitations)	Score	Justification / explanation for shortlisting or not	Will this source be taken forward for data extraction?		
139	Epidemic of liver disease caused by hydrochlorofluorocarbons used as ozone-sparing substitutes of chlorofluorocarbons	Hoet et al	1997	https://www.thelancet.com/journal/S0140-6736(97)03094-8/fulltext	HFCs		x													High - relevant to some EU countries		Medium - Answers to at least one research question, but does not conform with inclusion criteria for that question, or is not within scope boundaries	Medium - doubts about one of credibility of the source (e.g. peer-reviewed study or renowned institution), robustness and transparency of method, or limitations affecting the validity of results	3.5	HFCs hazards	Yes				
140	Formation of Trifluoroacetic Acid from the Atmospheric Degradation of Hydrofluorocarbon 134a: A Human Health Concern?	Ball et al	1993	https://www.tandfonline.com/doi/pdf/10.1080/1073161X.1993.10467204	TFA		x													High - relevant to some EU countries		Medium - Answers to at least one research question, but does not conform with inclusion criteria for that question, or is not within scope boundaries	Medium - doubts about one of credibility of the source (e.g. peer-reviewed study or renowned institution), robustness and transparency of method, or limitations affecting the validity of results	3.5	TFA hazards	Yes				
141	The Global Threat from the Irreversible Accumulation of Trifluoroacetic Acid (TFA)	Arp et al	2024	https://pubs.acs.org/doi/full/10.1021/acs.est.4c06189	TFA		x													High - relevant to some EU countries		Medium - Answers to at least one research question, but does not conform with inclusion criteria for that question, or is not within scope boundaries	High - no doubts about the credibility of the source (e.g. peer-reviewed study or renowned institution), robustness and transparency of method, or limitations affecting the validity of results	4.5	TFA hazards	Yes				
142	Mammalian toxicity of trifluoroacetate and assessment of human health risks due to environmental exposures	Dekant et al	2023	https://link.springer.com/article/10.1007/s00204-023-03454-y	TFA		x													High - relevant to some EU countries		Medium - Answers to at least one research question, but does not conform with inclusion criteria for that question, or is not within scope boundaries	High - no doubts about the credibility of the source (e.g. peer-reviewed study or renowned institution), robustness and transparency of method, or limitations affecting the validity of results	4.5	TFA hazards	Yes				
143	Are Fluoropolymers Really of Low Concern for Human and Environmental Health and Separate from Other PFAS?	Lohmann et al	2020	https://pubs.acs.org/doi/full/10.1021/acs.est.0c03244	Fluoropolymers		x													High - relevant to some EU countries		Medium - Answers to at least one research question, but does not conform with inclusion criteria for that question, or is not within scope boundaries	High - no doubts about the credibility of the source (e.g. peer-reviewed study or renowned institution), robustness and transparency of method, or limitations affecting the validity of results	4.5	FP hazards	Yes				
144	PTFE-coated non-stick cookware and toxicity concerns: a perspective	Sajid et al	2017	https://link.springer.com/article/10.1007/s11356-017-0085-y	Fluoropolymers		x													High - relevant to some EU countries		Medium - Answers to at least one research question, but does not conform with inclusion criteria for that question, or is not within scope boundaries	High - no doubts about the credibility of the source (e.g. peer-reviewed study or renowned institution), robustness and transparency of method, or limitations affecting the validity of results	4.5	FP hazards	Yes				
145	Toxicology of ultrafine particles: in vivo studies	Oberdurst	2000	https://royalsocietypublishing.org/doi/abs/10.1098/rsos.2000.0680	Fluoropolymers		x													High - relevant to some EU countries		Medium - Answers to at least one research question, but does not conform with inclusion criteria for that question, or is not within scope boundaries	High - no doubts about the credibility of the source (e.g. peer-reviewed study or renowned institution), robustness and transparency of method, or limitations affecting the validity of results	4.5	FP hazards	Yes				
146	Baseline Toxicity Model to Identify the Specific and Nonspecific Effects of Per- and Polyfluoroalkyl Substances in Cell-Based Bioassays	Qin et al.	2024	https://pubs.acs.org/doi/10.1021/acs.est.3c00950	Generic PFAS	This study was recommended by a stakeholder but its focus is on cellular biomarkers rather than overall effects of PFAS on organisms																					Not yet rated			
147	Combined toxicity of perfluoroalkyl substances and microplastics on the sentinel species Daphnia magna: Implications for freshwater ecosystems	Soltanighias et al.	2024	https://www.sciencedirect.com/science/article/pii/S0269749124011850	Generic PFAS							x		x											Not yet rated					
148	Neurotoxic Effects of Mixtures of Perfluoroalkyl Substances (PFAS) at Environmental and Human Blood Concentrations	Rios-Bonilla, K. M., Aga, D. S., Lee, J., König, M., Qin, W., Cristobal, J. R., Atilla-Gokumen, G. E. and Escher, B. I	2024	https://pubmed.ncbi.nlm.nih.gov/39238824/	Generic PFAS								x												Not yet rated					
149	Mixture exposure to PFAS: A relative potency factor approach	Zeilmaker, M., Fragki, S., Verbruggen, E., Bokkers, B. and Lijzen, J.	2018	https://rivm.openrepository.com/server/api/core/bitstreams/8be5e9f6-29c9-495c-9337-6571a082ef1b/content	Generic PFAS								x												Not yet rated					
150	Exposure routes, bioaccumulation and toxic effects of per- and polyfluoroalkyl substances (PFASs) on plants: A critical review	Li et al.	2022	https://pubmed.ncbi.nlm.nih.gov/34592655/	Generic PFAS								x												Not yet rated					
151	An (eco) toxicity life cycle impact assessment framework for per- and polyfluoroalkyl substances	Holmquist, H., Fankke, P., Cousins, I. T., Owsianiak, M., Liagkouridis, I. and Peters, G. M.	2020	https://pubmed.ncbi.nlm.nih.gov/32364377/	PFAAs									x											Not yet rated					
152	Comparative toxicity assessment of alternative versus legacy PFAS: Implications for two primary trophic levels in freshwater ecosystems	Bardhi, A., Simonato, V., Zanella, M., Iori, S., Barbarossa, A., Giantin, M., Dacasto, M., De Liguoro, M. and Pualetto, M	2024	https://www.sciencedirect.com/science/article/abs/pii/S030438942401848X	PFNA, PFBA									x											Not yet rated					
153	Critical Evaluation and Meta-Analysis of Ecotoxicological Data on Per-and Polyfluoroalkyl Substances (PFAS) in Freshwater Species	Wang, L., Yang, T., Liu, X., Liu, J. and Liu, W.	2024	https://pubs.acs.org/doi/10.1021/acs.est.4c04818	PFCA's								x												Not yet rated					
154	A critical review of amphibian per- and polyfluoroalkyl substance ecotoxicity research studies: Identification of screening levels in water and other useful resources for site-specific ecological risk assessments	Pandelides, Z., Conder, J., Choi, Y., Allmon, E., Hoskins, T., Lee, L., Hoverman, J. and Sepulveda, M.	2023	https://academic.oup.com/etc/article/42/10/2078/7729672	PFHxA, PFOS, PFOA and 6:2 FTS	There are sme quant estimates of % decrease in bodymass associated with specific levels of exposure, but these are for northern leopard frogs and at relatively high concentrations																				Not yet rated				
155	Critical evaluation of ECOSAR and E-FAST platforms to predict ecological risks of PFAS	Massarsky, A., Donnell, M. T., de Gandiaga, E., Kozal, J. S., Garnick, L., Kubitz, J. A., Bartell, S. M. and Monnot, A. D.	2022	https://www.sciencedirect.com/science/article/pii/S0167636922000564	PFOA and PFOS	Not reviewed in too much detail as the study derives LC50 and EC50 values. A lot of values of this kind have already been extracted from the ECOTOX Knowledgegebase																				Not yet rated				

Reference ID	Potentially relevant source				PFAS in scope of study	Relevant research sub-questions and summary														Geography		Thematic relevance	Robustness and limitations	Shortlisting		
	Title	Author	Year	Link		1.1 To what extent are humans exposed to PFAS in the EU?	1.2 What PFAS exposure is associated with human health risks?	1.3 What are the observed risk relationships and/or predicted human health impacts from those risks?	1.4 What are the costs associated with the human health impacts?	1.5 What are the geographical and temporal trends in human health costs?	2.1 To what extent are environmental compartments (soil, water, air, and biota) contaminated with PFAS in the EU?	2.2 What are the environmental effects on aquatic and terrestrial species and populations?	2.3 What are the ecosystem-level effects?	2.4 What are the effects on biodiversity?	2.5 What are the monetised ecosystem service costs associated with impacts on species, ecosystems and biodiversity?	2.6 What are the environmental clean-up costs (soil and water remediation/treatment costs) and litigation costs?	2.7 What are the geographical and temporal trends in environmental costs?	3.1 What are the methods to calculate the societal costs from PFAS?	3.2 What are the indirect and direct, market and non-market, and one-off and recurring costs of PFAS pollution?	Geographic relevance rating	Notes	Thematic relevance rating (research questions, inclusion criteria, and scope boundaries)	Robustness rating (source credibility, method robust and transparent, significance of limitations)	Score	Justification / explanation for shortlisting or not	Will this source be taken forward for data extraction?
156	Analysis of the creation of value and hidden costs of synthetic phytosanitary products	BASIC	2021	Not publicly available	n/a																					
157	Ecosystem value database	Luuk Brander	n.d.	https://www.esvd.info/	n/a						x															
158	Serum perfluoroalkyl substances in residents following long-term drinking water contamination from firefighting foam in Ronneby, Sweden	Xu et al	2021	https://www.sciencedirect.com/science/article/pii/S0160412020322881?via%3Dihub	PFOA, PFOS, PFHxS	x													High - relevant to some EU countries		High - Answers at least one research question, conforms with inclusion criteria for that question, within scope boundaries	High - no doubts about the credibility of the source (e.g. peer-reviewed study or renowned institution), robustness and transparency of method, or limitations affecting the validity of results		Contaminated site 5.5 exposures	Yes	
159	Forever chemicals: French company poisoned environment near Lyon for decades, locals claim	Euro News	2023	https://www.lemonde.fr/en/france/article/2023/06/05/arkema-faces-criminal-charges-for-forever-chemical-contamination-in-lyon-region_60291917.html	Generic PFAS		x												High - relevant to some EU countries		Medium - Answers at least one research question, but does not conform with inclusion criteria for that question, or is not within scope boundaries	Medium - doubts about one of credibility of the source (e.g. peer-reviewed study or renowned institution), robustness and transparency of method, or limitations affecting the validity of results		Contaminated site 3.5 exposures	Yes	
160	Arkema faces criminal charges for forever chemical contamination in Lyon region	Le Monde	2023	https://www.researchgate.net/publication/379020767_Trend_of_PFA_S_concentrations_and_prediction_of_potential_risks_in_Taihu_Lake_of_China_by_AQIATOX	Generic PFAS									x					High - relevant to some EU countries		Medium - Answers at least one research question, but does not conform with inclusion criteria for that question, or is not within scope boundaries	Medium - doubts about one of credibility of the source (e.g. peer-reviewed study or renowned institution), robustness and transparency of method, or limitations affecting the validity of results		Contaminated site 3.5 exposures	Yes	
161	Trend of PFAS concentrations and prediction of potential risks in Taihu Lake of China	Ma et al.	2024	https://www.researchgate.net/publication/384291329_Critical_Evaluation_and_Meta-Analysis_of_Ecotoxicological_Data_on_Per-and-Polyfluoroalkyl_Substances_(PFAS)_in_Freshwater_Species	PFOS, PFOA										x											
162	Critical Evaluation and Meta-Analysis of Ecotoxicological Data on Per-and Polyfluoroalkyl Substances (PFAS) in Freshwater Species	Wang et al.	2024	https://www.sciencedirect.com/science/article/pii/S048995724007498	PFCAs, PFSAs									x												
163	Aquatic macroinvertebrate community responses to pollution of perfluoroalkyl substances (PFAS): Can we define threshold body burdens?	Byns	2024	https://www.sciencedirect.com/science/article/pii/S048995724007498	PFOA, PFOS, PFTeDA, PFDoDA, PFTiDA																					
164	Associations between longitudinal serum perfluoroalkyl substance (PFAS) levels and measures of thyroid hormone, kidney function, and body mass index in the Fernald Community Cohort. Environmental pollution (Barking, Essex : 1987).	Blake et al.	2018	https://doi.org/10.1016/j.envpol.2018.07.042	PFOA, PFNA, PFHxS and PFDeA																					
165	Examining the Associations of Perfluorooctanoic Acid Serum Levels with Two Outcomes. Environmental health perspectives.	Dhingra et al.	2017	https://doi.org/10.1289/EHP273	PFOA																					
166	Health. Bone mass density following developmental exposures to perfluoroalkyl substances (PFAS): a longitudinal cohort study. Environmental health : a global access science source	Kai Tao et al.	2024	https://doi.org/10.1186/s12940-022-00923-w	PFOA, PFOS, PFHxS, PFNA																					
167	source, 21(1), 113.	Bloomberg, et al.	2022	https://doi.org/10.1186/s12940-022-00923-w	PFNA																					

B. Additional tables of evidence against research question 2

Several of the sources referenced in Annex B are literature reviews which have sourced PFAS concentrations from other literature. The original references have been highlighted in the screening excel in Annex A.

Table 0-1 overview of PFAS species found in soil samples from literature.

Reference	Geographical scope	Sample taken from	Type of PFAS covered	Type of use / sector responsible for the exposure (if reported)	Type of study (modelling, sampling or monitoring)	Ambient environmental concentrations (mean)	Ambient environmental concentrations (range)	Metric
Nazmul Ehsan et al., 2024	Spain	n/a	PFOA, PFOS, PFNA, PFDA, PFUnDA, PFDoDA, PFHxS, PFBS, and PFHpA.	Industrial/urban discharge	Sampling	n/a	0.22-11.5	ng/g
Panieri et al.2022	Sweden	Lake sediment	PFASs (PFHxS, PFOS and PFBS) and PFCAs (in particular PFHxA)	firefighting facility	Sampling	n/a	range of <1.0 ng/g dw and 76 ng/g dw.	ng/g dw
Panieri et al.2022	Artic Ocean	Sea sediment	PFOS, PFNA and PFBS	Oxidation of consumer products containing PFOS, fluoropolymer transport through	Sampling	n/a	0.06–1.73	ng/g

Reference	Geographical scope	Sample taken from	Type of PFAS covered	Type of use / sector responsible for the exposure (if reported)	Type of study (modelling, sampling or monitoring)	Ambient environmental concentrations (mean)	Ambient environmental concentrations (range)	Metric
				oceanic systems and AFFF				
Nazmul Ehsan et al., 2024	Norway	n/a	11 species	AFFF	Sampling	n/a	0.3-6500	ng/g
Nazmul Ehsan et al., 2024	Norway	n/a	PFOS	AFFF	Sampling	n/a	9--2600	ng/g
Nazmul Ehsan et al., 2024	Finland	n/a	23 species	AFFF	Sampling	n/a	2800	ng/g
Nazmul Ehsan et al., 2024	Ireland	n/a	5 species	Landfill	Sampling	n/a	0.15-6	ng/g
Nazmul Ehsan et al., 2024	Netherlands	n/a	PFOS+PFOA	Atmospheric deposition near fluoropolymer plant	Sampling	n/a	3.3	ng/g
Nazmul Ehsan et al., 2024	France	n/a	11 PFAS species	Atmospheric deposition near fluoropolymer plant	Sampling	n/a	42-347	ng/g

Reference	Geographical scope	Sample taken from	Type of PFAS covered	Type of use / sector responsible for the exposure (if reported)	Type of study (modelling, sampling or monitoring)	Ambient environmental concentrations (mean)	Ambient environmental concentrations (range)	Metric
Nazmul Ehsan et al., 2024	n/a	Plant sample	PFBA/PFOA	n/a	Modelling	n/a	100	ng/g, dw
Nazmul Ehsan et al., 2024	n/a	Plant sample	PFOA/PFBS	n/a	Modelling	n/a	500	ng/g, dw
Nazmul Ehsan et al., 2024	n/a	plant roots and shoots	PFOA	n/a	Appears to be a model (closed source)	n/a	>800000	ng/g, dw
Nazmul Ehsan et al., 2024	n/a	wheat seedlings	PFOA	n/a	Appears to be a model	n/a	>200000	ng/g, dw
Moghadasi et al. 2023		n/a	PFAS (general)	Areas affected by high-density PFAS point sources	Modelling	n/a	Over 40,000 ng/kg in Belgium/France/Germany/the Netherlands with around 30,000 ng/kg in central and Western Europe.	ng/kg
Drenning et al. 2023³⁷⁴	Sweden	n/a	13 PFAS species	Airport	Sampling	n/a	The sum total of the 13 analysed PFAS compounds ranged from 0.63 ng g ⁻¹ to 2700 ng g ⁻¹	ng-g-1

³⁷⁴ Drenning et al (2023) Comparison of PFAS soil remediation alternatives at a civilian airport using cost-benefit analysis. Available at: <https://www.sciencedirect.com/science/article/pii/S0048969723022842>

Reference	Geographical scope		Sample taken from	Type of PFAS covered	Type of use / sector responsible for the exposure (if reported)	Type of study (modelling, sampling or monitoring)	Ambient environmental concentrations (mean)	Ambient environmental concentrations (range)	Metric
								dw. (PFOS made up 88% of the PFAS compounds)	
ECHA, 2023	Netherlands		Sediment	PFOS	n/a	Modelling	n/a	0.07-1.	ng/l
ECHA, 2023	North Sea and Baltic Sea	Sea	Sediment	PFBA, PFHxA, PFHpA, PFOA, PFOS	n/a	Sampling	PFBA- 0.11 PFHxA-n/a PFHpA-n/a PFOA-n/a PFOS-n/a	PFBA-nd-0.54 PFHxA-nd-0.06 PFHpA-nd-0.12 PFOA-nd-0.65 PFOS-nd-0.39 (L), nd-0.03 (Br)	ng/g
Kotthoff et al. 2020	Germany		n/a	Short-chain PFCA Long-chain PFCA Short-chain PFSA Long-chain PFSA PFOSA-like	Baden-Wuerttemberg incident site in South West Germany (used as comparison)	One annual pool sample per Environmental Specimen Bank site (a cryo-archive, which contains samples from terrestrial, freshwater and coastal ecosystems. The soil from these specimen banks	Short-chain PFCA: 8.4 ± 6.63 Long-chain PFCA: 1.15 ± 0.88 Short-chain PFSA: <0.5 Long-chain PFSA: 1.77 ± 1.98 PFOSA-like: 0.07 ± 0.12		$\mu\text{g kg}^{-1}$

Reference	Geographical scope	Sample taken from	Type of PFAS covered	Type of use / sector responsible for the exposure (if reported)	Type of study (modelling, sampling or monitoring)	Ambient environmental concentrations (mean)	Ambient environmental concentrations (range)	Metric
					were then compared to soil samples from a contaminated site in South-West Germany.			
Kotthoff et al. 2020	Germany	n/a	Short-chain PFCA Long-chain PFCA Short-chain PFSA Long-chain PFSA PFOSA-like	Baden-Wuerttemberg incident site in South West Germany (used as comparison)	One annual pool sample per Environmental Specimen Bank site (a cryo-archive, which contains samples from terrestrial, freshwater and coastal ecosystems. The soil from these specimen banks were then compared to soil samples from a contaminated site in South-West Germany.	Short-chain PFCA: 31.4± 26.1 Long-chain PFCA: 246± 191 Short-chain PFSA: <0.5 Long-chain PFSA : 78.7± 95.1 PFOSA-like:75.65± 126	n/a	µg kg ⁻¹

Reference	Geographical scope	Sample taken from	Type of PFAS covered	Type of use / sector responsible for the exposure (if reported)	Type of study (modelling, sampling or monitoring)	Ambient environmental concentrations (mean)	Ambient environmental concentrations (range)	Metric
Drenning et al. 2023	Sweden	n/a	26 PFAS species	firefighting training sites at civilian and military airports	Sampling	n/a	Range from 20 to 160	ng/g-l
Arp et al., 2024.	China (Fuxin)	n/a	TFA	n/a	Monitoring	TFA-305.7	TFA-13-2400	ng/g dw
Arp et al., 2024.	China (northern, Beijing-Tianjin-Hebei)	n/a	TFA	n/a	Monitoring	TFA-3.510	TFA-0.435-16.7	ng/g dw
Arp et al., 2024.	China	n/a	TFA	n/a	Monitoring	TFA-0.792	TFA-0.059-2.081	ng/g dw
Arp et al., 2024.	China (Fuxin)	Sediment	TFA	n/a	Monitoring	TFA- 65.12	TFA-4.9-200	ng/g dw

Table 0-2 overview of PFAS species found in waterbodies from literature.

Reference	Geographical scope	Sample taken from	Type of PFAS covered	Type of use / sector responsible for the exposure (if reported)	Type of study (modelling, sampling or monitoring)	Ambient environmental concentrations (mean)	Ambient environmental concentrations (range)	Metric
ECHA, 2023	Switzerland	Lakes and Rivers	PFAAs (TFA)	n/a	Sampling	rivers: 87 Midland lakes: 119 mountain lakes:141 Moor water: 107	rivers: 12-328 Midland lakes: 37-204 mountain lakes:6-97 Moor water:59-175	ng/l
ECHA, 2023	Sweden	Snow, rain and rivers	PFAAs (PFETs and PFPrS)	Airports and training facilities	Sampling	n/a	PFETs- n.d- 2.9 PFPrS n.d-1.4	ng/l
ECHA, 2023	Netherlands	n/a	PFOS, PFOPA	n/a	Assumed to be modelling	n/a	PFOS: 3.3-25 PFOPA nd- ~1	ng/l
ECHA, 2023	Germany	n/a	PFAAs (TFA)	n/a	not sure. Modelling it appears/	500	NR-17000	ng/l
ECHA, 2023	German Bight	n/a	PFBA, PFPeA , PFHxA, PFHpA, PFOA,	n/a	Sampling	PFBA-1.5 PFPeA-0.4 PFHxA-0.84	PFBA- 1.1-2.2 PFPeA-0.27-0.64 PFHxA-0.47-1.3	ng/l

			PFBS, PFHxS, PFOS, HFPOD		PFHpA-0.28 PFOA-0.5 PFBS-0.55 PFHxS-0.16 PFOS-0.044 (L) 0.039 (Br) HFPOD-1.6	PFHpA-0.17-0.45 PFOA-0.27-0.71 PFBS-0.44-0.72 PFHxS-0.12-0.23 PFOS-0.02-0.08 (L), 0.02-0.08 (Br) HFPOD- 0.92-2.5	
ECHA, 2023	Elbe	River	PFBA, PFPeA , n/a PFHxA, PFHpA, PFOA, PFBS, PFHxS, PFOS, PFECCHS, HFPOD	Sampling	PFBA-1.5 PFPeA-1.1 PFHxA-3.1 PFHpA-0.88 PFOA-1.4 PFBS-0.75 PFHxS-0.32 PFOS-0.2 (L), 0.17 (Br) PFECCHS-n/a HFPOD-0.4	PFBA- 1.2-1.9 PFPeA- 0.65-1.7 PFHxA-1.5-4.6 PFHpA-0.48-1.2 PFOA-0.87-2.1 PFBS-0.43-0.99 PFHxS-0.22-0.49 PFOS-0.1-0.33 (L), 0.06-0.28 (Br) PFECCHS-nd-0.06 HFPOD-0.07-1.5	ng/l
ECHA, 2023	Baltic sea	Ocean	PFBA, PFPeA , n/a PFHxA, PFHpA, PFOA, PFBS, PFHxS, PFOS, PFECCHS, HFPOD	Sampling	PFBA-0.46 PFPeA-0.16 PFHxA-0.32 PFHpA-0.2 PFOA-0.32 PFBS-0.25	PFBA- 0.33-0.99 PFPeA- 0.1-0.75 PFHxA-0.22-0.84 PFHpA-0.13-0.38 PFOA-0.2-0.7 PFBS-0.15-0.43	ng/l

						PFHxS-0.25 PFOS-0.043 (L), 0.05 (Br) PFECHS- 0.06 HFPOD-0..05	PFHxS-nd-0.48 PFOS-0.02-0.08 (L), 0.03-0.1 (Br) PFECHS-nd-0.14 HFPOD-0.03-0.08	
ECHA, 2023	Germany/ Netherlands (Rhine River)	River	PFBA, PFPeA , PFHxA, PFHpA, PFOA, PFBS, PFHxS, PFOS, HFPOD	n/a	n/a	PFBA-1.7 PFPeA- 4.7 PFHxA-2.7 PFHpA-1.9 PFOA-4.8 PFBS-1.6 PFHxS-1.8 PFOS-.12 HFPOD-n/a	PFBA-0.2-2.7 PFPeA- 3.2-11 PFHxA-1.8-5.4 PFHpA-1.2-2.9 PFOA-3.5-7.1 PFBS-1.4-40 PFHxS-0.8-3.6 PFOS-nd-2.7 HFPOD-nd-108	ng/l
ECHA, 2023	Germany (Elbe river)	River	PFBA, PFPeA , PFHxA, PFHpA, PFOA, PFBS, PFHxS, PFOS, HFPOD	n/a	n/a	PFBA-1 PFPeA-2.4 PFHxA-2.8 PFHpA-0.6 PFOA-2 PFBS-2.3 PFHxS-0.8 PFOS-n/a	PFBA-nd-1.9 PFPeA- 0.4-4.8 PFHxA-1.5-4.1 PFHpA-nd-1.8 PFOA-0.8-3.6 PFBS-0.8-3.6 PFHxS-0.3-1.4 PFOS-nd-11	ng/l
ECHA, 2023	Germany (Elbe	Sea	PFBA, PFPeA , PFHxA,	n/a	n/a	PFBA-1	PFBA-0.3-1.8	ng/l

	estuary/ North sea)		PFHpA, PFOA, PFBS, PFHxS, PFOS, HFPOD			PFPeA-0.8 PFHxA-1.9 PFHpA-0.6 PFOA-1.6 PFBS-1.1 PFHxS-0.5 PFOS-n/a HFPOD-n/a	PFPeA- 0.2-1.4 PFHxA-0.4-4 PFHpA-nd-1.3 PFOA-0.4-5.1 PFBS-0.7-1.6 PFHxS-0.1-1 PFOS-nd-2.6 HFPOD-nd-3.7	
ECHA, 2023	Germany, (Ems estuary/ North sea)	estuary	PFBA, PFPeA , PFHxA, PFHpA, PFOA, PFBS, PFHxS, PFOS, HFPOD	n/a	n/a	PFBA-n/a PFPeA- n/a PFHxA-1.3 PFHpA-2.8 PFOA-4.6 PFBS-1.2 PFHxS-0.4 PFOS-n/a HFPOD-n/a	PFBA- nd-3.7 PFPeA- nd-3.8 PFHxA-0.3-4.4 PFHpA-nd-8.4 PFOA-1.4-12 PFBS-0.6-2.7 PFHxS-nd-1.6 PFOS-nd-0.8 HFPOD-nd-2	ng/l
ECHA, 2023	Greenland Sea, Norwegian Sea, North Sea , Fram strait	Sea	PFHxA, PFHpA, PFOA, PFBS, PFHxS, PFOS, PFHpS, PFECBS, 6:2 CI PFESA, HFPOD	n/a	Sampling?	PFHxA-0.056 PFHpA-0.04 PFOA-0.066 PFBS-0.039 PFHxS-n/a PFHpS-n/a	PFHxA-.0.017-0.11 PFHpA-0.02-0.1 PFOA-0.038-0.17 PFBS-0.015-0.093 PFHxS-nd-0.054 PFHpS-<0.03	ng/l

						PFOS-0.042	PFOS-nd-0.11	
						PFECHS-n/a	PFECHS-<0.02	
						6:2 Cl-PFESA-n/a	6:2 Cl PFESA-<0.02	
						HFPODA-0.03	HFPOD-nd-0.12	
ECHA, 2023	North Atlantic Ocean	Ocean	PFAAs (TFA)	n/a	Sampling	n/a	70-250	ng/l
ECHA, 2023	Spain	n/a	PFBA, PFPeA, PFHxA, PFHpA, PFOA, PFHxS, PFOS	n/a	Sampling	PFBA-30 PFPeA-n/a PFHxA-n/a PFHpA-n/a PFOA-13 PFHxS-n/a PFOS-n/a	PFBA-nd-125 PFPeA-nd-13 PFHxA-nd-31 PFHpA-nd-27 PFOA-nd-58 PFHxS-nd-37 PFOS-nd-2709	ng/l
ECHA, 2023	England	River	PFBA, PFPeA, PFHxA, PFHpA, PFOA, PFBS, PFHxS, PFOS, 6:2 Cl-PFESA, HFPODA	n/a	Sampling	PFBA-7 PFPeA-16 PFHxA-12 PFHpA-4.1 PFOA-8.5 PFBS-5.1 PFHxS-7.1 PFOS-14 6:2 Cl-PFESA-0.05	PFBA-4.6-9.8 PFPeA-10-20 PFHxA-7.3-15 PFHpA-2.6-5.2 PFOA-5.6-12 PFBS-3.3-6.7 PFHxS-5.0-11 PFOS-8.1-19 6:2 Cl-PFESA-0.001-0.08	ng/l

							HFPODA-1.1	HFPODA-0.7-1.6	
Panieri et al., 2022	Mediterranean Sea	Sea	15 different PFAS substances (PFHxA, PFHpA, PFOA, PFHxS and PFO mainly appeared)	Manufacturers of PFAS	Sampling	n/a		0.246–0.515	ng/l
Panieri et al., 2022	Eastern Sea	Red Sea (coastal)	11 different PFAS species (mainly-PFHxA, PFHxS, and 6:2 FTS were the most prevalent substances)	local industries or firefighting training facilities near WWTP	Sampling	n/a		Concentrations up to 956 ng/L	ng/l
Drenning et al 2023	Sweden	Groundwater	26 PFAS species	Firefighting training sites	Sampling			Groundwater samples at the locations showed concentrations ranging from 1200 to 34,000.	ng/l-1
Miljøstyrelsen, 2014	Denmark	Groundwater	PFHpA, PFOA, PFBS, PFOS, PFHxA	Fire drill site	Monitoring	PFHpA-34 PFOA- 22 PFBS-10 PFOS- 15 PFHxA-75		n/a	ng/l

Miljøstyrelsen, 2014	Denmark	Groundwater	PFHpA, PFOA, PFOS, PFHxS	Fire drill site	Monitoring	PFHpA-11 PFOA- 120 PFOS-17	PFHxS- 14-220	ng/l
Miljøstyrelsen, 2014	Denmark	Groundwater	PFHpA, PFOA, PFNA, PFBS, PFHxS, PFOS, PFHxS	Fire drill site	Monitoring	n/a	PFHpA-1100-1800 PFOA-340-710 PFNA-13-98 PFBS-17-20 PFHxS-34-55 PFOS-37-45 PFHxA-2700-5300	ng/l
Miljøstyrelsen, 2014	Denmark	Groundwater	PFOA	Fire drill site	Monitoring	PFOA-85	n/a	ng/l
Miljøstyrelsen, 2014	Denmark	Groundwater	PFHpA, PFOA, PFOS,	Fire drill site	Monitoring	PFHpA,-20 PFOA-20 PFHxS-100 PFOS-980	n/a	ng/l
JRC, 2022	EU (unless specified)	Surface water	PFBA, PFBS, PFHxA, PFOA, PFPeA	n/a	Monitoring	n/a	PFBA (IT)- <5-333.2 PFBS (IT)- <1-1666 PFHxA- 3-32 PFOA- 3.4-200 PFPeA (IT)-<2-584.7	ng/l

JRC, 2022	EU (unless specified)	Groundwater	PFBA, PFHxA, PFPeA	PFBS, PFOA, n/a	Monitoring	PFBA (IT)-8 PFBS- <LOQ PFBS (IT)- 1 PFHxA- 21 PFOA-3 PFOA (IT)-936 PFPeA (IT)- 2	n/a	ng/l
Arp et al., 2024.	Germany	Precipitation	TFA	n/a	Monitoring	TFA-335	TFA- 4-1200	ng/l
Arp et al., 2024.	Germany	Precipitation	TFA	n/a	Monitoring	TFA-104.5	TFA- 18-300	ng/l
Arp et al., 2024.	Germany (Neckar river)	Surface water (rivers and streams)	TFA	n/a	Monitoring	TFA- n/a	TFA-1000-140000	ng/l
Arp et al., 2024.	Sweden	Surface water (rivers and streams)	TFA	n/a	Monitoring	TFA-n/a	TFA-<34-14000	ng/l
Arp et al., 2024.	Sweden	Surface water (rivers and streams)	TFA	n/a	Monitoring	TFA-n/a	TFA-<34-2700	ng/l
Arp et al., 2024.	Germany	Surface water (rivers and streams)	TFA	n/a	Monitoring	TFA-480-1200	TFA-480-17000	ng/l
Arp et al., 2024.	Germany	Surface water (rivers and streams)	TFA	n/a	Monitoring	TFA-1913	TFA-300-6000	ng/l

Arp et al., 2024.	Germany	Surface water (rivers and streams)	TFA	n/a	Monitoring	TFA-1938	TFA-400-124000	ng/l
Arp et al., 2024.	Sweden	Surface water (lakes)	TFA	n/a	Monitoring	TFA-n/a	TFA-<34-74	ng/l
Arp et al., 2024.	Sweden	Groundwater	TFA	n/a	Monitoring	TFA-n/a	TFA-<34-120	ng/l
Arp et al., 2024.	Germany	Groundwater	TFA	n/a	Monitoring	TFA-640-2300	TFA-640-7500	ng/l
Arp et al., 2024.	Germany	Groundwater	TFA	n/a	Monitoring	TFA-5720	TFA-800-10700	ng/l
Arp et al., 2024.	Germany	Surface water	TFA	Waste water	Monitoring	TFA-n/a	TFA-570-1300	ng/l
Arp et al., 2024.	Sweden	Surface water	TFA	Waste water (STP effluent)	Monitoring	TFA-n/a	TFA-110-200	ng/l
Arp et al., 2024.	Sweden	Surface water	TFA	Waste water (Paper mill effluent)	Monitoring	TFA-n/a	TFA-33-51	ng/l
Arp et al., 2024.	Sweden	Surface water	TFA	Landfill leachate	Monitoring	TFA-2400	TFA-<34-6900	ng/l
Brandsma et al., 2019.	The Netherlands (Dordrecht)	Surface water	PFHxA, PFHpA, PFOA, PFBS, Gen X	Distance from a fluoropolymer factory	Monitoring	PFHxA-3.0 PFHpA- 2.1 PFOA-2.4 PFBS- 2.5 Gen X-3.1	n/a	ng/l

Brandsma et al., 2019.	The Netherlands (Rotterdam)	Surface water	PFPeA, PFHxA, PFHpA, PFOA, PFBS, PFHxS, PFOS, Gen X	Distance from a fluoropolymer factory	Monitoring	PFPeA-5.1 PFHxA-5.6 PFHpA-3.1 PFOA-3.9 PFBS-4.8 PFHxS-0.6 PFOS-1.3 Gen X-5.9	n/a	ng/l
Brandsma et al., 2019.	The Netherlands (Spijkenisse)	Surface water	PFPeA, PFHxA, PFHpA, PFOA, PFBS, PFHxS, PFOS, Gen X	Distance from a fluoropolymer factory	Monitoring	PFPeA-4.9 PFHxA-5.9 PFHpA-3.0 PFOA-4.0 PFBS-4.9 PFHxS-0.7 PFOS-1.3 Gen X-5.9	n/a	ng/l
Brandsma et al., 2019.	The Netherlands (Goedereede)	Surface water	PFHxA, PFHpA, PFOA, PFBS, PFHxS, PFOS, Gen X	Distance from a fluoropolymer factory	Monitoring	PFHxA-4.4 PFHpA-3.2 PFOA-5.2 PFBS-9.6 PFHxS-1.3 PFOS-2.6	n/a	ng/l

								Gen X-1.8	
Brandsma et al., 2019.	et	The Netherlands (Albasserdam)	Surface water	PFBA, PFHXA, PFOA, PFBS, PFOS, Gen X	Distance from a fluoropolymer factory	Monitoring	PFBA-8.6	n/a	ng/l
							PFHXA-1.6		
							PFOA-7.1		
							PFBS-10.0		
							PFOS-1.1		
							Gen X-8.0		
Brandsma et al., 2019.	et	The Netherlands (Gouda)	Surface water	PFBA, PFHxA, PFOA, PFBS, PFOS, Gen X	Distance from a fluoropolymer factory	Monitoring	PFBA-10	n/a	ng/l
							PFHxA-2.1		
							PFOA-1.9		
							PFBS-11.0		
							PFOS-1.2		
							Gen X-1.4		

Table 0-3 overview of PFAS species found in air values from literature.

Reference	Geographical scope	Sample taken from	Type of PFAS covered	Type of use / sector responsible for the exposure (if reported)	Type of (modelling, sampling monitoring)	study or	Ambient environmental concentrations (mean)	Ambient environmental concentrations (range)	Metric
ECHA, 2023	Spain	Indoor houses	air-	FTOHs, FOSAs	n/a	Sampling	8:2FTOH: 42	6:2FTOH: 2.0-47 8:2FTOH: 7.5-170 10:2 FTOH: <0.6-47 ΣFTOHs: 13-234	pg/m3
ECHA, 2023	Germany-Munich	indoor schools	air-	FTOHs, FOSAs, FOSEs and FTACs	n/a	Sampling/modelling	6:2FTOH: 3 342 8:2FTOH: 4 435 10:2FTOH: 1 807 EtFOSA- 243 MeFOSE-n/a 6:2FTACS: n/a 8:2FTAC: 448 10:2FTAC: 307	6:2FTOH: 1428-46 867 8:2FTOH: 2480-13 888 10:2FTOH: 1166-4 774 EtFOSA- <LOD-692 MeFOSE: <LOD-2604 6:2FTACS: <LOD-2 604	pg/m3

									8:2FTAC: LOD-47739)		
									10:2FTAC: <LOD-17360)		
ECHA, 2023	Germany-Munich	Indoor houses	air-	FTOHs, FOSAs, FOSEs and FTACs	n/a	Sampling/modelling	6:2FTOH: 1808	6:2FTOH: 5424	289-	pg/m3	
							8:2FTOH: 8679	8:2FTOH: 4702-			
							10:2FTOH: 2531	21698			
							MeFOSA-n/a	10:2FTOH: 759-			
							EtFOSA-n/a	10306			
							MeFOSE- n/a	MeFOSA-<LOD-166			
							EtFOSE-66	EtFOSA-<LOD-119			
							8:2FTAC- 271				
							10:2 FTAC- 123	MeFOSE- <LOD-3796			
								EtFOSE- <LOD-155			
								8:2FTAC- 58-1040			
								10:2 FTAC- <LOD-560			

ECHA, 2023	Norway-Oslo	Indoor houses	air-	FTOHs, FOSAs, FOSEs	n/a	n/a	4:2FTOH:n/a	4:2FTOH:<LOQ- 38	pg/m3
							6:2FTOH: 933	6:2FTOH: 63-9414	
							8:2FTOH: 5 173	8:2FTOH: 921-25	
							10:2FTOH: 2 822	10:2FTOH: 377- 28 898	
							MeFOSA: 82	MeFOSA: <LOQ- 70	
							EtFOSA: n/a	EtFOSA: <LOQ- 95	
							MeFOSE: 265	MeFOSE: 63-1 433	
							EtFOSE: 78	EtFOSE: 3.7-338	
ECHA, 2023	Norway- Tromsø	Indoor houses	air-	FTOHs, FOSAs, FOSEs	n/a	Sampling	4:2FTOH:21	4:2FTOH:<16-34	pg/m3
							6:2FTOH: 42	6:2FTOH: 16-332	
							8:2FTOH: 10005	8:2FTOH: 3373- 11109	
							10:2FTOH: 3405	10:2FTOH: 1 231-5 901	
							NMeFOSA: 37	NMeFOSA: 9.2- 224	
							NEtFOSA: 29		

							NMeFOSE: 846				
							NEtFOSE: 156		NEtFOSA: 7.4-104		
									NMeFOSE: 222-1288		
									NEtFOSE: 65-333		
ECHA, 2023	Norway-Oslo	Indoor houses	air-	FTOHs, FOSAs, FOSEs	n/a	Sampling	6:2FTOH: 2970	6:2FTOH: 604-101000		pg/m3	
							8:2FTOH: 10400	8:2FTOH: 1220-446000			
							10:2FTOH: 3120				
							MeFOSA: n/a	10:2FTOH: 697-255000			
							EtFOSA: n/a	MeFOSA: <35-78300			
							MeFOSE: 134	EtFOSA: <35-1350			
ECHA, 2023	n/a	Personal (dust exposure within a home over 24hrs)	air	FTOHs, FOSAs, FOSEs	n/a	Sampling	6:2FTOH: 1970	6:2FTOH: 543-37000		pg/m3	
							8:2FTOH: 7170	8:2FTOH: 2690-57800			
							10:2FTOH: 1590				
							MeFOSA: n/a	10:2FTOH: 170-9000			
							EtFOSA: n/a	MeFOSA: <70-			

								MeFOSE: n/a	225	
								EtFOSE: n/a	EtFOSE: <70	
									MeFOSE: <350-1105	
									EtFOSE: <350	
ECHA, 2023	Germany	Indoor Offices	air-	FTOHs	n/a	Sampling	n/a		4:2 FTOH-<LOD	pg/m3
									6:2 FTOH-150-650	
									8:2 FTOH -250-830	
									10:2 FTOH-110-290	
ECHA, 2023	Germany	Indoor Kitchen (commercial)	air-	FTOHs	n/a	Sampling	n/a		4:2 FTOH-<LOD	pg/m3
									6:2 FTOH-240	
									8:2 FTOH -270	
									10:2 FTOH-110	
ECHA, 2023	Germany	Indoor air-Metal workplace		FTOHs	n/a	Sampling	n/a		4:2 FTOH-<LOD	pg/m3
									6:2 FTOH-280	
									8:2 FTOH -360	
									10:2 FTOH-160	

ECHA, 2023	Germany	Indoor air- lacquering	Car	FTOHs	n/a	Sampling	n/a	4:2 FTOH-<LOD 6:2 FTOH-9910 8:2 FTOH -1890 10:2 FTOH-800	pg/m3
ECHA, 2023	Germany	Indoor air-Sport Shop		FTOHs	n/a	Sampling	n/a	4:2 FTOH-<LOD 6:2 FTOH-1070- 6180 8:2 FTOH -12450- 17980 10:2 FTOH-3620- 5150	pg/m3
ECHA, 2023	Germany	Indoor air- Carpet shop		FTOHs	n/a	Sampling	n/a	4:2 FTOH-<LOD 6:2 FTOH-35960 8:2 FTOH -26150 10:2 FTOH-9640	pg/m3
ECHA, 2023	Artic Alert Station	Canada Outdoor air		PFBA, PFPeA, PFHxA, ,PFHpA, PFOA, PFBS, PGHxS,	n/a	Sampling	PFBA-3.6 PFPeA-n/a PFHxA-n/a PFHpA-0.055	PFBA -<LOD-29 PFPeA-<LOD- 0.19 PFHxA -<LOD- 0.39	pg/m3

			PFOS , PFNS			PFOA-0.19 .066PFBS- PFHxS-n/a PFOS-0.19 PFNS-n/a	PFHpA-<LOD-0.47 PFOA-<LOD-1.3 PFBS-<LOD-1.5 PFHxS-<LOD-0.62 PFOS -<0.006-2.8 PFNS-<LOD-0.022	
ECHA, 2023	Canada	Reference site (for comparison with the sites in Canada below)	PFBA, PFPeA, PFHxA, PFHpA , PFOA, PFOS	n/a	n/a, appears to be an overview of monitoring data?	PFBA-44 PFPeA-<0.26 PFHxA-2.2 PFHpA-3.7 PFOA-7.4 PFOS-3.0	n/a	pg/m3
ECHA, 2023	Canada	Above WWTPs (in comparison with the sample site above)	PFBA, PFPeA, PFHxA, PFHpA , PFOA, PFOS	Wastewater treatment	n/a, appears to be an overview of monitoring data?	PFBA-89 PFPeA-11 PFHxA-33 PFHpA-11	PFBA-55-116 PFPeA-3.4-24 PFHxA-10-63 PFHpA-3.3-20	pg/m3

							PFOS-112	PFOS-43-171	
ECHA, 2023	Canada	Above Landfills (in comparison with the sample site above)	PFBA, PFPeA, PFHxA, PFHpA, PFOA, PFOS	Landfill	n/a, appears to be an overview of monitoring data?		PFBA-101 PFPeA-11 PFHxA-35 PFHpA-10 PFOA-25 PFOS-3.9	PFBA-101-102 PFPeA-2.7-20 PFHxA-7.2-62 PFHpA-2.5-18 PFOA-3.0-4.6 PFOS-3.2-4.6	pg/m3
ECHA, 2023	China	fluorochemical production plant (incl. production TFA)	TFA	fluorochemical producer	Monitoring around China	4106 ± 1780	n/a		pg/m3
ECHA, 2023	China	Upwind, down-wind or above landfills	TFA, PFPrA, PFBA, PFPeA, PFHxA, PFHpA, PFOA, PFBS, PFHxS, PFOS	Landfill	n/a, appears to be an overview of monitoring data?	n/a		TFA- 1400-3000 PFPrA - 64-360 PFBA 190-590 PFHxA-3.6-24 PFHpA-7-54 PFOA-22-100 PFBS-4.8-70	pg/m3

							PFHxS - <0.02-4.2 PFOS- 4.4-23	
Arp et al., 2024.	China (Beijing)	n/a	TFA	n/a	Monitoring	TFA-1459	TFA-n/a-6317	pg/m3
Arp et al., 2024.	China (Fuxin)	n/a	TFA	n/a	Monitoring	TFA-48875	TFA- 1900-170000	pg/m3
Arp et al., 2024.	Bohai and Yellow Seas	n/a	TFA	n/a	Monitoring	TFA-120	TFA- 11-270	pg/m3
Arp et al., 2024.	China	n/a	TFA	n/a	Monitoring	TFA-	TFA-1400-3000	pg/m3
Arp et al., 2024.	China (Beijing)	n/a	TFA	n/a	Monitoring	TFA-1459	TFA-n/a	pg/m3
Arp et al., 2024.	China (Beijing)	n/a	TFA	n/a	Monitoring	TFA-1712	TFA-n/a	pg/m3
Arp et al., 2024.	China (Beijing)	n/a	TFA	n/a	Monitoring	TFA-1162	TFA-n/a	pg/m3
Arp et al., 2024.	China (Beijing)	n/a	TFA	n/a	Monitoring	TFA-n/a	TFA-283-6317	pg/m3
Arp et al., 2024.	China	n/a	TFA	n/a	Monitoring	TFA-3684.9	TFA-892-6816	pg/m3
Arp et al., 2024.	China (Fuxin)	Dust (outdoors)	TFA	n/a	Monitoring	TFA-4524.2	TFA- 65-29000	ng/g dw
Arp et al., 2024.	China	Dust (outdoors)	TFA	n/a	Monitoring	TFA-n/a	TFA- 1100-3700	ng/g dw
Arp et al., 2024.	China (northern)	Dust (outdoors)	TFA	n/a	Monitoring	TFA-133.3	TFA-21.5-348	ng/g dw

	Beijing-Tianjin-Hebei)							
Arp et al., 2024.	China	Dust (outdoors)	TFA	n/a	Monitoring	TFA-123.5	TFA-n.d-827	ng/g dw
Arp et al., 2024.	China	Dust (outdoors)	TFA	n/a	Monitoring	TFA-28.25	TFA-n.d-1136	ng/g dw
Arp et al., 2024.	China	Dust (Indoor)	TFA	n/a	Monitoring	TFA-270.3	TFA-16-895	ng/g dw
Arp et al., 2024.	USA (Indiana)	Dust (Indoor)	TFA	n/a	Monitoring	TFA-n/a	TFA-n.d.-1400	ng/g dw

Table 0-4 overview of PFAS species found in biota samples from literature.

Source	Geographical region	Sample taken from	Type of PFAS covered	Type of use / sector responsible for the exposure (if reported)	Type of study (modelling, sampling monitoring) or	Ambient environmental concentrations (mean)	Ambient environmental concentrations (range)	Metric

Nazmul Ehsan et al. 2024	n/a	grass root	PFHpA, PFOA, PFNA, PFDA, PFUnDA, PFDoDA	Contaminated site (FP manufacturer)	n/a appears to be sampling	61	n/a	ng/g, dw
Nazmul Ehsan et al. 2024	n/a	grass leaf	PFHpA, PFOA, PFNA, PFDA, PFUnDA, PFDoDA	Contaminated site (FP manufacturer)	n/a appears to be sampling	68	n/a	ng/g, dw
Nazmul Ehsan et al. 2024	n/a	tree leaf	PFHpA, PFOA, PFNA, PFDA, PFUnDA, PFDoDA	Contaminated site (FP manufacturer)	n/a, appears to be sampling	430	n/a	ng/g, dw
Nazmul Ehsan et al. 2024	n/a	Straw	PFBA, PFPeA, PFHxA, PFHpA, PFOA, PFNA, PFDA, PFUnA, PFTeA, PFBS, PFHxS, PFOS.	Site contaminated by biosolids	Modelling	n/a	36.2-178	ng/g, dw

Nazmul Ehsan et al. 2024	n/a	Husks	PFBA, PFPeA, PFHxA, PFHpA, PFOA, PFNA, PFDA, PFUnA, PFTeA, PFBS, PFHxS, PFOS.	Biosolids	Modelling in a field site	n/a	6.15-37.8	ng/g, dw
Nazmul Ehsan et al. 2024	n/a	Grains	PFBA, PFPeA, PFHxA, PFHpA, PFOA, PFNA, PFDA, PFUnA, PFTeA, PFBS, PFHxS, PFOS.	Biosolids	Modelling in a field site	n/a	7.32-35.6	ng/g, dw
Nazmul Ehsan et al. 2024	n/a	Roots	PFBA, PFPeA, PFHxA, PFHpA, PFOA, PFNA, PFDA, PFUnA, PFTeA,	Biosolids	Modelling in a field site	n/a	140-472	ng/g, dw

				PFBS, PFHxS, PFOS.					
Nazmul Ehsan et al. 2024	n/a	Earthworm	C8-C14	Biosolids	Modelling in a field site	n/a	9.88-99.86	ng/g, dw	
Nazmul Ehsan et al. 2024	n/a	Sediment-Benthic Organism (worms)	14 PFAS species	n/a	Bioaccumulation modelling test	2216.7	n/a	ng/g, dw	
Nazmul Ehsan et al. 2024	n/a	Sediment-Benthic Organism (worms)	14 PFAS species	n/a	Bioaccumulation modelling test	61.7	n/a	ng/g, dw	
Nazmul Ehsan et al. 2024	n/a	Sediment-Benthic Organism (worms)	14 PFAS species	n/a	Bioaccumulation modelling test	21.1	n/a	ng/g, dw	
Nazmul Ehsan et al. 2024	n/a	Sediment-Benthic Organism (worms)	7 PFAS species	n/a	Sampling	31.65	n/a	ng/g, dw	
Nazmul Ehsan et al. 2024	n/a	Sediment-Benthic Organism (worms)	7 PFAS species	n/a	Sampling	27	n/a	ng/g, dw	
Nazmul Ehsan et al. 2024	n/a	Sediment-Benthic Organism (worms)	7 PFAS species	n/a	Sampling	13.4	n/a	ng/g, dw	

Nazmul Ehsan et al. 2024	n/a	Sediment-Benthic Organism (worms)	7 PFAS species	n/a	Sampling	11.37	n/a	ng/g, dw
Peritore et al. 2023	Norway and the UK	Barnacle geese	PFOS	n/a	n/a	1.21 ± 2.97	n/a	ng/g
Peritore et al. 2023	Norway and the UK	White tailed eagle nestlings	PFOS	n/a	Sampling	n/a	4.58 e 52.94	ng/mL
Peritore et al. 2023	Greenland, Norwegian Artic	Polar Bears	PFOS, PFNA, PFUnDA	n/a	Sampling	PFOS- 205 PFNA- 37.6 PFUnDA- 25.5		ng/mL
Peritore et al. 2023	Sweden	Cattle	PFOS	n/a	Modelling I believe using Swedish cows	n/a	3	ng/mL
Peritore et al. 2023	Germany/Netherlands	Sheep	PFOS	n/a		103 and 240 µg/L (Pilot study after exposure to 1.16–1.45 µg/kg bw/d)		µg/L
Panieri et al. 2022	France	filter-feeding shellfish	PFCAs	n/a		1.36	n/a	ng/g ww
Panieri et al. 2022	Mediterranean Sea	sharks and rays species	PFTTrDA	n/a		27.1	n/a	ng/g ww
Kotthoff et al 2020	Germany	Tree leaves (taken from Environmental Specimen Bank)	Short-chain PFCA Long-chain PFCA	n/a	One annual pool sample per Environmental Specimen Bank site. This was exposed to PFAS	Short-chain PFCA: 2.58± 0.96 Long-chain PFCA: 0.03± 0.09	n/a	µg kg ⁻¹

				Short-chain PFSA Long-chain PFSA PFOSA-like ³⁷⁵		from an incident site, and a spike matrix was used.	Short-chain PFSA: <0.5 Long-chain PFSA : 0 PFOSA-like: 0.13± 0.23		
Kotthoff et al 2020	Germany	Tree (taken from Environmental Specimen Bank))	Shoots from	Short-chain PFCA Long-chain PFCA Short-chain PFSA Long-chain PFSA PFOSA-like	n/a	One annual pool sample per Environmental Specimen Bank site. This was exposed to PFAS from an incident site, and a spike matrix was used.	Short-chain PFCA: 7.66± 4.41 Long-chain PFCA: 0.03± 0.09 Short-chain PFSA: n.d Long-chain PFSA: 0.03± 0.09 PFOSA-like: 0	n/a	µg kg ⁻¹
Kotthoff et al 2020	Germany	Earthworm (taken from Environmental Specimen Bank)		Short-chain PFCA Long-chain PFCA Short-	n/a	One annual pool sample per Environmental Specimen Bank site. This was exposed to PFAS from an incident	Short-chain PFCA: 0.13± 0.14 Long-chain PFCA: 0 Short-chain PFSA: n.d	n/a	µg kg ⁻¹

³⁷⁵ Short-chain PFCA: PFPrA, PFBA, PFPeA, PFHxA. Long-chain PFCA: PFHpA, PFOA, PFNA, PFDA, PFUnDA, PFDoDA, PFTrDA, PFTeDA, PFHxDA, PFODA. Short-chain PFSA: PFBS. Long-chain PFSA: PFHxS; PFHpS; PFOS; PFDS. PFOSA-like substances: FOSAA, N-MeFOSAA; N-EtFOSAA, PFOSA, N-MeFOSA-M, N-EtFOSA-M. FTS: 4:2 FTS, 6:2 FTS, 8:2 FTS. PAP: 6:2 PAP, 8:2 PAP, 6:2 diPAP, 8:2 diPAP, 10:2 diPAP, 6:2/8:2 diPAP, 8:2/10:2 diPAP

			chain PFSA Long- chain PFSA PFOSA- like		site, and a spike matrix was used.	Long-chain PFSA :<0.5 PFOSA-like: 0		
Kotthoff et al 2020	Germany	Roe Deer liver (taken from Environmental Specimen Bank)	Short- chain PFCA Long- chain PFCA Short- chain PFSA Long- chain PFSA PFOSA- like	n/a	One annual pool sample per Environmental Specimen Bank site. This was exposed to PFAS from an incident site, and a spike matrix was used.	Short-chain PFCA: 0.06± 0.13 Long-chain PFCA: 0.41± 0.65 Short-chain PFSA: n.d. Long-chain PFSA : 1.11± 0.39 PFOSA-like: 0	n/a	µg kg ⁻¹
Kotthoff et al 2020	Germany	Zebra mussel (taken from Environmental Specimen Bank)	Short- chain PFCA Long- chain PFCA Short- chain PFSA Long- chain PFSA	n/a	One annual pool sample per Environmental Specimen Bank site. This was exposed to PFAS from an incident site, and a spike matrix was used.	Short-chain PFCA: 0.24±0.49 Long-chain PFCA: 0 Short-chain PFSA: n.d Long-chain PFSA :<0.5	n/a	µg kg ⁻¹

				PFOSA-like			PFOSA-like:0.63 ±0.44		
Kotthoff et al 2020	Germany	Bream (taken from Environmental Specimen Bank)	liver from	Short-chain PFCA Long-chain PFCA Short-chain PFSA Long-chain PFSA PFOSA-like	n/a	One annual pool sample per Environmental Specimen Bank site. This was exposed to PFAS from an incident site, and a spike matrix was used.	Short-chain PFCA:0.11 ±0.20 Long-chain PFCA: 20.8±14.3 Short-chain PFSA: n.d. Long-chain PFSA : 145±88.6 PFOSA-like: 2.21±1.31	n/a	µg kg ⁻¹
Kotthoff et al 2020	Germany	Bladder wrack		Short-chain PFCA Long-chain PFCA Short-chain PFSA Long-chain PFSA PFOSA-like	n/a	One annual pool sample per Environmental Specimen Bank site. This was exposed to PFAS from an incident site, and a spike matrix was used.	Short-chain PFCA: 3.48±0.48 Long-chain PFCA: 0 Short-chain PFSA :n.d Long-chain PFSA :0 PFOSA-like:0	n/a	µg kg ⁻¹
Kotthoff et al 2020	Germany	Eelpout filet		Short-chain	n/a	One annual pool sample per	Short-chain PFCA: <0.5	n/a	µg kg ⁻¹

				PFCA Long-chain PFCA Short-chain PFSA Long-chain PFSA PFOSA-like		Environmental Specimen Bank site. This was exposed to PFAS from an incident site, and a spike matrix was used.	Long-chain PFCA: 1.38 ±1.59 Short-chain PFSA: n.d. Long-chain PFSA : 6.53 ±4.0 PFOSA-like: 1.67±1.65		
Kotthoff et al 2020	Germany	Herring eggs	gull	Short-chain PFCA Long-chain PFCA Short-chain PFSA Long-chain PFSA PFOSA-like	n/a	One annual pool sample per Environmental Specimen Bank site. This was exposed to PFAS from an incident site, and a spike matrix was used.	Short-chain PFCA: 0 Long-chain PFCA: 8.03±2.04 Short-chain PFSA: n.d. Long-chain PFSA : 37.0±1.48 PFOSA-like: 0.13±0.18	n/a	µg kg ⁻¹
Giara et al 2024	Italy	Bleak		PFBS PFHxS PFHpS PFOS PFBA PFPeA PFHxA	n/a	Sampling	PFBS:0 PFHxS:<LOQ PFHpS: <LOQ PFOS:62.2	n/a	µg kg ⁻¹

			PFHpA			PFBA:<LOQ		
			PFOA			PFPeA:<LOQ		
			PFNA			PFHxA:<LOQ		
			PFDA			PFHpA: <LOQ		
			PFUnDA			PFOA: <LOQ		
			PFDoDA			PFNA:0.5		
			PFTTrDA			PFDA:13.6		
			PFTeDA			PFUnDA:13.8		
						PFDoDA:5.8		
						PFTTrDA:4.6		
						PFTeDA:1.6		
Giara et al 2024	Italy	Channel catfish	PFBS	n/a	sampling	PFBS:0.1	n/a	ng/g w.w
			PFHxS			PFHxS:<LOQ		
			PFHpS			PFHpS:<LOQ		
			PFOS			PFOS:45.0		
			PFBA			PFBA:<LOQ		
			PFPeA			PFPeA:0.1		
			PFHxA			PFHxA:<LOQ		
			PFHpA			PFHpA: <LOQ		
			PFOA			PFOA: 0.4		
			PFNA			PFNA:0.2		
			PFDA			PFDA:4.9		
			PFUnDA			PFUnDA:2.1		
			PFDoDA					
			PFTTrDA					
			PFTeDA					

						PFDODA:1.3		
						PFTTrDA:1.0		
						PFTeDA:0.1		
Giara et al 2024	Italy	Batnel	PFBS	n/a	sampling	PFBS:<LOQ	n/a	ng/g w.w
			PFHxS			PFHxS:<LOQ		
			PFHpS			PFHpS:<LOQ		
			PFOS			PFOS:20.5		
			PFBA			PFBA:<LOQ		
			PFPeA			PFPeA:0.6		
			PFHxA			PFHxA:<LOQ		
			PFHpA			PFHpA: <LOQ		
			PFOA			PFOA: 0.4		
			PFNA			PFNA:<LOQ		
			PFDA			PFDA:2.6		
			PFUnDA			PFUnDA:9.1		
			PFDODA			PFDODA:7.5		
			PFTTrDA			PFTTrDA:5.3		
			PFTeDA			PFTeDA:1.3		
Giara et al 2024	Italy	intestinal parasites	PFBS	n/a	sampling	PFBS: <LOQ	n/a	ng/g w.w
			PFHxS			PFHxS:<LOQ		
			PFHpS			PFHpS:<LOQ		
			PFOS			PFOS:13.1		
			PFBA			PFBA:<LOQ		
			PFPeA					

				PFHpA PFOA PFNA PFDA PFUnDA PFDoDA PFTTrDA PFTeDA			PFPeA:2 PFHxA:<LOQ PFHpA: <LOQ PFOA: 0.4 PFNA:<LOQ PFDA:1.8 PFUnDA:4 PFDoDA:7.2 PFTTrDA:6.2 PFTeDA:0.9		
Arp et al., 2024.	Germany (different origin)	Rosemary	TFA	n/a	Monitoring		TFA-n/a-48000	ng/g dw	
Arp et al., 2024.	China (Fuxin)	Willow, Maize, Chinese juniper	TFA	n/a	Monitoring	TFA-448062.5	TFA-3900-3800000	ng/g dw	
Arp et al., 2024.	China	Chinese pine, Oriental plane, White poplar	TFA	n/a	Monitoring	TFA-n/a	TFA-276-717	ng/g dw	
Arp et al., 2024.	China (northern, Beijing-Tianjin-Hebei)	Poplar (leaves)	TFA	n/a	Monitoring	TFA-533	TFA-274-748	ng/g dw	
Arp et al., 2024.	China (northern, Beijing-Tianjin-Hebei)	Maize (leaves)	TFA	n/a	Monitoring	TFA-516.8	TFA-11.8-149	ng/g dw	
Arp et al., 2024.	China (northern, Beijing-Tianjin-Hebei)	Maize (straws)	TFA	n/a	Monitoring	TFA-74.8	TFA-15.8-102	ng/g dw	
Arp et al., 2024.	China (northern, Beijing-Tianjin-Hebei)	Maize (kernels)	TFA	n/a	Monitoring	TFA-62.1	TFA-n/a	ng/g dw	

Arp et al., 2024.	Germany	European beech (leaves)	TFA	n/a	Monitoring	TFA-312	TFA-n/a	ng/g dw
Arp et al., 2024.	Germany	Lombardy poplar (leaves)	TFA	n/a	Monitoring	TFA-1060	TFA-n/a	ng/g dw
Arp et al., 2024.	Germany	Norway spruce (leaves)	TFA	n/a	Monitoring	TFA-538	TFA-n/a	ng/g dw
Arp et al., 2024.	Germany	Scots pine (leaves)	TFA	n/a	Monitoring	TFA-453	TFA-n/a	ng/g dw
Arp et al., 2024.	Germany	European beech (leaves)	TFA	n/a	Monitoring	TFA-24.6	TFA-n/a	ng/g dw
Arp et al., 2024.	Germany	Lombardy poplar (leaves)	TFA	n/a	Monitoring	TFA-156	TFA-n/a	ng/g dw
Arp et al., 2024.	Germany	Norway spruce (leaves)	TFA	n/a	Monitoring	TFA-42.8	TFA-n/a	ng/g dw
Arp et al., 2024.	Germany	Scots pine (leaves)	TFA	n/a	Monitoring	TFA-98.5	TFA-n/a	ng/g dw
Arp et al., 2024.	China (northern, Beijing-Tianjin-Hebei)	Locusts	TFA	n/a	Monitoring	TFA-65.12	TFA-4.9-200	ng/g dw
Brandsma et al., 2019.	Netherlands	Grass (50m from site)	PFPeA, PFOA, Gen X	Fluoropolymer manufacturer	Monitoring	PFPeA-0.7 PFOA-11.0 Gen X-27.0	n/a	ng/g w/w
Brandsma et al., 2019.	Netherlands	Grass (3000m from site)	PFOA, Gen X	Fluoropolymer manufacturer	Monitoring	PFOA-0.7 Gen X-1.0	n/a	ng/g w/w
Brandsma et al., 2019.	Netherlands	Leaves (50m from site)	PFBA, PFOA,	Fluoropolymer manufacturer	Monitoring	PFBA-42.0 PFOA-28.0 PFBS-0.5	n/a	ng/g w/w

			PFBS, Gen X			Gen X-86.0	
Brandsma et al., 2019.			PFBA, PFHpA, PFOA, PFBS, Gen X	Fluoropolymer manufacturer	Monitoring	PFBA-3.5 PFHpA-0.5 PFOA-16 PFBS-0.5 Gen X-4.3	ng/g w/w
Netherlands	Leaves (3000m from site)					n/a	

Table 23 Summary of PFAS hazard effect thresholds based on the US EPA Ecotox Knowledgebase

Type	Substance acronym	Ecotox average LC50 (AI mg/L)	Terrestrial average LC50	Ecotox average EC50 (AI mg/L)	Terrestrial average EC50
PFAAs	TFA	1535	No data	4784	No data
	PFBS	2268	794 uM	3150	No data
	PFPeA	464	No data	412	No data
	PFHxA	1474	No data	1147	No data
	PFHxS	11	No data	12	121.5 uM
	PFHpA	771	No data	810	No data
	PFHpS	76	No data	76	No data
	PFOA	267	576 mg/kg*	208	332 mg/kg*
	PFOS	52	394 mg/kg*	52	118.25 mg/kg soil*
	PFNA	124	No data	139	0.9 mM
	PFDA	85	No data	92	0.3 mM
	PFDS	135	No data	112	No data
	PFUnDA	47	No data	44	No data
	PFDoDA	85	No data	85	No data
	PFTTrDA	No data	No data	No data	No data
	PFTeDA	116	No data	116	No data
Precursors to PFAA	PFHxPA	No data	No data	No data	No data
	FOSA	No data	No data	No data	No data
	6:2 DiPAP	No data	No data	No data	No data
F-gases	SF6	No data	No data	No data	No data
	HFC143a	No data	No data	No data	No data
	HFC 134a	818	No data	No data	No data
	HFC245fa	No data	No data	No data	No data
	HFC152a	No data	No data	No data	No data
	HFC125a	No data	No data	No data	No data
	Halothane	60	No data	47	No data
	HCFC123	No data	No data	No data	No data
	HCFC124	No data	No data	No data	No data
	Desflurane	No data	No data	No data	No data

Type	Substance acronym	Ecotox average LC50 (AI mg/L)	Terrestrial average LC50	Ecotox average EC50 (AI mg/L)	Terrestrial average EC50
	Isoflurane	31	No data	11	No data
	Sevoflurane	32	No data	32	No data
Fluoro-polymers	PTFE	No data	No data	No data	No data
	PVDF	No data	No data	No data	No data

*Unless specified, mg/kg includes a combination of mg/kg (dry) soil, mg/kg diet, and mg/kg body weight. For these entries, data using other units were excluded.

Annex B – Task 2 report (method development)

1. Introduction	3
1.1. This report.....	3
1.2. Project context	3
1.3. Task 2 purpose, scope, and method.....	3
2. How this report builds on Task 1.....	4
2.1. Purpose of this section.....	4
2.2. Summary of relevant findings from Task 1 concerning the human health costs of PFAS pollution	5
2.3. Summary of relevant findings from Task 1 concerning the environmental costs of PFAS pollution.....	8
2.3.1. State of the evidence on environmental impacts that incur direct costs	8
2.3.2. Possible ways to directly assess ecosystem service impacts	10
2.3.3. Proxies to estimate ecosystem service impacts and other environmental costs ..	11
3. Recommended methodology to update and expand the existing knowledge on the societal costs of PFAS pollution in the EEA.....	12
3.1. Purpose of this section.....	12
3.2. Recommended methods for human health cost assessment.....	13
3.2.1. Existing estimates of human health costs from PFAS pollution in Europe	13
3.2.2. Stepwise methodology proposed	14
3.2.3. Data inputs required.....	36
3.2.4. Gaps, assumptions and limitations.....	36
3.3. Recommended methods for environmental cost assessment.....	38
3.3.1. Existing estimates of environmental costs from PFAS pollution	38
3.3.2. Proposed methodology: Direct ecosystem service costs (category 1)	39
3.3.3. Proposed methodology: Remediation/treatment costs (category 2).....	40
3.3.4. Data inputs required	48
3.3.5. Gaps, assumptions and limitations	49
4. Sensitivity analysis.....	50
4.1. Purpose of this section	50
4.2. Overview of the horizontal approach.....	50
4.3. Approach for human health costs	50
4.4. Approach for environmental costs.....	53
4.4.1. Direct ecosystem services	53
4.4.2. Remediation / treatment costs	53

5. Exposure assessment (Task 3).....	54
5.1. Purpose of this section.....	54
5.2. Proposed approach for Task 3.....	54
5.2.1. Evolution of approach from proposal.....	54
5.2.2. Background context to exposure assessment	55
5.2.3. Approach	55
5.2.4. Data input requirements.....	59
5.2.5. Gaps, assumptions, and limitations	59
Appendices to Annex B.....	61
A. Brief comparative analysis of different valuation methods.....	62
B. Reference willingness-to-pay values of disease burden associated with chemical exposure.....	64
C. Ecosystem services potentially affected by PFAS and how they will be considered in Task 4	76
D. Remediation and treatment costs – literature overview	81
E. Modelling prospective scenarios to feed into the cost assessments (Task 3)	86

1. Introduction

1.1. This report

WSP and Ricardo are supporting DG ENV with a **study on the cost of PFAS pollution for our society**¹ under framework contract ENV.01/FRA/2023/0006 *Economic analysis of environmental policies and analytical support in the context of Better Regulation* led by Trinomics B.V.

This is the **'Task 2 Report'**, which provides an interim project deliverable setting out a methodology to estimate the societal costs of PFAS pollution in the European Economic Area (EEA). This methodology triangulates the available evidence identified as part of the literature review and interviews (Task 1) and the prospective PFAS pollution scenarios (Task 3) to provide up-to-date monetary estimates of the costs of current (i.e., accumulated until present time) and future total PFAS pollution for the whole EU society and EEA region.

1.2. Project context

The objective of this study is to complement and update the existing sources of information (such as the Goldenman *et al.* (2019) study for the Nordic Council of Ministers²) on the overall external costs of PFAS pollution in the EU and in the EEA. More specifically, the objective of this contract is to present information on all components of the societal costs of PFAS pollution, expressed in monetary terms and based on an up-to-date list of impacts of PFAS on the environment and human health. This assessment will describe not only the cost of current pollution but also the future costs under a limited number of prospective scenarios representing hypothetical future developments, hence showing the current and future costs of inaction compared to alternative levels of action.

The project is organised in the following tasks:

- Task 1: Literature review of existing studies on the costs of PFAS pollution and identification of possible knowledge gaps
- Task 2: Development of a methodology to update and expand the existing knowledge on societal costs of current and future PFAS pollution in the EEA
- Task 3: Development of 4 prospective scenarios representing hypothetical PFAS future pollution levels in EEA
- Task 4: Assessment of the societal costs of current and future PFAS pollution (up to 2050, under hypothetical future scenarios)

1.3. Task 2 purpose, scope, and method

This task aims to develop a methodology able to produce up-to-date monetary estimates of the costs of current (i.e., accumulated until present time) PFAS pollution based on the

¹ Specific Contract No 090202/2024/924706/ENV.B2

² Goldenman *et al.* (2019). *The cost of inaction: A socioeconomic analysis of environmental and health impacts linked to exposure to PFAS*. Available at: [THE COST OF INACTION](#)

available evidence (Task 1) and future total PFAS pollution for the whole EU society and EEA region, under different scenarios (Task 3).

The Table below summarises the scope of the methods and, thus, overall study.

Study dimension	Scope description
Geographies	EEA
Timeline	Present day (2025) up to 2050 under hypothetical, prospective scenarios (Task 3).
Base year	All monetary figures will be presented in constant, 2024 euros
Substances	There might be more than 10,000 per- and poly-fluoroalkyl substances (PFAS). ³ This study focusses on a selection of acids (PFAAs) and precursors to acids, polymeric PFAS and fluorinated gases on which there is the necessary evidence, including some of the most common substances (i.e., PFOA, PFOS, PFHxS, TFA and PTFE, PVDF) as agreed with the Commission.

The human health and environmental costs that will be included in this assessment will be based on the outputs of Task 1, and the extent to which there is evidence to quantify and monetise the impacts attributable to PFAS pollution in the EEA.

The approach we have taken to determine the most effective methodology to achieve the aims of this study has been to:

- Firstly, we have identified the key sources for the analysis and monetisation of human health and environmental costs of PFAS pollution, summarised in Section 2 and a separate Task 1 Report.
- Secondly, we have defined the methodologies that are recommended to be taken forward to achieve the objectives of the Study, summarised in Section 3.
- Thirdly, we have further specified the proposed approach to conduct sensitivity analysis, presented in Section 4.
- Lastly, we have set out the proposed methodology to Task 3 in Section 5.

2. How this report builds on Task 1

2.1. Purpose of this section

This section presents a summary of key outputs from the literature review and interviews (Task 1) and sets out how these play a role in the methodological recommendations included in this Report.

³ ECHA (2023). ECHA publishes PFAS restriction proposal. <https://echa.europa.eu/-/echa-publishes-pfas-restriction-proposal>

2.2. Summary of relevant findings from Task 1 concerning the human health costs of PFAS pollution

Firstly, the outputs of the literature review and interviews undertaken as part of this Study have resulted in an evidence base of human exposure to PFAS, the health risks associated with this, observed and/or studied risk relationships, available assessment of human health impacts and monetary costs associated with this exposure and risks, and geographical and historical trends. These findings are presented in the Task 1 Report and summarised on the Table below.

Table 2-1 Research findings against Question 1 'What are the human health costs of PFAS pollution?'

Research questions	Findings
1.1 To what extent are humans exposed to PFAS in the EU?	Recent (2019-2024) human biomonitoring studies have found levels of PFAS in the blood serum of different EU population groups. There is more evidence of legacy PFAAs (PFOA, PFOS, PFNA, PFHxS), when compared to other, less regulated substances (e.g., PFPeA, PFHxA, etc). ⁴
1.2 What PFAS exposure is associated with human health risks?	Studies suggest that the following human health endpoints are associated with PFAS exposure confidently: respiratory infections, autoimmune thyroid disease, liver diseases, reproductive disorders (low sperm count/mobility), maternal/neonatal risks (gestational hypertension, decreased foetal growth, low birth weight). ⁵ There are other human health outcomes that are associated with PFAS exposure less confidently, such as diabetes.
1.3 What are the observed risk relationships and/or predicted human health impacts from those risks?	There is literature evidence quantifying risk-relationships for infections, autoimmune disorders, musculoskeletal disorders, cardiovascular disease risk factors, chronic kidney disease, non-alcoholic fatty liver disease, cancers, reproductive disorders and maternal/neonatal risks. Confidence in these risk-relationships varies.⁶ Other links to health risks remain more suggestive or speculative and lack quantified risk-relationships. Only a few studies identified have quantified the human health impacts that could be attributable to PFAS exposure, and this is primarily in terms of events or days of ill health, attributable incident or prevalent cases, Disability-Adjusted Life Years (DALYs), and preventable deaths.
1.4 What are the costs associated with the human health impacts?	A few studies, such as Goldenman <i>et al.</i> (2019) for the Nordic Council of Ministers and Obsekov, Kahn and Trasande (2023), have developed estimates of the potential human health costs of PFAS. The EEA study by Plass <i>et al.</i> (2023) identifies the burden of disease for a subset of European countries; however, this burden is not monetised.

⁴ Sources are detailed on the Task 1 Report, including HMB4EU and related studies such as Richterova *et al.* (2023), Uhl *et al.* (2023), Fabelova *et al.* (2023); and other studies such as Andersen *et al.* (2024), Goen *et al.* (2023), Palesova *et al.* (2023), Plass *et al.* (2023), Rihackova *et al.* (2023), DeLuca *et al.* (2022), Papadopoulou *et al.* (2021), Gebbink *et al.* (2020), Pitter *et al.* (2020), Poothong *et al.* (2020), Balk *et al.* (2019), etc.

⁵ Sources are detailed on the Task 1 Report, including Mahdavi *et al.* (2024), Pan *et al.* (2023), Pinney *et al.* (2023), Plass *et al.* (2023), Xu *et al.* (2023), Birru *et al.* (2021), Fenton *et al.* (2021), Steenland *et al.* (2021), Banjabi *et al.* (2020), European Food Safety Authority (2020), Goldenman *et al.* (2019), Kim *et al.* (2016).

⁶ Sources are detailed on the Task 1 Report, including Ebel *et al.* (2023), Hu *et al.* (2023), Pan *et al.* (2023), Plass *et al.* (2023), Obsekov, Kahn & Trasande (2023), Zhang *et al.* (2023), Costello *et al.* (2022), Bartell and Vieira (2021), Dalsager *et al.* (2021), Shearer *et al.* (2021), Eves *et al.* (2020), Goldenman *et al.* (2019), Impinen *et al.* (2019), Govarts *et al.* (2018), Lauritzen *et al.* (2018), Liu *et al.* (2018), Steenland *et al.* (2018), Sun *et al.* (2018), Wielsøe *et al.* (2017), Dalsager *et al.* (2016), Khalil *et al.* (2016), Zhang *et al.* (2015), Johnson *et al.* (2014), Vagi *et al.* (2014), Eriksen *et al.* (2013), Wen *et al.* (2013), Buck Louis *et al.* (2012), Min *et al.* (2012), Steenland & Woskie (2012), Whitworth *et al.* (2012), Shankar *et al.* (2011), Stein *et al.* (2009).

Research questions	Findings
	These studies are focused on direct, non-market cost valuation of 'life' or 'years lived in good health' (drawing on stated preference methods), and some estimations of indirect, market health costs (cost of illness method) resulting from increases in healthcare demand. Generally, other impacts are not quantified nor monetised.
1.5 What are the geographical and temporal trends in human health costs?	Variations in PFAS blood serum concentrations were identified across geographies and time. For example: higher concentrations of four PFAS compounds were found in teenagers residing in Northern (Norway, Sweden) and Western Europe (France, Germany, Belgium) compared to lower levels in Southern (Spain, Greece, Slovenia) and Eastern Europe (Slovakia); and blood serum levels of PFAS increased significantly during peak production years (1979–2001) and decreased by 23% and 22% for PFOA and PFOS respectively between 2001 and 2007. In contrast, blood serum levels for compounds such as PFNA, PFDA, and PFUnDA continued to rise after 2001. ⁷

In addition, the literature review and interviews highlighted the **types of human health costs** that could be attributable to PFAS pollution and a range of **methods** that have been employed in the literature to monetise these (Research Question 3).

Type of costs or cost categories

There are a wide range of human health costs that could be associated with PFAS exposure, and these can be direct (D) or indirect (I), market (M) or non-market (NM), and one-off (OC) or recurring (RC) costs. Five most significant costs are presented on the Table below.

Table 2-2 Types of human health costs

Human health costs identified	Description of costs identified	Types (D or I; M or NM; OC and/or RC)		
Health and wellbeing losses	Loss of both quality and quantity of life due to illness or disability from pollution, measured as Disability-Adjusted Life Years gained or Quality-Adjusted Life Years lost.	D	NM	RC
Demographic impacts	Adverse impacts on birth rates and birth outcomes, potentially including birth defects or low birth weights.	I	NM	RC
Increased health care demand	Increased need for medical/healthcare services due to pollution-attributable health conditions, leading to higher healthcare costs.	I	M	RC
Increased social care demand	Increased need for care services due to pollution-related health conditions, which might include services provided in the market economy or outside of it.	I	M, NM	RC
Economic productivity losses	Losses in productivity captured or resulting from sickness (absence/ absenteeism), and/or from lower concentration and/or efficiency (presenteeism)	I	M	RC

⁷ Sources include Plass et al. (2023), Richterova et al (2023), Goldenman et al (2019), Haugdahl Nøst (2014)..

Methods

Methods identified for monetising human health costs include market-based, avoided damage, revealed preferences, stated preferences and benefit transfer methods. These are outlined briefly below.

- **Cost-based methods** use market data to value health impacts. This includes methods such as the cost of illness (COI) method, human capital approach and the present value of lifetime earnings (PVLE).
- **Avoided damage methods:** Cost-based approach used to estimate the economic value of preventing negative health outcomes, that is, the market and/or non-market costs that would have been incurred if the health damage had not been prevented.
- **Revealed preferences methods** use observed behaviours and market transactions by market actors to estimate the economic value of health outcomes. This includes hedonic pricing method, travel cost method and the averting behaviour method.
- **Stated preferences methods** are used to estimate the economic value of health outcomes based on individuals' expressed preferences in hypothetical scenarios, generally summarised in terms of their willingness to pay to avoid years of life lived with disability and/or lost. These methods are particularly useful when market data is unavailable or insufficient. This group includes Contingent Valuation (CV), which appears predominant in the literature as well as employed by the European Chemicals Agency and the Organisation for Economic Cooperation and Development, and Discrete Choice Experiments (DCE).
- **Benefit transfer methods** can also be employed, which draw on valuation data gathered in one situation and applying it, with adjustments, in a similar situation to a population with similar attributes and suffering from similar burden of disease. This method is used frequently as it limits the need for primary valuation studies. **lood**

The literature precedent that is most relevant primarily relies on stated preference methods and cost-of-illness approaches to assess, respectively, non-market impacts on people's health and wellbeing, and market impacts on healthcare systems and worker productivity. For non-market health and wellbeing impacts, Contingent Valuation or CV are employed. This involves presenting respondents with a hypothetical scenario and asking them how much they would be willing to pay for a specific benefit or to avoid a negative outcome. For example, researchers investigate people's willingness to pay to reduce risk of premature death by a small probability and estimate the social 'Value of Statistical Life' (VSL), and/or their willingness to pay for an additional year of life and estimate the 'Value of a Life Year' (VOLY). The VOLY can also be derived from VSL estimates based on considerations of life expectancy.

For example, Goldenman *et al.* (2019) use the **'value of statistical life' contingent valuation method to monetise non-market disease burden**, drawing on available evidence of the 'Value of a Statistical Life' from ECHA (2016)'s 'Valuing selected health impacts of chemicals: Summary of the results and a critical review of the ECHA study'⁸ and OECD (2012)'s

⁸ Note that a more recent study was published by ECHA in 2023 of "Reference willingness-to-pay values for monetising chemicals health impacts". Available at: https://echa.europa.eu/documents/10162/17229/seac_reference_wtp_values_en.pdf/403429a1-b45f-4122-ba34-77b71ee9f7c9

'Mortality risk valuation in environment, health and transport policies'⁹. To do this, Goldenman *et al.* (2019) also draw on a case study approach, for example, of populations living near contaminated areas in Minnesota, U.S.; West Virginia, U.S.; Dordrecht, Netherlands; Ronneby, Sweden; and Veneto Region, Italy; to quantify, extrapolate and monetise impacts across larger populations.

Obsekov, Kahn and Trasande (2023) draw on market-based methods, such as **the cost of illness approach, to develop estimates of medical costs and productivity losses, and non-market (CV) methods to quantify and monetise disease burden.**

Key insights for the specification of the human health cost assessment methodology

The literature review and interviews **confirm there are opportunities to build upon the work conducted by Goldenman *et al.* (2019) for the Nordic Council of Ministers**, by:

1. Refining and expanding the analysis to cover additional health risks associated with PFAS exposure, and specific PFAS types, when possible
2. Updating the exposure-risk relationships to reflect the latest available evidence, and
3. Expanding the coverage of the types of costs included in the analysis beyond the monetisation of disease burden using non-market methods, by systematically including, at least, the indirect costs of healthcare and productivity losses.

2.3. Summary of relevant findings from Task 1 concerning the environmental costs of PFAS pollution

2.3.1. State of the evidence on environmental impacts that incur direct costs

The economic value of the natural environment to society is generally assessed in the context of an ecosystem services framework.¹⁰ Ecosystem services represent nature's contribution to people, in terms of provisioning services (e.g. food, water), regulating services (e.g. climate regulation), and cultural services (e.g. recreational activities in nature, such as hiking and running). Methods exist to place monetary values on several of these services. Environmental pressures, including chemical pollution, can degrade ecosystems and thereby affect the quality and quantity of ecosystem services, incurring losses in terms of their monetary value. As such, this project would ideally look at the available evidence that PFAS pollution affects ecosystem service provisioning in the EEA in order to understand the societal costs associated with environmental impacts of PFAS.

The scientific evidence is clear that some PFAS have the potential to harm aquatic and terrestrial animals and plants due to their (eco)toxicological properties, their persistence, and their ability to bioaccumulate in organisms. Possible effects have been observed in fish,

⁹ Note that we will also consider more up-to-date evidence from the OECD's work on Surveys on Willingness-to-Pay to Avoid Negative Chemicals-Related Health Effects. Available at: <https://www.oecd.org/en/topics/sub-issues/risk-management-risk-reduction-and-sustainable-chemistry/the-costs-and-benefits-of-regulating-chemicals.html>

¹⁰ Eurostat (2021) Accounting for ecosystems and their services in the European Union, Final report from phase II of the INCA project aiming to develop a pilot for an integrated system of ecosystem accounts for the EU. Available at: <https://ec.europa.eu/eurostat/web/products-statistical-reports/-/ks-ft-20-002>

crustaceans, amphibians, terrestrial invertebrates, birds, mammals, algae, and plants. These effects relate to reproduction, development, behaviour, neurology, lethality, the liver, and the immune system. If materialised, these toxic effects in organisms could lead to ecosystem damage (e.g. through reduced survival and reproductive success of organisms), which could incur ecosystem service costs (e.g. through damage to food provisioning organisms and damage to primary producers which support food webs in ecosystems providing other services).

Generally, the available evidence raises significant concerns about the effects of PFAS on the environment, however, the research landscape is patchy, meaning that the specific scale and nature of the environmental impacts of PFAS cannot be confidently concluded on (e.g. effects on ecological systems such as population decline).

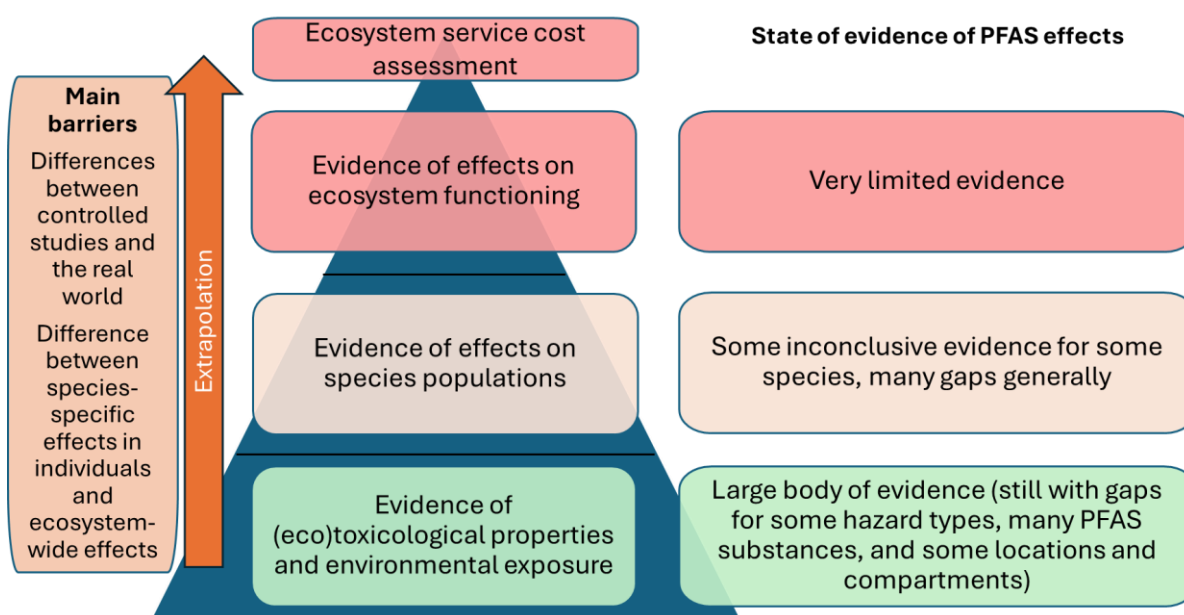
Most studies are based on traditional chemical risk assessment methods which look at the effects of substances on individual organisms under controlled conditions. These methods can be used to indicate that substances have potential effects on the environment but cannot be used to assess and quantify the impacts of substances on populations and ecological systems. Depending on the quality of data from chemical risk assessments, it may be extrapolated to estimate the potential scale of ecological impacts. However, this extrapolation is likely to be coupled with large ambiguities and uncertainties due to the differences between controlled laboratory studies and the real-world environment (which hosts complex ecological networks and is influenced by a range of biotic and abiotic factors).

In particular, there are challenges in understanding the impacts of PFAS compared to some other chemicals because of the wide range of PFAS substances, the bioaccumulation potential and persistence of some PFAS, the potential mixtures effects of some PFAS, the potential lag time between exposure and effects from PFAS, and the complex hazard endpoints that may be relevant for some PFAS.

Some field studies looking at real life environmental effects in uncontrolled conditions have been undertaken, but often have limitations such as small sample sizes, inconclusive results (e.g. with statistically insignificant correlations), or contradictions with other studies.

The figure below summarises the challenges in undertaking an ecosystem services cost assessment for PFAS pollution. At the same time, it highlights that while the evidence of effects on ecosystem functioning is thin, it may be possible to extrapolate the evidence of (eco)toxicological properties and environmental exposure to PFAS to estimate ecosystem service impacts.

Figure 2-1 Challenges in assessing the impacts of PFAS pollution on ecosystem services



2.3.2. Possible ways to directly assess ecosystem service impacts

The goal of this project is to quantify the societal costs of PFAS. Under an ecosystem services framework, this would require evidence on the extent to which ecosystem services are disrupted by PFAS. This evidence does not yet exist. In contrast, there is a large volume of data on the risks from certain PFAS substances to certain species. Some scientific methods exist which enable the extrapolation of hazard and exposure data to estimate the potential damage to ecosystems. For example, Fantke et al. (2018) describes how species sensitivity distribution approaches may be applied based on EC50 thresholds¹¹ to model the potential damage to ecosystems.¹² The results of species sensitivity distribution approaches can be used to estimate the potentially affected fraction of species in an ecosystem (i.e. how many species out of the total number of species present in an ecosystem might be negatively affected). While the potentially affected fraction may be indicative of potential disruption of ecosystem services, it does not explicitly determine the level of disruption of ecosystem functioning and ecosystem service provisioning.

Some studies have looked at ecosystem functioning and ecosystem service delivery in the context of chemical risk assessment,¹³ however, we did not identify any established methods that we could apply to PFAS within the scope of this study. Maltby et al. (2021) summarise the general need to further develop tools for extrapolating toxicity data to

¹¹ This is the half maximal effective concentration, i.e. the concentration of a compound where 50% of its maximal effect is observed.

¹² Fantke et al. (2018) Toward harmonizing ecotoxicity characterization in life cycle impact assessment. Available at: <https://core.ac.uk/download/pdf/388644844.pdf>

¹³ E.g. Forbes and Galic (2016) Next-generation ecological risk assessment: Predicting risk from molecular initiation to ecosystem service delivery. Available at: <https://www.sciencedirect.com/science/article/abs/pii/S0160412016300824>; He et al. (2019) Combining species sensitivity distribution (SSD) model and thermodynamic index (exergy) for system-level ecological risk assessment of contaminants in aquatic ecosystems. Available at: <https://www.sciencedirect.com/science/article/pii/S0160412019324535>

ecosystem service delivery.¹⁴ Limitations to methods assessing the impacts of chemicals on ecosystem services are also described by Faber et al. (2021).¹⁵

A quantitative cost assessment is not feasible given the lack of empirical evidence that PFAS occurrence causes ecosystem service disruption. However, it may be possible to consider a weight-of-evidence approach based on a mechanistic understanding of the potential pathways by which PFAS exposure might lead to ecosystem service impacts. This will be important to indicate where further work is needed to understand, at least qualitatively, the full scale of environmental costs from PFAS pollution. The proposed approach is described in section 3.4.

2.3.3. Proxies to estimate ecosystem service impacts and other environmental costs

Given the challenges related to direct ecosystem service cost assessments for chemical pollution, alternative cost assessment methods have been developed to determine the value of a non-polluted environment. This is reflected by society's willingness-to-pay to clean up the environment (e.g. through soil remediation and water treatment).

Remediation and water treatment costs indirectly represent the cost *to recover* ecosystem services. Even without characterising the direct impacts of PFAS on ecosystem services, these costs demonstrate the price of a clean environment, capturing the essence of the ecosystem services framework (in terms of nature's contribution to people). In comparison, the concepts described in section 2.3.2 focus on the value of *lost* ecosystem services. In reality, PFAS pollution is causing both losses in ecosystem service delivery and costs to recover ecosystem services. As clean-up costs increase, ecosystem service losses should decrease, although this relationship may not be linear. Nevertheless, remediation and water treatment costs are a tangible way to estimate the monetary value of ecosystem service impacts of PFAS. Previous assessments of the non-health costs of PFAS pollution have largely focused on remediation and treatment costs (as discussed further in section 3.3.1).

In some cases of PFAS contamination, ecosystem service recovery (via clean-up) may not be possible, but the contamination may be considered unacceptable, which can result to losses in ecosystem services and other economic costs. This cost type is different to that described in section 2.3.2 as it relates to societal/political definitions on levels of acceptable risk. These definitions may be extrapolated from (eco)toxicological evidence, but do not generally characterise the influence of (eco)toxicological effects on the processes involved in ecosystem service delivery. They may also relate to human health protection goals rather than environmental protection goals. These costs include:

1. Food contaminated with PFAS may need to be disposed of to avoid risks to human health. This can incur costs from losses in food production (as an ecosystem service), quantifiable in terms of lost profits to farms. Task 1 identified some case studies where these costs have been predicted.

¹⁴ Maltby et al. (2021) *Assessing chemical risk within an ecosystem services framework: Implementation and added value*. Available at: <https://www.sciencedirect.com/science/article/pii/S0048969721037037>

¹⁵ Faber et al. (2021) *Identifying ecological production functions for use in ecosystem services-based environmental risk assessment of chemicals*. Available at: <https://www.sciencedirect.com/science/article/pii/S0048969721014777>

2. PFAS concentration limits in waste can lead to the need for diversion of waste from recycling or landfill to incineration to protect the environment and human health, which can result in losses in material value and costs of incineration. This is related to ecosystem services in terms of material provisioning.
3. Where land has been designated as a contaminated site due to unacceptable risks to human health or the environment, there may be losses in ecosystem services provided and opportunity costs of not being able to use the land for economic activities. Assessing these costs would rely on assumptions on what the land would be used for if not contaminated with PFAS.

Lastly, litigation costs were also investigated in Task 1. PFAS lawsuits have been filed in the US and other countries to cover the costs of monitoring, treating, and remediating PFAS. We suggest that it would be more appropriate under Task 4 to look directly at water treatment and remediation costs, rather than overall litigation costs, because of the variables and uncertainties which influence the scale of litigation costs, and because the cost categories overlap.

Summary of conclusions for the development of the environmental cost assessment methodology

1. A quantitative assessment of ecosystem service impacts and associated costs is not feasible due to gaps in the empirical evidence. However, it may be possible to consider a weight-of-evidence approach based on a mechanistic understanding of the potential pathways by which PFAS exposure might lead to ecosystem service impacts.
2. Previous assessments of the non-health costs of PFAS pollution have largely focused on remediation and treatment costs. They indirectly represent the cost to recover ecosystem services and therefore provide a tangible way to estimate the monetary value of ecosystem service impacts of PFAS.

3. Recommended methodology to update and expand the existing knowledge on the societal costs of PFAS pollution in the EEA

3.1. Purpose of this section

This section presents the methodology to be used to update and expand the existing knowledge on the societal costs of PFAS pollution in the European Economic Area, particularly building on a study by Goldman *et al.* (2019) for the Nordic Council of Ministers. These will be applied using the exposure estimates developed in Task 3 (through the method described in Section 5 of this report).

3.2. Recommended methods for human health cost assessment

This section summarises the existing estimates of human health costs from PFAS pollution in Europe, presents a proposed stepwise methodology to build on these and develop new, up-to-date estimates of the human health costs, and describes the data inputs that are required, as well as main gaps, assumptions and limitations of the proposed methods.

3.2.1. Existing estimates of human health costs from PFAS pollution in Europe

Goldenman *et al.* (2019)¹⁶ has produced the most up-to-date assessment of the monetary human health costs of PFAS pollution in the European Economic Area, at an **annual cost between €52 billion and €84 billion per year**.

This is based on a quantification of impacts on human health for people facing different levels of PFAS exposure, following an impact pathway approach and ‘what-if’ scenarios that draw on selected studies. The table below presents key insights.

Table 3-1 Human health impacts quantified and monetised in Goldenman *et al.* (2019)

Affected populations	Health risk and impact quantified	Sources of evidence
Workers facing occupational exposure	Increased risk of premature mortality from attributable kidney cancer , leading to preventable deaths	Epidemiological evidence from a study of workers from West Virginia ¹⁷ extrapolated to the European context.
People residing nearby contaminated sites	Increased risk of all-cause premature mortality , leading to preventable deaths	Differences in the risk of mortality (from all causes) for adult populations found in a study based in the Veneto Region, Italy ¹⁸ when compared to the general population.
People drinking water and eating food with measurable PFAs concentration	Increased risk of premature mortality from attributable hypertension , leading to preventable deaths	Data from the US National Health and Nutrition Examination Survey to present quantitative differences in risk of developing hypertension (and attributable premature mortality) for people with different levels of PFOA concentration in their blood serum.

The monetary value of the burden of disease (in terms of Preventable Deaths or Years of Life Lost) were estimated using a ‘value of statistical life’ valuation method.

Other human health impacts were considered and quantified using similar ‘what-if’ analyses, albeit these were not monetised (e.g. increased risk of cholesterol and increased incidence of low birth weight, which are risk factors for other conditions and/or adverse health outcomes; and increased risk of infections quantified in terms of days of fever/sickness among children ages 1 to 4 years).

¹⁶ Goldenman *et al.* (2019). *The cost of inaction: A socioeconomic analysis of environmental and health impacts linked to exposure to PFAS*. Nordic Council of Ministers. Available at: <https://norden.diva-portal.org/smash/get/diva2:1295959/FULLTEXT01.pdf>

¹⁷ Steenland K and Woskie S (2012). Cohort mortality study of workers exposed to perfluorooctanoic acid. *American journal of epidemiology*. 176(10) pp.909–917.

¹⁸ Mastrantonio M *et al.* (2017). Drinking water contamination from perfluoroalkyl substances (PFAS): an ecological mortality study in the Veneto Region, Italy. *The European Journal of Public Health*. Feb 1;28(1):180–185.

A more recent study by Plass *et al.* (2023)¹⁹ for the European Environment Agency contains a more comprehensive review of the available scientific evidence and more up-to-date estimates of the burden of disease from PFAS exposure (particularly PFOS and PFOA) drawing on the latest human biomonitoring evidence from the European Human Biomonitoring Initiative (HMB4EU)²⁰.

This study quantified the Disability Adjusted Life Years associated with hypertension and associated premature mortality, developmental impacts ('small for gestational age' and IQ losses), and hospitalisation from Lower Respiratory Tract Infection that might be attributable to general (or 'background') PFOS and PFOA exposure in selected European countries. These are not extrapolated to the EU or EEA regions nor monetised.

3.2.2. Stepwise methodology proposed

We have specified a **five-step methodology to quantify and value human health costs attributable to PFAS exposure in Europe**, that is based on the literature and evidence collected under Task 1 and the future outputs of the scenario analysis undertaken under Task 3. These steps are:

1. **Step 1 Affected populations:** To characterise mutually exclusive groups of adults (exposed workers), adults (general population), teenagers (general population), children (general population), pregnant women (general population) and a cross-cutting group of people living near PFAS-manufacturing or PFAS-using industrial sites in the EEA.
2. **Step 2 Exposure:** To identify the level of PFAS, by type, in the blood serum across these population groups in the EEA at present, and across prospective scenarios; focussing on those PFAS for which there is sufficient evidence to conduct an impact and valuation study.
3. **Step 3 Health risks and exposure-risk relationships:** To document and identify the health risks and associated health outcomes which have been most confidently attributed to PFAS exposure; with sufficient and robust quantitative evidence of the relationship between PFAS exposure and these risks.
4. **Step 4 Health impact analysis:** To quantify the potential health impacts of PFAS exposure across the 'affected population' groups for the prioritised health endpoints in terms of attributable cases of ill health (Numbers of cases, etc.), burden of these disease cases in Disability-Adjusted Life Years, and preventable deaths.
5. **Step 5 Human health cost valuation:** To apply appropriate valuation methods in line with the literature and good practice guidelines and estimate the human health monetary costs that could be attributable to PFAS in the EEA, at present and in the future under prospective scenarios.

¹⁹ Plass *et al.* (2023). *Estimating the burden of disease due to lead, PFAS, phthalates, cadmium, pyrethroids and bisphenol A using HBM4EU data – test of feasibility and first results for selected countries*. European Environment Agency. Available at: <https://www.eionet.europa.eu/etcs/etc-he/products/etc-he-products/etc-he-reports/etc-he-report-2023-13-estimating-the-burden-of-disease-due-to-lead-pfas-phthalates-cadmium-pyrethroids-and-bisphenol-a-using-hbm4eu-data-2013-test-of-feasibility-and-first-results-for-selected-countries/@download/file/ETC-HE-2023-13-EIONET-REPORT-3-2-6-3-EBD-chemicals-FINAL.pdf>

²⁰ Please see the Task 1 Report and/or <https://cordis.europa.eu/project/id/733032> or <https://www.hbm4eu.eu/> for more information.

These steps are specified in detail in the following subsections.

Step 1: Affected populations

There are a range of sources available to develop estimates of the **number of people across each of the population groups that might be potentially affected** by different levels of PFAS exposure in the EEA. The Table below sets out our proposed estimates and assumptions for the evolution of these population groups from 2024 to 2050, by drawing on Eurostat, the World Bank, and relevant literature, including a couple of key assumptions developed and employed by Goldenman *et al.* (2019).

Table 3-2: Potentially affected EEA populations by group (Sources: Eurostat²¹, World Bank or WB²², Goldenman *et al.* (2019)²³, and Frick, 2021²⁴ and Andersen *et al.* 2000²⁵)

Population group	Population estimates in 2024 (No. people) and estimated CAGR ²⁶ to 2050 (%)	Description of assumptions
Total population	455,279,983 (CAGR: -0.3%)	Eurostat; population groups and CAGR based on WB projections
Adults (Exposed workers)	703,100 (CAGR: -0.7%)	Mid-point of exposed worker estimates in Goldenman <i>et al.</i> (2019) ²⁷
Adults (20+)	350,586,806 (CAGR: -0.2%)	Adults 20+ from Eurostat, minus pregnant women, workers or people 15+ living near contaminated sites
Teenagers (15-19 years)	23,405,944 (CAGR: -1.0%)	Eurostat; population groups and CAGR based on WB projections
Children (5-14 years)	45,527,998 (CAGR: -0.7%)	
Children (1-4 years)	16,372,319 (CAGR: -0.3%)	
Newborns (0 years)	3,726,318 (CAGR: -0.5%)	Estimate based on live births (Eurostat)

²¹ <https://ec.europa.eu/eurostat/en/web/products-eurostat-news/w/ddn-20240711-1>;
<https://ec.europa.eu/eurostat/web/interactive-publications/demography-2024>

²² <https://databank.worldbank.org/source/population-estimates-and-projections>

²³ Goldenman *et al.* (2019). The cost of inaction: A socioeconomic analysis of environmental and health impacts linked to exposure to PFAS. Nordic Council of Ministers. Available at: <https://norden.diva-portal.org/smash/get/diva2:1295959/FULLTEXT01.pdf>

²⁴ Frick, Alexander (2021). Advanced maternal age and adverse pregnancy outcomes. Available at: <https://www.sciencedirect.com/science/article/pii/S1521693420301127>

²⁵ Nybo Andersen AM, Wohlfahrt J, Christens P, Olsen J, Melbye M. Maternal age and fetal loss: population-based register linkage study. *BMJ*. 2000 Jun 24; Available at <https://pmc.ncbi.nlm.nih.gov/articles/PMC27416/>

²⁶ Compound Annual Growth Rate based on projections published by the World Bank.

²⁷ Goldenman *et al.* (2019) conducted an analysis of the number of plants and workers in a set of sectors where there could be manufacturing of PFAS or PFAS-treated products. This amounted to 6% of the total worker population in the EEA. Of this proportion, the study assumed that 3% to 10% of these workers might suffer from occupational exposure to PFAS.

Population group	Population estimates in 2024 (No. people) and estimated CAGR ²⁶ to 2050 (%)	Description of assumptions
Pregnant women	4,108,444 (CAGR: -0.6%)	Estimate based on live births (Eurostat), projections (WB) and miscarriages (Frick, 2021 and Andersen et al., 2000)
People (15+) living near contaminated sites	10,988,490 (CAGR: -0.2%)	Estimate based on the Goldenman <i>et al.</i> (2019) assumption of 3% of adults living near polluted sites, applied to population of 15+ ²⁸

Please note that the population categories presented above have been estimated and are presented in a mutually exclusive way, so that the total population is equivalent to the sum of the population estimates against each population group. For example, total number of adults of ages 20 and above is equivalent to the sum of populations: 'adults (20+)', 'exposed workers', and the majority of 'pregnant women' and 'people (15+) living near industrial sites'. 'People living near industrial sites' includes all population groups of ages 15 and above that are living near the sites. The rest of the groups are either 'pregnant women' or age-based population groupings who are not living near a contaminated site. These population groups are separated in this way, primarily because they face different levels of exposure to PFAS and, in addition and only in some cases, face slightly different risks based on the literature review conducted for this study.

In some cases, it will be important to differentiate by sex. The Table below sets out our proposed estimates for the proportion of the female population in each group in 2024, by drawing on Eurostat and World Bank datasets.

Table 3-3: Proportion of females in the EEA population in 2024 by group (Sources: Eurostat²⁹, World Bank³⁰)

Population group	Proportion of females in 2024 (% of group)
Total population	51.1%
Adults (Exposed workers)	51.6%
Adults (20+)	51.0%
Teenagers (15-19 years)	48.8%

²⁸ Goldenman *et al.* (2019) used a best estimate of 3% of the population exposed to excess levels of PFAS via drinking water, drawn from Swedish data in Holmström *et al.* (2014). Recent data from the Forever Pollution project identifies 23,000 known PFAS contaminated sites in Europe. Based on our analysis, this 3% estimate would be consistent with an average population density of 5 people per sq. km within a 5 km radius of each of these sites. This would be considered reasonable, if the 23,000 known contaminated sites were typically located in remote areas, which can be the case for specialised manufacturing/industrial activities. This could not be checked as part of this project. In addition, as of March 2025, the Forever Pollution project does not offer a readily accessible estimate of the population living near contaminated sites.

²⁹ [https://ec.europa.eu/eurostat/databrowser/view/demo_fasec\\$defaultview/default/table?lang=en](https://ec.europa.eu/eurostat/databrowser/view/demo_fasec$defaultview/default/table?lang=en)

³⁰ <https://databank.worldbank.org/source/population-estimates-and-projections>

Children (5-14 years)	48.8%
Children (1-4 years)	48.8%
Newborns (0 years)	48.7%
Pregnant women	100.0%
People (15+) living near contaminated sites	51.4%

Step 2: Exposure

This section summarises the present-day exposure, defined as the internal concentration of PFAS in a human blood serum in line with the available literature, which is required to quantify the burden of disease as part of this methodology.

Specifically, exposure data for the present day (averaged between 2019-2024) is presented across the population groups and for specific PFAA and PFAA precursor substances: PFOA, PFOS, PFNA, PFHxS, and PFPeA. This is because exposure-response functions (ERFs) have not been identified in the literature for other PFAS for which there is available exposure data³¹, and thus, any potential associated burden of disease cannot be calculated. In addition, conclusive studies investigating mixtures or cumulative effects of the total level of PFAS, across substances, in blood have not been identified. Thus, it is proposed that this study is centred around the attributable burden of disease associated with exposure to these five substances, additively, given that the ERFs provide isolated relationships between exposure to the specific PFAS and health outcomes.

In addition, a scientifically sound ‘read across’-type approach has not been identified to consider the extrapolation of the potential burden of disease associated with exposure to the other PFAS for which scientific studies have not identified quantitative ERFs.

The following sections summarise the present-day exposure evidence that will be taken forward and considered as part of the human health impact and valuation analysis and specify a method for approximating potential levels of PFAS in blood serum under prospective scenarios over time.

Exposure at present

The following table summarises blood serum levels of five PFAS across European populations at present (averaging evidence from 2019-2024).

Table 3-4: Blood serum levels of PFAS, in µg/L, across European populations (Sources include HMB4EU³². Please Section 2.2 and Task 1 Report)

Population group	PFOA	PFOS	PFNA	PFHxS	PFPeA
Adults (Exposed workers)	2.37 [0.4 - 3.35]	17.43 [0.95 - 831.33]	0.43 [0.18 - 1.55]	0.75 [0.2 - 21.23]	0.4 [0.4 - 0.5]

³¹ These include PFHxA, PFHpA, PFDA, PFUnDA, PFDoDA, PFTrDA, PFBS, PFHpS, PFDS, PFHxPA, PFOSA, and 6:2diPAP.

³² HMB4EU and related studies such as Richterova et al (2023), Uhl et al (2023), Fabelova et al (2023); and other studies such as Andersen et al (2024), Goen et al (2023), Palesova et al (2023), Plass et al. (2023), Rihackova et al (2023), DeLuca et al (2022), Papadopoulou et al (2021), Gebbink et al (2020), Pitter et al (2020), Poonthong et al (2020), Balk et al (2019), etc.

Population group	PFOA	PFOS	PFNA	PFHxS	PFPeA
Adults (20+)	1.81 [0.4 - 12.01]	5.04 [1.27 - 22.78]	0.77 [0.22 - 2.08]	0.68 [0.16 - 2.09]	-
Teenagers (15-19 years)	0.75 [0.2 - 1.29]	1.76 [0.5 - 2.82]	0.33 [0.08 - 0.82]	0.37 [0.12 - 1.07]	0.04 [0 - 0.18]
Children (0-14 years)	2.1 [0 - 14]	1.64 [0 - 17]	0.35 [0 - 1.14]	0.83 [0 - 16]	-
Pregnant women	2.04 [0.45 - 9.28]	10.54 [2.54 - 34.26]	0.56 [0.17 - 1.71]	0.47 [0.04 - 1.11]	-
People (15+) living near contaminated sites	19.46 [1.45 - 396.48]	5.65 [1.65 - 54.35]	0.5 [0.5 - 39.7]	1.91 [0.5 - 36.98]	0.5 [0.5 - 0.5]

Note: Children aged 0-14 years are split into additional sub-groups (e.g., groups of ages 0, 1-4, etc.) for the purposes of the analysis in this study, assuming the same average concentration of PFAS in blood serum.

Exposure under prospective scenarios

In addition, this study will consider PFAS exposure, measured as the level of PFAS in human blood serum, under future, prospective scenarios to quantify how future human health costs may vary across them.

Evidence of the levels of PFAS in blood serum, both present day (in response to research question 1.1) and historical (in response to research question 1.5), will inform the estimation of future levels of PFAS in blood serum the under prospective scenarios.

Available data has allowed us to identify potential time-trends concerning human exposure to PFAS (measured by blood serum levels) between 2001 and 'present day' (2001-2006³³ from secondary sources, and present-day exposure data covered by averaging recent available data across 2019-2024, primarily from HBM4EU as highlighted in the previous section). This historical perspective will build an understanding of past dynamics and serve as the foundation for projecting future exposure. Table 3-5 below presents the blood serum level time-trends for PFOA, PFOS, PFNA, PFHxS, and PFPeA.

Table 3-5 Blood serum level CAGR between 2001-2006 and 2019-2024 for PFOA, PFOS, PFNA, PFHxS, and PFPeA

PFAS type	CAGR 2001-2006	CAGR 2006- (2019-2024)
PFOA	-10.0%	-3.6%
PFOS	-8.8%	-8.9%
PFNA	-9.0%	0.2%
PFHxS	-5.6%	-4.3%
PFPeA	3.3%	-5.2%

The trends observed in the data available, expressed as compound annual growth rates

³³Haug, L. S., Thomsen, C., & Becher, G. (2009). Time trends and the influence of age and gender on serum concentrations of perfluorinated compounds in archived human samples. *Environmental Science & Technology*.

(CAGR), will support the development of the prospective scenarios. A baseline scenario will be developed, which will reflect how exposure levels might evolve under existing conditions and time-trends (see Section 5 Task 3 for more details on the prospective scenarios).

A separate task (Task 3, see Section 5) under this study will focus on characterising a range of prospective scenarios, including what PFAS pollution might look like under the continuation of the baseline and other prospective scenarios. The outputs of this analysis will include estimations of PFAS content or concentrations of PFAS in air, drinking water and food over time. The modelling work will look backwards to 2021 as well, to isolate quantitative trends in the concentration of air, drinking water and foods over the same period for which there is evidence of PFAS exposure.

Based on this, analyses will be conducted to identify and characterise high-level relationships between PFAS in air, drinking water and food, when compared against blood serum levels (which might include considerations of time lags and exploration of relevant dynamics between the metrics explored). Please see Section 5 (Task 3) for more details.

The outputs of these analyses, overlaid with expert input from the study team, will result in a set of quantitative assumptions describing the links (or function) between the estimates of PFAS concentrations in air, drinking water and food and the available evidence of levels of PFAS in blood serum.

These assumptions can enable reasonable and proportionate projection of blood serum concentrations for PFOA, PFOS, PFNA, PFHxS, and PFPeA over time under the prospective scenarios in scope of the study, with limitations that will be presented transparently and tested as part of the sensitivity analysis (Section 4).

Step 3: Health risks and exposure-risk relationships

This section presents the **health risks and associated health endpoints which have been most confidently attributed to PFAS exposure**, with sufficient weight of evidence to justify their inclusion in the study.

The evidence identified as part of the literature review³⁴ under Task 1 of this study, which was synthesised in Section 2.2, resulted in a longlist of health risks and endpoints associated with PFAS exposure. Each was considered for inclusion in the next stages of the project, resulting in a final list that excluded any health risks or endpoints:

- With low confidence based on our assessment of the evidence³⁵ (i.e., a confidence score of 1, or when meta-analyses or scientific papers report inconclusive

³⁴ Sources are detailed on the Task 1 Report, including Mahdavi et al. (2024), Ebel et al. (2023), Hu et al. (2023), Pan et al. (2023), Pinney et al. (2023), Plass et al. (2023), Obsekov, Kahn & Trasande (2023), Xu et al. (2023), Zhang et al. (2023), Costello et al. (2022), Bartell and Vieira (2021), Birru et al. (2021), Fenton et al. (2021), Dalsager et al. (2021), Steenland et al. (2021), Shearer et al. (2021), Banjabi et al. (2020), European Food Safety Authority (2020), Eves et al. (2020), Goldenman et al. (2019), Impinen et al. (2019), Govarts et al. (2018), Lauritzen et al. (2018), Liu et al. (2018), Steenland et al. (2018), Sun et al. (2018), Wielsøe et al. (2017), Dalsager et al. (2016), Khalil et al. (2016), Kim et al. (2016), Zhang et al. (2015), Johnson et al. (2014), Vagi et al. (2014), Eriksen et al. (2013), Wen et al. (2013), Buck Louis et al. (2012), Min et al. (2012), Steenland & Woskie (2012), Whitworth et al. (2012), Shankar et al. (2011), Stein et al. (2009).

³⁵ Please note that the assessment of confidence in the association between human exposure to PFAS and the specific health outcome/risk was conducted (Task 1) using a scoring system of 5 for the associations with the highest confidence. A score of...

5, when meta-analyses underpinned by robust science that reports a causal link between PFAS exposure and an adverse health outcome, and without any conflicting evidence.

4, when meta-analyses underpinned by robust science report associations, which could be causal but not necessarily proven, between PFAS exposure and health risks, and without any conflicting evidence or notable uncertainties.

associations between PFAS exposure and health risk, with/without conflicting evidence or areas of uncertainty).

- For which there were no Exposure-Response Functions (ERFs) identified in the literature or any other substantial evidentiary gaps, and thus cannot be quantitatively assessed as part of this study.

The Table below presents the final list of thirteen endpoints with available and sufficient weight of evidence to justify their inclusion in the study and, thus, are proposed to be taken forward in the analysis. The Table also reiterates, and organises these endpoints, by the confidence score of the association between the health risk and PFAS exposure; the affected population that has been studied in the literature and which concerns the ERFs identified, also documented on the Table.

The ERFs are outputs of technical, scientific studies. These functions are an essential part of the quantification of potential human health burden attributable to PFAS exposure, as they represent the risks (Risk Ratio), odds (Odds Ratio) or hazards (Hazard Ratio) of developing a condition or disease at different levels of PFAS exposure when compared to a reference of comparable, less exposed populations. The evidence identified was presented in more detail in the Task 1 Report and it is summarised briefly for reference following the Table.

Table 3-6 Overview of health risks and exposure risk relationships proposed for inclusion in the study

Specific health risk/ endpoint in scope	Confidence (0=None, 5=High)	Affected population	Exposure response functions identified in the literature with sufficient weight of evidence
Lower respiratory tract infections (LRTI)	4	Children (1-4 years)	HR ³⁶ = 1.27 per doubling of PFOA (ng/mL) (95% CI: 1.01-1.59) HR = 1.54 per doubling of PFOS (ng/mL) (95% CI: 11%-115%)
Maternal hypertensive disorders ³⁷	4	Adult females	RR ³⁸ = 1.39 (95% CI: 1.10-1.76) per ln-unit PFOS
Low (and very low) birth weight	4	Newborns (years)	β ³⁹ = -10.5 g per PFOA (ng/mL) (95% CI: -16.7, -4.4) β = -45.2 g per doubling of PFOS (ng/mL) (95% CI: -76.8, -13.6)

3, when meta-analyses underpinned by robust science report associations, which could be causal but not necessarily proven, between PFAS exposure and health risk, with some conflicting evidence, areas of uncertainty and/or weaknesses (e.g., some papers saying that PFAS exposure poses a health risk, whilst others do not).

2, when meta-analyses OR a limited number of scientific papers report associations OR several scientific papers report suggestive or weak associations between PFAS exposure and health risk, with or without conflicting evidence and/or areas of uncertainty.

1, when meta-analyses OR scientific papers report inconclusive associations between PFAS exposure and health risk, with/without conflicting evidence or areas of uncertainty.

³⁶ A hazard ratio (HR) is a measure used to compare the risk of a particular event occurring at any given point in time between two groups. It's commonly used in clinical trials and medical research to assess the effectiveness of treatments.

³⁷ This includes gestational hypertension and preeclampsia.

³⁸ A risk ratio (RR) (also called a relative risk) is a measure used to compare the risk (or probability) of an event happening in an 'exposed' group to the risk of such a happening in a reference group. A RR = 1 implies no difference in risk between two groups, a RR > 1 implies a higher risk in the 'exposed' group compared to a reference group, and a RR < 1 implies a lower risk in the 'exposed' group. For example, evidence presented in this section suggests that there might be a RR of 1.27 for pneumonia and PFOA exposure, which means that individuals exposed to PFOA are 27% more likely to get pneumonia than those exposed to reference levels of PFOA.

³⁹ Beta, representing the slope of a relationship between two variables.

Specific health risk/ endpoint in scope	Confidence (0=None, 5- High)	Affected population	Exposure response functions identified in the literature with sufficient weight of evidence
Hypothyroidism	4	Adults	OR ⁴⁰ = 7.42 (95% CI: 1.14–48.12) per ln-unit PFOA OR = 3.03 (95% CI: 1.14–8.07) per ln-unit PFOS
Osteoporosis	3	Adult females	OR = 1.84 (95% CI: 1.17, 2.905) per ln-unit PFOA OR = 1.64 (95% CI: 1.14, 2.38) per ln-unit PFHxS OR = 1.45 (95% CI: 1.02, 2.05) per ln-unit PFNA
Kidney cancer	3	Adults	OR = 1.16 (95%CI: 1.03, 1.3) per 10 ng/mL PFOA
High LDL cholesterol	3	Adults	β =1.57 (95% CI: 0.02-3.13) mg/dL per ng/mL of PFOA β =0.08 (95% CI: -0.01-0.16) mg/dL per ng/mL of PFOS
Testicular cancer	2	Adults males	OR = 1.03 (95% CI: 1.02, 1.04) per 10 ng/mL PFOA
Obesity	2	Children (10 years ⁴¹)	β = 0.09 per PFOA (ng/mL) (95% CI: 0.02-0.17) β = 0.18 per ln((PFOS) (ng/mL)) (95% CI: 0.01-0.35)
		Adults	Tertile 1:<19.2 ng/mL; β = 1.5 kg gained Tertile 2: 19.2–32.1 ng/mL; β = 3.5 kg gained Tertile 3:>32.1 ng/mL; β = 3.2 kg gained
High blood pressure	2	Adults	PFNA: OR = 1.11 (95% CI: 1.04–1.19) PFOA: OR = 1.12 (95% CI: 1.02–1.23) PFOS: OR = 1.19 (95% CI: 1.06–1.34) PFHxS: OR = 1.03 (95% CI: 1.00–1.06)
Chronic kidney disease (CKD)	2	Adults	PFOA: OR = 1.73 (95% CI: 1.04-2.88) quartile 4 vs quartile 1 PFOS: OR = 1.82 (95% CI: 1.01-3.27) quartile 4 vs quartile 1
Endometriosis	2	Adult females	OR = 1.89 per log((PFOA (ng/mL)) (95% CI = 1.17– 3.06)
Time to pregnancy/ female infertility	2	Adult females	OR = 0.67 per log((PFOA (ng/mL)) (95% CI: 0.51– 0.88) OR = 0.62 per log((PFOS (ng/mL)) (95% CI: 0.47– 0.83)

As noted, the following list summarises the evidence underpinning the ERFs presented above, which are described in more detail as part of the Task 1 report and the literature.

- **Lower respiratory tract infection:** Dalsager et al. (2021)⁴² found that every doubling of maternal PFOA or PFOS blood concentration increased the risk of lower respiratory tract infections by 27% (95% Confidence Interval or CI: 1%-59%) and 54% (95% CI: 11%-115%) respectively.

⁴⁰ An odds ratio (OR) is a measure of association used to compare the odds of an event occurring in an 'exposed' group to the odds of such an event occurring in a reference group. An OR > 1 suggests a positive association between the exposure and the outcome, an OR = 1 suggests no association and an OR < 1 suggests a negative association. For example, evidence presented in this section concerning PFOA exposure and kidney cancer (renal cell carcinoma) presents an odds ratio of 1.71, which means that individuals with PFOA exposure are 1.71 times more likely to have cancer compared to those with reference PFOA exposure.

⁴¹ Childhood obesity burden is estimated in 10-year olds due to prenatal PFOA/PFOS exposure, based on the approach and methodology of Obsekov, Kahn and Trasande (2023).

⁴² Dalsager et al. (2021). Exposure to perfluoroalkyl substances during fetal life and hospitalization for infectious disease in childhood: A study among 1,503 children from the Odense Child Cohort. *Environment international*, 149, 106395. Available at: <https://doi.org/10.1016/j.envint.2021.106395>

- **Maternal hypertensive disorders:** Hu et al. (2023)⁴³ showed that each ln-unit increment in PFOS exposure was also associated with a risk ratio (RR) of 1.39 (95% CI: 1.10-1.76).
- **Low (and very low) birth weight:** Meng et al. (2018)⁴⁴ observed a 45.2 g decrease (95% CI: -76.8, -13.6) in birth weight per doubling of maternal plasma concentrations of PFAS. Steenland et al. (2018)⁴⁵ found a change of birthweight of -10.5 g (-16.7, -4.4) for every ng/mL of PFOA in maternal blood.
- **Hypothyroidism:** Wen et al. (2013)⁴⁶ estimated an OR of 7.42 (95% CI: 1.14–48.12) per natural logarithm (ln)-unit⁴⁷ increase of PFOA serum concentration and an OR of 3.03 (95% CI: 1.14–8.07) per natural logarithm (ln)-unit increase of PFOS serum concentration.
- **Osteoporosis:** Khalil et al. (2016)⁴⁸ found that the ORs for osteoporosis prevalence in women with a one ln-unit increase in serum PFOA, PFHxS, and PFNA were as follows: 1.84 (95% CI: 1.17, 2.905), 1.64 (95% CI: 1.14, 2.38), and 1.45 (95% CI: 1.02, 2.05), respectively
- **Kidney cancer:** Bartell and Vieira (2021)⁴⁹ observed an average relative increase in cancer risk per 10 ng/mL increase in serum PFOA of 16% (95% CI: 3%, 30%).
- **High LDL cholesterol:** The U.S. EPA (2024)⁵⁰ estimated a positive increase in total cholesterol (TC) of 1.57 (95% CI: 0.02-3.13) mg/dL per ng/mL serum PFOA, and of 0.08 (95% CI: -0.01-0.16) mg/dL per ng/mL serum PFOS.
- **Testicular cancer:** Bartell and Vieira (2021)⁵¹ observed an average relative increase in cancer risk per 10 ng/mL increase in serum PFOA of 3% (95% CI: 2%, 4%).
- **Obesity:** Liu et al. (2018a)⁵² identified a 0.09 (95% CI: 0.02-0.17) increase in child body mass index (BMI) z-score⁵³ per ng/ mL increase in prenatal PFOA. Lauritzen et al. (2018)⁵⁴ identified a 0.18 (95% CI: 0.01-0.35) increase in child BMI z-score per ln-unit

⁴³ Hu et al. (2023). Perfluoroalkyl and polyfluoroalkyl substances and hypertensive disorders of pregnancy: A systematic review and meta-analysis. *Environmental research*, 231(Pt 2), 116064. Available at: <https://doi.org/10.1016/j.envres.2023.116064>

⁴⁴ Meng et al. (2018). Prenatal Exposure to Perfluoroalkyl Substances and Birth Outcomes: An Updated Analysis from the Danish National Birth Cohort. *International journal of environmental research and public health*, 15(9), 1832. Available at: <https://doi.org/10.3390/ijerph15091832>

⁴⁵ Steenland et al. (2018). Serum Perfluorooctanoic Acid and Birthweight: An Updated Meta-analysis With Bias Analysis. *Epidemiology (Cambridge, Mass.)*, 29(6), 765-776. Available at: <https://doi.org/10.1097/EDE.0000000000000903>

⁴⁶ Wen et al. (2013). Association between serum perfluorinated chemicals and thyroid function in U.S. adults: the National Health and Nutrition Examination Survey 2007-2010. *The Journal of clinical endocrinology and metabolism*, 98(9), E1456-E1464. Available at: <https://doi.org/10.1210/jc.2013-1282>

⁴⁷ Could be approximated to 'percentage growth' against an original series/baseline

⁴⁸ Khalil et al. (2016). Association of perfluoroalkyl substances, bone mineral density, and osteoporosis in the U.S. population in NHANES 2009-2010. *Environ Health Perspect* 124:81-87. Available at: <https://doi.org/10.1289/ehp.1307909>

⁴⁹ Bartell and Vieira (2021). Critical review on PFOA, kidney cancer, and testicular cancer. *Journal of the Air & Waste Management Association* (1995), 71(6), 663-679. Available at: <https://doi.org/10.1080/10962247.2021.1909668>

⁵⁰ U.S. EPA (2024). Economic Analysis for the Final Per- and Polyfluoroalkyl Substances National Primary Drinking Water Regulation. EPA Document Number: EPA-815-R-24-001. Available at: https://www.epa.gov/system/files/documents/2024-04/pfas-npdwr_final-rule_ea.pdf

⁵¹ Bartell and Vieira (2021). Critical review on PFOA, kidney cancer, and testicular cancer. *Journal of the Air & Waste Management Association* (1995), 71(6), 663-679. Available at: <https://doi.org/10.1080/10962247.2021.1909668>

⁵² Liu et al. (2018a). Perfluorooctanoic Acid (PFOA) Exposure in Early Life Increases Risk of Childhood Adiposity: A Meta-Analysis of Prospective Cohort Studies. *International Journal of Environmental Research and Public Health*, 15(10), 2070. Available at: <https://doi.org/10.3390/ijerph15102070>

⁵³ Body mass index (BMI) is a measurement of body fat based on height and weight. The z-score, the number resulting from the calculation, indicates where a particular measurement falls in the range of body fat measurements.

⁵⁴ Lauritzen et al. (2018). Prenatal exposure to persistent organic pollutants and child overweight/obesity at 5-year follow-up: a prospective cohort study. *Environmental health : a global access science source*, 17(1), 9. Available at: <https://doi.org/10.1186/s12940-017-0338-x>

ng/ mL increase in prenatal PFOS. Liu et al. (2018b)⁵⁵ also found that adults with PFOS levels >32.1 ng/mL gained 3.2 kg over the study period, adults with levels 19.2–32.1 ng/mL gained 3.5 kg, and adults with levels <19.2 ng/mL gained 1.5 kg.

- **High blood pressure:** Pan et al. (2023)⁵⁶ showed that PFNA (OR = 1.11, 95% CI: 1.04–1.19), PFOA (OR = 1.12, 95% CI: 1.02–1.23), PFOS (OR = 1.19, 95% CI: 1.06–1.34) and PFHxS (OR = 1.03, 95% CI: 1.00–1.06) were significantly associated with hypertension.
- **Chronic kidney disease:** Shankar et al. (2011)⁵⁷ used data for 4,587 adults and found that the odds ratio for chronic kidney disease (CKD) was 1.73 (95% CI: 1.04–2.88) for PFOA and 1.82 (95% CI: 1.01–3.27) for PFOS among subjects in quartile 4 compared with subjects in quartile 1.
- **Endometriosis:** Buck Louis et al. (2012)⁵⁸ found an OR of 1.89 (95% CI: 1.17–3.06) per log unit (ng/mL) exposure to PFOA.
- **Time to pregnancy/ female infertility:** Whitworth et al. (2012)⁵⁹ estimated a 0.67 (95% CI: 0.51–0.88) fecundability ratio per ln unit PFOA exposure and a 0.62 (95% CI: 0.47–0.83) fecundability ratio per log unit PFOS exposure for couple infertility, defined as time to pregnancy of more than 12 months.

Given the available evidence and the impact pathways, it is considered the female infertility and time to pregnancy capture similar implications on people's health and wellbeing and their ability to procreate; whilst decreased foetal growth and small for gestational age are considered direct risk factors for low (and very low) birthweight, which was assumed to capture the primary health risks associated with PFAS exposure during gestation.

Other endpoints were excluded from this list due to insufficient evidence or confidence in the exposure-risk relationships. Diabetes, breast cancer, and gestational diabetes were not taken forward because the level of confidence or strength of the attribution between these health risks and PFAS exposure was very low (a confidence score of 1). Inflammatory bowel disease, low sperm count and mobility, liver disease, non-alcoholic fatty liver disease cirrhosis, liver cancer, prostate cancers and other cancers were not included in the study as robust ERFs were not identified in the literature.

Step 4: Health impact analysis

This section specifies the methods to **quantify the potential health impacts of PFAS exposure across the 'affected population' groups for the selected health endpoints**, in terms of attributable cases of ill health (Numbers of cases, etc.), burden of these disease cases in Disability-Adjusted Life Years, and preventable deaths. As noted in Section 2.2., the methods build on good practice guidelines and the literature, especially approaches employed in Goldenman *et al.* (2019), Plass *et al.* (2023), and Obsekov, Kahn and Trasande (2023).

⁵⁵ Liu et al. (2018b). Perfluoroalkyl substances and changes in body weight and resting metabolic rate in response to weight-loss diets: A prospective study. *PLoS medicine*, 15(2), e1002502. Available at: <https://doi.org/10.1371/journal.pmed.1002502>

⁵⁶ Pan et al., (2023). The relationship between perfluoroalkyl substances and hypertension: A systematic review and meta-analysis, *Environmental Research*, 232, 116362. Available at: <https://doi.org/10.1016/j.envres.2023.116362>

⁵⁷ Shankar et al. (2011). Perfluoroalkyl chemicals and chronic kidney disease in US adults. *American journal of epidemiology*, 174(8), 893–900. Available at: <https://doi.org/10.1093/aje/kwr171>

⁵⁸ Buck Louis et al. (2012). Perfluorochemicals and endometriosis: the ENDO study. *Epidemiology (Cambridge, Mass.)*, 23(6), 799–805. Available at: <https://doi.org/10.1097/EDE.0b013e31826cc0cf>

⁵⁹ Whitworth et al. (2012). Perfluorinated compounds and subfecundity in pregnant women. *Epidemiology (Cambridge, Mass.)*, 23(2), 257–263. Available at: <https://doi.org/10.1097/EDE.0b013e31823b5031>

Impact analysis approach

To quantify the human health impacts attributable PFAS exposure, inputs from Steps 1-3 are used to characterise the baseline burden of disease and estimate the statistical cases of ill health attributable to PFAS exposure for each of the health endpoints presented in Table 3-6. These inputs are:

- **Size of the affected population** groups in the EEA (Step 1).
- **Exposure levels** for each affected population group to specific substances in scope (Step 2).
- **Exposure-risk relationships** characterising how the levels of exposure for each of these European populations might be associated with ill health across the selected health endpoints (Step 3)
- **Baseline levels of risk**, taking the incidence (or prevalence) rates across health endpoints for the general population as an approximation for the risk that may be faced by unexposed or relatively less exposed people.

These inputs are used to estimate the **'statistical cases' of ill health** of an endpoint i (e.g., cancer) attributable to PFAS pollution in period or year t estimated as follows:

$$SC_i^t = Impact_i * Pop_i^t * Risk_i$$

Where:

SC_i^t , refers to the 'statistical cases' of ill health for an endpoint i attributable to PFAS pollution in period or year t .

$Impact_i$ refers to the health impact for an endpoint i in the exposed group that is due to exposure to PFAS, expressed as a proportion of the baseline cases of ill health

Pop_i^t and $Risk_i$ refer to the affected population and baseline risk (incidence or prevalence rate as applicable), respectively, and for endpoint i in period or year t .

Following this, the cases of ill health associated with an endpoint i are used to estimate the **burden of disease (in terms of Disability-Adjusted Life Years and preventable deaths)** in period or year t as follows:

$$DALYs_i^t = SC_i^t * DALY/case_i^t$$

$$Preventable\ deaths_i^t = \frac{(DALY_i^t * \%YLL/DALY_i)}{YLL\ per\ death_i}$$

Where:

$DALY_i^t$ refers to the total Disability-Adjusted Life Years associated with an endpoint i that are attributable to PFAS pollution in period or year t .

$Preventable\ deaths_i^t$ refers to the preventable deaths associated with an endpoint i attributable to PFAS pollution in period or year t .

$DALY/case_i^t$ refers to the Disability-Adjusted Life Years attributable to a typical case of ill health for an endpoint i in period or year t , based on evidence from IHME global burden of disease studies.

$\%YLL/DALY_i$ refers to the years of life lost expressed as a proportion of the Disability-Adjusted Life Years attributable to a typical case of an endpoint i , based on evidence from IHME global burden of disease studies.

$YLL \text{ per death}_i$ refers to the average years of life lost per preventable death for the affected population, where possible, associated with a specific endpoint i or more broadly otherwise, based on IHME global burden of disease evidence for Europe.

The values assumed for the $DALY/case_i$ and $\%YLL/DALY_i$ have been developed based on IHME Global Burden of Disease⁶⁰ database and are represented in the Table below.

Table 3-7 DALY/case and % of YLL/DALY for a typical case across the selected endpoints, in the EU, based on evidence from 2021

Specific health risk/ endpoint in scope	DALY/case	%YLL/DALY
Lower respiratory tract infections (LRTI)	0.40	99.7%
Maternal hypertensive disorders	0.01	24.0%
Low (and very low) birth weight	3.34	50.3%
Hypothyroidism	0.02	59.0%*
Osteoporosis	0.08	0.0%
Kidney cancer	3.35	95.3%
High LDL cholesterol	0.03	91.1%
Testicular cancer	1.06	80.2%
Obesity	0.06	59.1%
High blood pressure	0.17	89.7%
Chronic kidney disease (CKD)	0.22	71.1%
Endometriosis	0.66	0.1%
Time to pregnancy/ female infertility	0.01	0.0%

*An average across all of the endpoints

The Box below presents an illustration of the analysis that will be conducted to estimate attributable burden of disease for the low (and very low) birth weight endpoint. A similar approach will, based on the principles outlined above, will be followed for the other 12 endpoints.

⁶⁰ <https://vizhub.healthdata.org/gbd-results/>

Box 3-1 Illustrated example of the estimation of attributable health impacts of PFOA exposure through low (and very low) birth weight

Low (and very low) birth weight, LBW

Around 7% of newborns in the EEA suffer from low birth weight (< 2.5 kg) at present. Evidence suggests that some of these cases might be attributable to PFOA exposure. These cases are identified below, as well as estimating the disability-adjusted life years that are associated with such said health risk and estimated attributable 'statistical' deaths.

Pathway	Unit	Central estimate	Formula/ Source
Affected population	Newborns	3,726,318	Step 1
Exposure	µg/L PFOA	2.0	Step 2
Baseline incidence rate	Percentage	7.0%	IHME Database. In addition, it has been assumed 1.0% births below 1.5kg, 6% births between 1.5-2.5kg, 92% births between 2.5-4.5kg and 1% above 4.5kg, based on the available evidence from Euro-Peristat. ⁶¹
Baseline numbers	Number of new cases	260,842	= 7% × 3,726,318
ERF	Decrease in birth weight per µg/L PFOA	-10.5g	Step 3
Attributable health impact of PFAS exposure	Decrease in birth weight at current exposure	-21g	= -10.5g per µg/L × 2 µg/L
	Attributable statistical cases of low birth weight (birth weight <2.5kg)	4,789	PFOA exposure is attributable to lower weight at birth compared to the alternative. Evidence of the distribution of births across different birth weight brackets has been explored to estimate attributable statistical cases due to PFOA exposure. Around 6% of newborns weigh between 1.5-2.5 kg at birth. The ERF and associated evidence suggest that a proportion of newborns closer to 2.5 kg find themselves in this weight bracket due to 'losing' around 21 g from PFOA exposure. This means that, under a uniform distribution of births in the weight bracket 1.5-2.5 kg, around 4,789 newborns could have had low birth weight due to an attributable loss of 21g from PFOA exposure.
	Disease burden (DALYs)	16,001	= 3.34 DALY/case × 4,789 cases

⁶¹European Perinatal Health Report: Core indicators of the health and care of pregnant women and babies in Europe from 2015 to 2019. Available at: https://www.europeristat.com/wp-content/uploads/2022/11/Euro-Peristat_Fact_sheets_2022_for_upload.pdf

	Preventable statistical deaths	100	At present, the average estimated life expectancy at birth in the EU is 80.6 years (Eurostat). $= \frac{16,001 (DALY) * 50\% (YLL \text{ per } DALY)}{80.6 (YLL \text{ per statistical death})}$

The estimated burden of disease from low (and very low) birth weight attributable to PFOA exposure in the EEA at present is estimated to be around 4,789 cases, 16,001 DALYs and 100 preventable statistical deaths.

Please note that additional burden will also be estimated from exposure to PFOS, following the same methods.

These estimates are based on core assumptions which are affected by uncertainty. Section 4 specifies our approach to conduct sensitivity analysis, which will seek to test and understand how some of these assumptions and uncertainties affect these conclusions.

Again, these proposed methods will be used to quantify the attributable health impacts of PFAS exposure for the other 12 selected health endpoints. Please refer to the sensitivity analysis Section 4 to consider our proposed approach for developing a likely medium, unlikely lower and upper bound estimates of the human health impacts attributable to PFAS exposure.

Prospective scenarios

The same methods will be employed to consider potential health impacts attributable to different levels of PFAS exposure under prospective scenarios. In addition to drawing on a time series of PFAS levels under those scenarios over time, we also propose to specify the evolution of key variables of interest under a baseline trend scenario, including:

- The size of the affected population. We have identified prospective CAGR that reflect baseline population projects (see Table 3.2 in Step 1) and enable us to estimate changes in population over time.
- Incidence (or prevalence) rates. We have historical evidence of incidence rates across the relevant endpoints in the EU, as well as an understanding of changes in the population. These trends will be used to estimate incidence/prevalence rates in the future for baseline populations.
- DALYs/case and YLL/DALY. The available historical evidence also presents the evolution of DALYs/case and YLL/DALY. Changes in burden per case of ill health can be driven by changes in how we manage acute and chronic conditions, medical advances as well as changes in people's perception of illness.

Our suggestion is to retain ERFs as presented by the literature and maintain the assumptions of the monetary value of a life year and/or statistical life, medical costs, and sickness absence constant in real terms over time, for the purposes of this study.

Step 5: Human health cost valuation

Finally, having quantified the impacts of different levels of PFAS exposure across European populations, **Step 5 specifies the proposed approaches to monetise these human health**

impacts and thus quantify the monetary cost of PFAS pollution ‘at present’ and under a range of ‘prospective scenarios’ over time.

Literature precedent and guidelines

Section 2.2 summarises the direct precedent identified in the literature, quantifying the monetary value of human health cost of PFAS pollution in Europe and the U.S. This includes:

- Goldenman *et al.* (2019) use the ‘value of statistical life’, contingent valuation method to monetise non-market disease burden in Europe.
- Obsekov, Kahn and Trasande (2023) draw on market-based methods, such as the cost of illness approach, to develop estimates of medical costs and productivity losses, and non-market contingent valuation methods to quantify and monetise disease burden in the U.S.

In addition, the Commission’s Better Regulation Toolbox, and especially Tool #63 ‘Cost-Benefit Analysis’⁶², has been considered especially to align the method to ‘the principle of proportionate analysis’ that is specified in this Tool.

Previous studies conducted or commissioned by the Commission have also been reviewed, such as baseline studies into the health, socio-economic and environmental impacts concerning workplace chemical exposure conducted or commissioned by DG Employment^{63,64,65}. These provide additional precedent and insights that support the specification of a practical, proportionate and robust method for this study into the costs of PFAS pollution.

Furthermore, guidelines and studies led or commissioned by the European Chemicals Agency (ECHA) and the Organisation for Cooperation and Development (OECD) have been considered.

- The OECD⁶⁶ and ECHA^{67,68} conduct studies into the willingness-to-pay to avoid negative chemical related health effects, which they report on their webpages and can be used as reference to quantify the monetary value or cost associated with: i)

⁶² European Commission (2023). Better Regulation Toolbox Chapter 8 Methodologies for analysing impacts in impact assessments, evaluations and fitness checks. Available at: https://commission.europa.eu/document/download/0d32ee11-92da-434d-9c86-fd4579d95dc6_en?filename=BRT-2023-Chapter%208-Methodologies%20for%20analysing%20impacts%20in%20IAs%20evaluations%20and%20fitness%20checks_0.pdf

⁶³ Garrett S., Vencovsky D., Collins H. (2021). Study on collecting information on substances with the view to analyse health, socio-economic and environmental impacts in connection with possible amendments of Directive 98/24/EC (Chemical Agents) and Directive 2009/148/EC (Asbestos). Available at: <https://op.europa.eu/en/publication-detail/-/publication/03b0cc5a-5e22-11ec-9c6c-01aa75ed71a1/language-en>; and the methodological note, available at: <https://op.europa.eu/en/publication-detail/-/publication/371c9593-5e1f-11ec-9c6c-01aa75ed71a1/language-en>

⁶⁴ Vencovsky et al. (2019). Study to collect recent information relevant to modernising EU Occupational Safety and Health chemicals legislation with a particular emphasis on reprotoxic chemicals with the view to analyse the health, socio-economic and environmental impacts in connection with possible amendments of Directive 2004/37/EC and Directive 98/24/EC. Available at: <https://op.europa.eu/en/publication-detail/-/publication/094387fb-da9a-11e9-9c4e-01aa75ed71a1>

⁶⁵ Postle et al. (2016). Study to collect updated information for a limited number of chemical agents with a view to analyse the health, socio-economic and environmental impacts in connection with possible amendments of Directive 2004/37/EC on the protection of workers from the risks related to exposure to carcinogens or mutagens at work. Available at: <https://op.europa.eu/en/publication-detail/-/publication/c688d768-9954-11e9-9d01-01aa75ed71a1/language-en>

⁶⁶ OECD. Surveys on Willingness-to-Pay to Avoid Negative Chemicals-Related Health Effects. Available at: <https://www.oecd.org/en/topics/sub-issues/risk-management-risk-reduction-and-sustainable-chemistry/the-costs-and-benefits-of-regulating-chemicals.html>

⁶⁷ ECHA (2023). Reference willingness-to-pay values for monetising chemicals health impacts. Available at: https://echa.europa.eu/documents/10162/17229/seac_reference_wtp_values_en.pdf/403429a1-b45f-4122-ba34-77b71ee9f7c9

⁶⁸ ECHA (2016). Valuing selected health impacts of chemicals. Summary of the results and a critical review of the ECHA study. Available at: https://echa.europa.eu/documents/10162/17228/echa_review_wtp_en.pdf/dfc3f035-7aa8-4c7b-90ad-4f7d01b6e0bc

a statistical case of ill health, the health burden measured in Disability-Adjusted Life Years, and/or the burden of a premature death (or a 'statistical life' lost).

- In addition, when quantifying the non-market burden of disease attributable to chemical pollution and exposure, studies by ECHA note that 'it has been argued that DALYs [Disability-Adjusted Life Years] are more appropriate [to measure the burden of disease] in the context of REACH, as the aim is to reduce burden of disease within society'⁶⁹.

Based on non-market, contingent valuation methods, ECHA publishes reference monetary values of the disease burden associated with a 'statistical' case⁷⁰ of 'ill health' (e.g., very low birth weight, valued at €167,000-€538,000 per case⁷¹) by health endpoint; a premature death (or 'Value of a Statistical Life', VSL); and a disability-adjusted life year (or 'Value of a Life Year', VOLY).

These references and guidelines have been considered, complemented by additional secondary literature, to specify a practical, robust and proportionate approach, outlined below.

Valuation methods and assumptions

For each health risk (and endpoint) which has been confidently associated with human exposure to PFAS, and where there is sufficient available evidence, the following methods are specified to quantify three additional human health impacts on health and wellbeing, healthcare systems and economic productivity:

- **Health and wellbeing losses (or the 'non-market disease burden', NMDB)**, defined as losses of both quality and quantity of life due to illness or disability from pollution, and measured as Disability-Adjusted Life Years and/or preventable deaths. These will be monetised based on case-specific reference values published by ECHA⁷², or VSL or VOLY based valuation, which are underpinned by contingent valuation non-market methods.
- **Healthcare costs (HC)**, defined as the increased need for medical or healthcare services due to the pollution-attributable cases of ill health, leading to higher healthcare costs. These will be monetised based on a cost of illness market-based approach, drawing primarily on case-specific secondary evidence and previous related studies and focussing on the first year after diagnosis.
- **Economic productivity costs (EPC)**, defined losses in economic productivity from sickness absence or absenteeism due to direct implications of typical morbidity pathways⁷³. These will be monetised based on a value of earnings market-based

⁶⁹ ECHA (2011). Quantification and valuation of human health impacts of chemicals based on quality and disability-adjusted life-years. Available at: https://echa.europa.eu/documents/10162/17231/report_quality_daly_en.pdf/f8c20060-8e7d-4b87-9e0c-64ba2999e63d

⁷⁰ 'Statistical' case or death refers to the estimation of events that might have or not occurred but could be associated to, in this case, chemical exposure based on the available evidence.

⁷¹ ECHA (2023). Reference willingness-to-pay values for monetising chemicals health impacts. Available at: https://echa.europa.eu/documents/10162/17229/seac_reference_wtp_values_en.pdf/403429a1-b45f-4122-ba34-77b71ee9f7c9

⁷² ECHA (2023). Reference willingness-to-pay values for monetising chemicals health impacts. Available at: https://echa.europa.eu/documents/10162/17229/seac_reference_wtp_values_en.pdf/403429a1-b45f-4122-ba34-77b71ee9f7c9

⁷³ Please note that we have excluded estimates of productivity impacts from premature death, to mitigate for any potential overlaps with the non-market reference VOLYs. We have also isolated any additional, indirect implications of further disease, especially in the case of risk factors, such as hypertension, high cholesterol, etc., also because of challenges associated with managing overlaps in the valuation estimates. Section 3.3.2 highlights these limitations and sets out recommendations for further research.

approach, drawing also on case-specific secondary evidence and previous, related studies.

The most significant monetary costs, when considering their potential magnitude or scale, are the monetary ‘health and wellbeing losses’. These costs, which were also the focus of Goldenman *et al.* (2019), are thus prioritised. The available evidence and presented in this document suffices to conduct a reasonable and proportionate analysis of associated healthcare costs and economic productivity losses, which aim to provide a broad estimate of the magnitude of these additional, direct and indirect health-related costs of PFAS pollution.

Other human health costs that might result from PFAS pollution are not captured directly, such as adverse impacts on informal or formal social care, due to a lack of evidence transparently isolating these impacts. There are, however, a range of indirect, knock-on implications of the direct human health impact of PFAS pollution captured in the proposed valuation approach, which are described in the following paragraphs.

Please note, also, that Section 2.2. and Appendix A to Annex B provide a list of other valuation methods identified in the literature review undertaken for this study (Taks 1), and a high-level review of their strengths and weaknesses for reference.

A targeted review of the relevant literature highlighted earlier in this section was conducted to assemble a proposition for the monetary values (or costs) associated with a ‘statistical’ case of ill health attributable to PFAS pollution, based on the available evidence. These are summarised in the following Table, specified by endpoint in scope (see previous Steps 3 and 4) and cost ‘category’ (i.e., non-market disease burden, healthcare costs and economic productivity losses). Please note that the Table presents approximate values for total costs per statistical case, albeit in some cases, such as the case for chronic conditions with high survival rates, medical costs especially might be underestimated. The information presented on the Table below is complemented by a more detailed presentation of the underpinning evidence, assumptions and analysis in Appendix B to Annex B.

Table 3-8 Monetary values or costs associated with a 'statistical' case of ill health (EUR₂₀₂₄/case)⁷⁴, by endpoint in alphabetical order and cost category (see Appendix B to Annex B for a more detailed presentation of sources and analysis underpinning this and Section 4.3 on sensitivities).

Specific health risk/ endpoint in scope	Non-market disease burden (EUR ₂₀₂₄ / case)	Healthcare costs (EUR ₂₀₂₄ / case)	Productivity Costs (EUR ₂₀₂₄ / case)	Commentary (see Appendix B to Annex B for more detail)
Chronic kidney disease	175,000	5,000	13,000	The non-market disease burden is based on ECHA's reference values for the median (ECHA, 2023); healthcare costs are based on evidence from Falducci <i>et al.</i> (2024); and economic productivity losses and costs are based on the evidence-based assumption that a typical case result in around 30 days of sickness absence.
Endometriosis	123,000	4,000	8,000	The non-market disease burden is based on DALY-based VOLY valuation drawing on ECHA's reference VOLY values for the mean (ECHA, 2016); healthcare costs and economic productivity loss estimates are based on Simoens <i>et al.</i> (2011).
Maternal hypertensive disorders	6,000	4,000	10,000	The non-market disease burden is based on estimates presented by on Garrett, Vencovsky, Collins (2021) study for DG EMPL, broadly aligned with DALY-based VOLY valuations drawing on ECHA's reference VOLY values for the mean (ECHA, 2016); attributable healthcare costs are based on Fox <i>et al.</i> (2017); and economic productivity loss estimates are also based on Garrett, Vencovsky, Collins (2021).
High LDL cholesterol	5,000	5,000	3,000	The non-market disease burden is based on DALY-based VOLY valuation drawing on ECHA's reference VOLY values for the mean (ECHA, 2016); healthcare costs based on Allahyari <i>et al.</i> (2020); and economic productivity loss estimates are based on Leynen <i>et al.</i> (2016) and the assumption that attributable sickness absence might be up to 6.25 workdays (or no more than half 12.5 days, or the average days of absenteeism per employee in Europe based on WHO evidence).
High systolic blood pressure	32,000	900	3,000	The non-market disease burden is based on DALY-based VOLY valuation, drawing on ECHA's reference VOLY values for the mean (ECHA, 2016); healthcare costs based on Garrett, Vencovsky, Collins (2021); and economic productivity loss estimates are based on

⁷⁴ All monetary values are presented in 2024 euros, having adjusted data from secondary sources using evidence from the GDP deflator where necessary. See Appendix B.

Specific health risk/ endpoint in scope	Non-market disease burden (EUR ₂₀₂₄ / case)	Healthcare costs (EUR ₂₀₂₄ / case)	Productivity Costs (EUR ₂₀₂₄ / case)	Commentary (see Appendix B to Annex B for more detail)
				Leynen <i>et al.</i> (2016) and the assumption that attributable sickness absence could be up to 6.25 work-days.
Hypothyroidism	3,500	1,000	3,000	The non-market disease burden is based on DALY-based VOLY valuation, drawing on ECHA's reference VOLY values for the mean (ECHA, 2016); healthcare costs are based on EURIPID and Møllehave <i>et al.</i> (2018); and economic productivity loss estimates are based on Nexo <i>et al.</i> (2014) and the assumption that attributable sickness absence could be up to 6.25 workdays.
Kidney cancer	626,000	18,000	32,000	The non-market disease burden is based on DALY-based VOLY valuation, drawing on ECHA's reference VOLY values for the mean (ECHA, 2016); healthcare costs based on Buja <i>et al.</i> (2022); and economic productivity loss estimates are based on the assumption that cancer patients might typically take around 75-120 days off work, although acknowledging this will depend on the type of cancer (developed based on a study from reframe cancer 2024 and breast cancer evidence in Drolet <i>et al.</i> , 2005).
Low (and very low) birth weight	624,000	23,000	10,000	The non-market disease burden is based on DALY-based VOLY valuation, drawing on ECHA's reference VOLY values for the mean (ECHA, 2016), albeit this is also aligned or just between the median and mean reference case values (ECHA, 2023); healthcare costs based on Cavallo <i>et al.</i> (2015); and economic productivity loss estimates are based on the assumption that one parent may take up to 24 additional days off work, due to additional care/hospitalisation of their newborn/infant (developed based on evidence from Mehretie <i>et al.</i> , 2024).
Obesity	11,000	800	1,800	The non-market disease burden is based on DALY-based VOLY valuation, drawing on ECHA's reference VOLY values for the mean (ECHA, 2016); healthcare costs and productivity loss estimates are based on the European Food Information Council's 'Europe's Obesity Statistics: Figures, Trends & Rates by Country', updated in 2024.
Osteoporosis	14,000	2,000	3,000	The non-market disease burden is based on DALY-based VOLY valuation, drawing on ECHA's reference VOLY values for the mean

Specific health risk/ endpoint in scope	Non-market disease burden (EUR ₂₀₂₄ / case)	Healthcare costs (EUR ₂₀₂₄ / case)	Productivity Costs (EUR ₂₀₂₄ / case)	Commentary (see Appendix B to Annex B for more detail)
				(ECHA, 2016); healthcare costs based on the International Osteoporosis Foundation 'Key Statistics for Europe', dated 2021; and economic productivity loss estimates are based on the assumptions that, on average, an osteoporosis patient may take up to 8 days of attributable sickness absence.
Lower respiratory tract infection	75,000	200	3,000	The non-market disease burden is based on DALY-based VOLY valuation, drawing on ECHA's reference VOLY values for the mean (ECHA, 2016); healthcare costs based on Oppong <i>et al.</i> (2010); and economic productivity loss estimates are based on the assumptions that, on average, a LRTI patient (and a guardian with the patient, where relevant) may take up to a total 7 days of attributable sickness absence (drawing also on Fisman <i>et al.</i> , 2024).
Testicular cancer	198,000	8,000	32,000	The non-market disease burden is based on DALY-based VOLY valuation, drawing on ECHA's reference VOLY values for the mean (ECHA, 2016); healthcare costs based on Schlueter <i>et al.</i> (2020), albeit these data are unspecific to the type of cancer; and economic productivity loss estimates are based on the assumption that cancer patients might typically take around 75-120 days off work, although acknowledging this will depend on the type of cancer (developed based on a study from <i>reframe cancer 2024</i> and breast cancer evidence in Drolet <i>et al.</i> , 2005).
Time to pregnancy/ female infertility	41,000	8,000	3,000	The non-market disease burden is based on DALY-based VOLY valuation, drawing on ECHA's reference VOLY values for the mean (ECHA, 2016); healthcare costs associated with infertility treatment are based on Bourrion <i>et al.</i> (2022); and economic productivity loss estimates are based on the assumptions that, on average, a typical infertility patient (and partner, where relevant) may take up to a total 7 days of attributable absence from work (drawing on the typical length of infertility treatment cycles and associated care commitments).

Please see Appendix B to Annex B for underpinning evidence/sources and the analysis undertaken to conclude on these proposals. In addition, please note that these figures are rounded to the nearest '000 euros, or '00 where relevant.

In summary, these monetary values in 2024 euros per case have been developed to update the estimates of the potential burden of disease attributable to PFAS exposure in Europe, based on the latest available evidence and the confidence in said evidence of the links between PFAS and human health and established precedent and good practice on human health cost valuation. As noted, again, the focus will be on estimating the non-market burden of disease associated with health and wellbeing losses, which are considered the relatively most significant costs from a magnitude perspective. This will be complemented by a reasonable and proportionate analysis of direct healthcare costs within a year of 'diagnosis' or equivalent, per case; and economic productivity losses associated with 'lost output' from sickness absence resulting from the associated morbidity and additional employer costs from supporting their employees through this process.

These suggested monetary values are proposed as 'central' or 'most reasonable' if not 'most likely' values for the purpose of this study. Additional information is presented in Appendix B to Annex B. In addition, sensitivity analysis will be conducted by exploring uncertainties associated with the key assumptions made in this study and their impact on the estimates of monetary costs of PFAS pollution (see Section 4).

Quantifying the monetary value of human health costs

Upon agreement of these assumptions, the monetised disease burden or human health costs (HHC) attributable to PFAS pollution will be quantified, for a given year t , as follows:

$$(1) HHC^t = \sum_{i=1}^{13} SC_i^t \times (NMDB_i^t + HC_i^t + w_i \times EPC_i^t)$$

Where:

HHC^t , refers to the total, estimated human health costs attributable to PFAS pollution in period or year t .

SC_i^t , refers to the 'statistical cases' of ill health for an endpoint i (e.g., cancer) attributable to PFAS pollution in period or year t .

$NMDB_i^t$, HC_i^t , EPC_i^t , refer to the monetary value of non-market disease burden, healthcare costs and economic productivity costs, respectively, per statistical case of ill health for an endpoint i (e.g., cancer) attributable to PFAS pollution in period or year t .

w_i , refers to a weighting factor to reflect the 'statistical cases' of ill health for an endpoint i , equivalent to the proportion of the cases that might affect workers and thus result in sickness absence.

This is illustrated below, drawing on the LBW example.

Box 3-2 Illustrated example of the estimation of attributable health impacts of PFOA exposure through low (and very low) birth weight

Low (and very low) birth weight (LBW)

The estimated burden of disease from low (and very low) birth weight attributable to PFOA exposure in the EEA at present is estimated to be around 4,789 cases, 16,001 DALYs and 100 preventable statistical deaths (see Box 3-1). As a result, the human health cost from LBW attributable to PFOA exposure is estimated to surpass €3 billion/year (4,789 cases*657,000 €/case).

Please note that additional burden will also be estimated to result from PFOS exposure following the same methods.

Finally, a methodological summary table is presented below, which is followed by a recapitulation of the key data inputs required to conduct this assessment, and the gaps, limitations and assumptions. These sections are complemented by additional details summarised in Appendixes A and B to Annex B.

Summary of the proposed stepwise methods for the human health cost assessment

The Table below summarises the proposed stepwise methods, identifying key inputs, core assumptions and main sources.

Table 3-9: Summary of the steps for the human health cost assessment, including key inputs, core assumptions and main sources

Steps	Key inputs	Core assumptions	Main sources
1. Estimating the size of the population across relevant groups	Population data	Future projections (i.e., CAGR) and % of people living near polluted sites	Eurostat, the World Bank, Goldenman <i>et al.</i> (2019), Andersen <i>et al.</i> , 2000
2. Establishing the levels of PFAS exposure across population groups	Definition of exposure as PFAS levels in human blood serum Recent monitoring and case studies (e.g., Minnesota, U.S.; West Virginia, U.S.; Dordrecht, Netherlands; Ronneby, Sweden; and Veneto Region, Italy) Estimated prospective blood serum levels under prospective scenarios	Scenario projections for the future	HMB4EU and scientific literature (see Step 1 and 2 above)
3. Identification of relevant health risks or endpoints and ERFs	Outputs of scientific studies, and an assessment of confidence or strength of evidence	Levels of confidence or strength of evidence Applicability	Scientific literature (see Step 3 above)
4. Quantification of impacts	Baseline levels of risk (incidence or prevalence rates depending on the endpoint), and the population size and ERFs confirmed in previous steps Disability-Adjusted Life Years attributable to a case of ill health, by endpoint	Applicability Projections for the drawing on historical trends and relationships	IHME, Goldenman <i>et al.</i> (2019), Plass <i>et al.</i> (2023), Obsekov, Kahn and Trasande (2023) and other literature

Steps	Key inputs	Core assumptions	Main sources
5. Monetary valuation of impacts	Unit values, such as VOLY, VSL and/or reference case values based on willingness to pay studies Typical care pathways and medical cost values per case Sickness absence valuation Factors, including GDP deflator, wages and salaries, etc.	Applicability, focusing on 'scale' or 'magnitude'	ECHA, OECD, Better Regulation Guidelines, Eurostat, and scientific and/or grey literature

3.2.3. Data inputs required

The main data inputs that will be required to implement each of the five steps have been highlighted previously and will be primarily driven by evidence gathered under Task 1 and/or the work that will be undertaken under Task 3. In summary, these include data for the EEA on:

- Population size, by relevant groups
- PFAS levels in human blood serum by population group, at present and under prospective scenarios (Task 3)
- ERFs for the health risks confidently associated with PFAS exposure
- Baseline incidence and/or prevalence of disease, typical disability-adjusted life years associated with a case of ill health and typical sick leave or sickness absence, by health endpoint
- VOLY, VSL, reference values of a case of ill health, medical costs for a typical care pathway by endpoint, average wages and salaries, and 'sick pay' (i.e., the payments made by employers to employees who take sick leave for a time-limited period)

3.2.4. Gaps, assumptions and limitations

There are a range of gaps, limitations and assumptions required to conduct this analysis. The steps and methods proposed consider these and suggest a way forward that seeks to maximise the quantification of impacts of PFAS exposure on human health and their valuation, where the evidence suffices.

The **main gaps** in evidence include:

- **Lack of detailed evidence on the size of more or less exposed population groups.** There is a lack of confirmation on the number of people potentially exposed across population groups, especially concerning workers and people living near polluted sites in the EEA (these are primarily estimates at present).
- **Lack of exposure evidence and future projections.** Evidence of PFAS levels in blood serum for specific populations and additional substances, noting that evidence of exposure has been found for 17 substances when there might be around

10,000 PFAS that humans could be exposed to in Europe. Studies projecting PFAS levels in blood serum into the future have not been found.

- **Limited studies into risk associations, limited confidence and lack of studies characterising exposure-risk relationships.** There remain limitations in the number and weight of scientific studies into the links between PFAS exposure and health risks. For some specific endpoints identified, there is currently insufficient evidence. It is also likely there are other relevant endpoints that remain unexplored. In addition, strengthening the coverage of substances particularly concerning the study of quantitative exposure-risk relationships. ERFs with sufficient evidence were identified for thirteen endpoints concerning human exposure to five PFAS substances only (of the 17 for which there is exposure evidence).
- **Limited to no understanding of mixture/cumulative effects of exposure.** There is a very limited to no understanding of any potential mixture or cumulative effects of PFAS exposure on health outcomes identified in the literature. The ERFs identified in the literature examine the attribution of health risks to the levels of specific PFAS in blood, in isolation.
- **Lack of readily accessible studies into the burden of disease, care pathways, medical costs, and sickness absence associated with each endpoint.** There is a wide range of scientific and grey literature exploring these themes or areas of research. However, there does not appear to be a consensus on the burden of disease, care, costs and sickness that might be associated with a typical case of ill health, for the endpoints in scope.

The **main assumptions** draw on the available evidence, literature precedent and good practices to address these gaps where that is reasonable and proportionate. Assumptions have been or will be developed for:

- The size of the population across groups, especially concerning those such as exposed workers and people living near polluted sites; as well as their potential evolution into the future (CAGR)
- PFAS in blood serum in the future, under prospective scenarios (based on output of Task 3 of this study)
- The confidence or strength of evidence of health risk associations and ERFs, based on an assessment of the available literature, and their applicability to EEA-wide population groups.
- Typical burden of disease for a case of ill health by endpoint, in terms of Disability-Adjusted Life Years (based on global burden of disease evidence available at the Institute for Health Metrics and Evaluation, IHME); the care pathways for these endpoints; and the typical sick leave taken by workers affected by a typical case.
- Unit values for VOLY, VSL (based on ECHA's latest reference values) and the resulting monetary values for the non-market disease burden by endpoint, and typical medical costs in the EEA for each typical care pathway by endpoint (monitoring, consultations, admissions, procedures, drugs, etc), and the economic costs associated with values in terms of lost output resulting from sickness absence (proposed to be proxied by average salaries and wages) and additional costs incurred by employers in sick pay.

Section 4 specifies approaches to conduct sensitivity analyses.

The **main limitations** of the study are the lack of coverage of PFAS and health risks due to limitations in the available and/or weight of evidence (i.e., the lack of substances studied, lack of endpoints examined in depth, etc).

The methods specified exclude the analysis of substances for which there is no exposure evidence, which is considered reasonable and proportionate. Substances for which there are no ERFs with sufficient weight of evidence and/or a lack of evidence that does not facilitate a reasonable nor proportionate approach to quantifying impacts are also excluded. This means that the assessment is focussed on the exposure and impacts associated with five PFAS substances. In addition, 13 exposure-risk associations (of the under 30 identified in the literature) are considered sufficiently evidenced and/or have ERFs established and thus can be assessed quantitatively.

That is, there could be thousands of substances and potentially more than 10 health risk associations that are not captured in this study. In our view, this is the main limitation and suggests that any estimates of health costs attributable to PFAS exposure and associated monetary values might continue to present a lower bound to the potential health damage that PFAS exposure may be causing in the EEA, even if more comprehensive than in the past.

There are other limitations associated with the association and quantification of health impacts, as well as their valuation (e.g., uncertainties in ERFs, monetary unit values, etc.), which are also considered in Section 4. However, the evidence review conducted suggests these limitations are dwarfed by the issues presented by the lack of coverage/evidence concerning thousands of substances and potential health risks associated with exposure to them.

Further research is required to continue to refine and build a scientific understanding and characterisation of PFAS exposure, the potential human health impacts of PFAS and the monetary valuation of these impacts.

3.3. Recommended methods for environmental cost assessment

3.3.1. Existing estimates of environmental costs from PFAS pollution

As explained in section 2.3, the types of environmental costs investigated in Task 1 included:

1. Costs arising directly from (eco)toxicological effects of PFAS that could lead to lost ecosystem service delivery (e.g. related to the impacts of reduced growth and survival of a species on ecosystem service provisioning).
2. Costs to recover ecosystem services based on soil pollution remediation and water treatment activities.
3. Costs associated with lost ecosystem services because of health/ environmental protection goals (e.g. limits in foodstuffs which result in the disposal of some agricultural produce).
4. Litigation costs (which overlap with remediation and treatment costs).

While cost category 1 is perhaps the most direct cost category based on the environmental impacts of PFAS (on species and ecosystems), no existing monetised estimates of costs

were identified. However, an approach to address this important cost category qualitatively is proposed in section 3.3.2.

Cost category 2 has been assessed the most in the literature. A 2020 report by Wood et al.⁷⁵ reports the costs of remediation by compartment within the EU. The report estimates that soil remediation costs are around €0.5-4.5 million per site, while ground water and drinking water remediation could cost over €30 million per site if remediation is undertaken over the course of 30 years.⁷⁵ The Forever Pollution Project estimates costs of €95 billion over the next 20 years for remediation of legacy PFAS.⁷⁶ The project estimates that cleaning up the most concentrated sources of long-chain PFAS in Europe alone will be €4.8 billion per year.⁷⁶ To remediate all PFAS over the next 20 years, the cost is estimated to be close to €2 trillion. Appendix D to Annex B provides information on the key literature estimates for remediation and treatment costs. Section 3.3.3 proposes a methodology to update these estimates and apply them to the scenarios developed in Task 3, for the purposes of the present study.

For cost category 3, only a few case studies were identified looking at the costs associated with lost food production. These case studies did not include monetised cost estimates. The available evidence for this category is sparse, and the category is therefore not taken forward for the cost assessment, hence leading to under-estimates.

For cost category 4, a wide range of litigation costs (from several millions of Euros to several billions of Euros per case) were identified based on many different lawsuits (noting that there were more than 2,000 PFAS litigations in 2023 in the US, but much fewer in the EEA). However, they largely represent costs of monitoring, remediation and treatment to address PFAS pollution, thus overlap with category 2 above, and are therefore not taken forward for the cost assessment.

3.3.2. Proposed methodology: Direct ecosystem service costs (category 1)

As described in section 2.3, the scale of direct impacts of PFAS on ecosystem service delivery is unknown. However, we suggest that some potential ecosystem service impacts can be characterised qualitatively based on a mechanistic understanding of the potential impact pathway to ecosystem service impacts. Although this approach will not determine or approximate the probability or magnitude of costs to society, we think it is appropriate to ensure that possible costs are not disregarded due to a lack of evidence at the necessary scale to monetise impacts. Appendix C to Annex B describes the ecosystem services potentially affected by PFAS and how they will be considered in Task 4. A summary of the Task 4 approach is presented below.

A quantitative ecosystem service assessment will not be undertaken given the uncertainty around the probability and scale of impacts of PFAS on ecosystem services. Instead, our report will include descriptive information on the potential impacts of PFAS on ecosystem services, which will be important to guide future research and ensure that potentially

⁷⁵ Wood et al. (2020). *The use of PFAS and fluorine-free alternatives in fire-fighting foams. Report produced for European Commission DG Environment / European Chemicals Agency (ECHA).* https://echa.europa.eu/documents/10162/6755610/pfas_flourine-free_alternatives_fire_fighting_en.pdf/d5b24e2a-d027-0168-cdd8-f723c675fa98

⁷⁶ Forever Pollution Project (2025). *Unaffordable - The absurd cost of 'PFAS as usual'*

significant cost categories are not entirely overlooked. In the final report, we propose to include:

1. A general description of the potential pathways from PFAS exposure to ecosystem service impacts. This will be based on the text above and section 2.3 of this report. The report section will explain the potential mechanisms by which impacts could be caused, the general lack of evidence, and the need for further research to understand the causal links between PFAS exposure and ecosystem service impacts.
2. Three types of ecosystem services in more detailed case studies. We propose to cover the following three types of ecosystem services:
 - Climate regulation (related to algae)
 - Crop pollination
 - Food provisioning (livestock, poultry, aquaculture).

These three services have been selected based on their significance and (relatively better) data availability. Given the lack of already synthesised data in the literature on ecosystem service impacts (which was searched for in Task 1), during the assessment in Task 4, we will undertake additional searches and reviews of the literature, mainly to identify information on:

- The value of each ecosystem service across the EEA
- The main species involved in the provisioning of those services, as well as how they are distributed and exposed to PFAS across the EEA
- How those species may be impacted by PFAS, using more targeted searches in comparison to Task 1 (which did not involve species-specific searches). This will include looking at data from (eco)toxicological studies, observational field studies, and ecological modelling data. It will also involve the consideration of data for similar species (e.g. within the same biological class or order) and similar chemicals (e.g. other persistent organic pollutants)

The case studies will highlight what additional evidence and analysis would be needed to better assess the monetary costs associated with impacts of PFAS on those ecosystem services.

These report sections will be set out before the remediation/treatment costs as they will explain the broad scope of direct impacts of PFAS on the environment, which are then approximated through the remediation/treatment cost assessment which looks at willingness to avoid environmental and health impacts.

3.3.3. Proposed methodology: Remediation/treatment costs (category 2)

We have specified a **stepwise methodology to estimate costs for the remediation of PFAS-polluted soil and treatment of PFAS-polluted water in the EEA**, based on the literature and evidence collected under Task 1 and the outputs of the scenario analysis undertaken under Task 3. These steps are:

1. Define PFAS concentration thresholds

2. Identify potential remediation and treatment sites
3. Apply pollution scenarios from Task 3
4. Apply unit costs for remediation and treatment to sites
5. Discuss implications for health and environmental costs

These steps are specified in detail in the following subsections.

Step 1: PFAS concentration thresholds

The concentration of PFAS at a specific site is a key factor in determining both the potential for environmental impacts (for which remediation/treatment can be used as a cost proxy), as well as the regulatory requirements triggering remediation/treatment that are thus incurred as a market cost to the relevant stakeholders (e.g. site owners).

The first step is therefore to identify relevant PFAS concentration thresholds. For any site exceeding these thresholds, remediation/treatment costs will be considered in the analysis. Different thresholds lead to different interpretations of the resulting remediation/treatment cost estimates:

- **Regulatory thresholds** yield an estimate of potential remediation/treatment costs in the real world. However, regulatory thresholds have only been defined for a small proportion of PFAS species, vary across countries, and can trigger a range of different risk management measures including but not limited to remediation or water treatment.
- **Environmental effects thresholds** could be used to yield avoided damage cost proxies for environmental costs, reflecting the removal of PFAS to achieve levels at which they can be shown to cause no environmental impacts. However, it should be noted that the literature review in Task 1 concluded that there are many uncertainties and gaps in evidence to conclusively determine the specific environmental effects of environmentally relevant concentrations of PFAS.

Regulatory thresholds will be applied in the **core analysis**. The following regulatory thresholds have been selected:

- Proposed Recast Drinking Water Directive (DWD) limits for individual PFAS, 0.5 ug/L for total PFAS and 0.1 ug/L for the sum of 20 PFAS in drinking water⁷⁷ are assumed to be adopted in Scenario 2. See section 5 for further detail.
- Proposed quality standards (EQS) of 4.4ng/l (as PFOA equivalents) for the sum of 24 PFAS in ground and surface water, and of 77ng/kg wet weight (as PFOA equivalents) for the sum of 24 PFAS in surface water only⁷⁸: are assumed to be adopted in Scenario 3. See section 5 for further detail.
- Regulatory limits for PFAS in groundwater, surface water and soils from selected EU Member States will be applied for all scenarios to cover the potential soil remediation and water treatment costs for additional PFAS species, stricter limits,

⁷⁷ <https://eur-lex.europa.eu/eli/dir/2020/2184/oj>

⁷⁸ https://environment.ec.europa.eu/publications/proposal-amending-water-directives_en

and additional compartments (soil), compared to the DWD and EQS thresholds mentioned above. These are listed in the tables below:^{79,80}

Table 3-10 Regulatory limits for various EU countries in drinking, ground, and surface waters and soils

Country	Compartment	Regulatory limit
Germany	Drinking water	0.02 ug/L for 4-PFAS, 0.1 ug/L for 20-PFAS
Denmark	Ground and drinking water	0.002 mg/L for 4-PFAS, 0.1 mg/L for 22-PFAS
Denmark	Soil	0.4 mg/kg for most PFAS ⁸¹
Italy	Ground water	0.03mg/L for PFOS
Sweden	Drinking water	4 ng/L for 4-PFAS, 100 ng/L for 21-PFAS
Norway	Surface and ground water	9.1 ng/L for PFOA
Norway	Surface water	0.00065 ug/L for PFOS
Norway	Soils	0.0023 mg/kg for PFOS, 0.013 mg/kg for PFOA
Netherlands	Drinking water	0.2 ug/L for PFOS
Netherlands	Ground water	56 ng/L for PFOS
Netherlands	Soils	0.960 mg/kg for HFPO-DA (Gen X)

Table 3-11 Most stringent regulatory limits per compartment

Drinking water	Surface water	Ground water	Soils
4 ng/L for 4-PFAS, 100 ng/L for 21-PFA (Sweden)	9.1 ng/L PFOA, 0.00065 ug/L PFOS (Norway)	0.002 mg/L 4-PFAS, 0.1 mg/L 22-PFAS (Denmark) [56 ng/L PFOS (Netherlands)] [9.1 ng/L PFOA (Norway)]	0.4 mg/kg for most PFAS (Denmark) [0.00003 mg/kg PFOS, 0.000061 mg/kg PFOA (USEPA)]

Due to the caveats and uncertainties mentioned above, the selection of environmental effects thresholds is not straight forward and will only be considered in the **sensitivity analysis** taking into account:

⁷⁹ <https://www.eea.europa.eu/en/analysis/publications/pfas-pollution-in-european-waters>

⁸⁰ ITRC PFAS Environmental Media Values Table Excel file, Updated Dec 2024.

⁸¹ Including: PFHxS, PFOA, PFNA, PFOS

- Environmental effects thresholds such as NOEC (No Observed Effect Concentration), LOEC (Lowest Observed Effect Concentration) LC50 (Lethal Concentration 50%), could be considered for all scenarios to approximate the level of remediation/treatment that would be required to avoid adverse environmental effects of PFAS pollution. These will be identified based on US EPA's Ecotox Knowledgebase, which was identified in Task 1 as the most comprehensive database searchable collection of such data.
- Category 4 Screening interim Levels (C4SLs) proposed by the CLAIRE project⁸² could also be considered for all scenarios to indicate levels of low toxicological concern for named PFAS (PFOA, PFNA, PFOS, and PFHxS) in soil.

It should be noted that some literature sources have attempted to estimate the complete remediation/treatment of all PFAS emissions or pollution (e.g. Ling, 2024⁸³). These estimates can help highlight potential problems posed by continued PFAS emissions or the unaffordability of managing PFAS pollution through remediation treatment alone, they cannot be used as a realistic proxy of the societal costs of PFAS pollution, because: (1) Complete remediation/treatment of all PFAS emissions or pollution would not be technically or economically feasible. Therefore, this would not be a realistic proxy of remediation/treatment costs that would be expected to be incurred by the responsible stakeholders in reality. (2) Complete remediation/treatment of all PFAS emissions or pollution would include the removal of PFAS species and PFAS concentration levels that have not been shown to have health/environmental impacts. Therefore, the associated costs could exceed the costs of the health and environmental costs that could be avoided through the remediation/treatment. These costs would therefore also not be an appropriate proxy for health/environmental costs.

Step 2: Remediation and treatment sites

Remediation and water treatment occurs at specific sites, such as facilities where PFAS are produced or used, leading to PFAS-contaminated soil and water, or at water treatment facilities. As shown in Appendix D to Annex B, most key sources in terms of previous estimates of PFAS remediation and treatment costs have applied per-site unit costs to the numbers of sites where remediation and treatment could be required.

The most comprehensive dataset of such sites in Europe was created by the Forever Pollution Project and has been further developed by the French National Centre for Scientific Research (Centre national pour la recherche scientifique, CNRS). It is available on the CNRS PFAS Data Hub⁸⁴ and has also been used in the most recent and most comprehensive estimate of PFAS remediation costs in Europe (Forever Pollution Project, 2025)⁸⁵. The dataset includes known and potential PFAS contaminated sites, with specific PFAS concentrations provided for many but not all of the identified sites.

⁸² <https://claire.co.uk/projects-and-initiatives/category-4-screening-levels>

⁸³ Ling, A.L. (2024). Estimated scale of costs to remove PFAS from the environment at current emission rates. <https://doi.org/10.1016/j.scitotenv.2024.170647>

⁸⁴ <https://pdh.cnrs.fr/en/>

⁸⁵ [Unaffordable - The absurd cost of 'PFAS as usual'](#)

We therefore propose to use the **Forever Pollution Project / CNRS dataset to identify sites requiring remediation/treatment at the PFAS concentration thresholds** defined in Step 1. Sites in the dataset for which PFAS concentrations are not available should be considered in the sensitivity analysis.

Step 3: Pollution scenarios

The Forever Pollution Project / CNRS dataset provides a snapshot of the current baseline number of sites requiring remediation/treatment. This number needs to be adjusted for each of the scenarios developed in Task 3. Task 3 is expected to yield average concentrations of major groups of PFAS in different environmental media/compartments at the EEA-level (see also Section 5 and Appendix E to Annex B). Modelling the impact of the scenarios on the concentration of individual PFAS species at individual sites throughout the EEA is realistically not feasible. Therefore, **a simplifying assumption needs to be applied to link the numbers of sites requiring remediation/treatment at certain concentration thresholds to the scenarios:**

- For sites where PFAS concentration data is available, it is assumed that the **concentration increases/decreases at the same rate as the EEA average** concentration of the relevant group of PFAS (as per the Task 3 results). For example, in a scenario where Task 3 modelling predicts a 10% increase in the concentration of PFAAs in soils on average in the EEA, for each site where there is data on the concentration of a PFAA in soil, it is assumed that the concentration will also increase by 10%.
- For sites where no PFAS concentration data is available (considered in the sensitivity analysis), it will be assumed that the **share of sites requiring remediation/treatment is the same as for sites where PFAS concentration data is available**. For example, in a scenario where the core analysis determined that 10% of sites with monitoring data exceed the concentration thresholds (and therefore require treatment/remediation) , it is assumed that also 10% of sites without monitoring data will require remediation/treatment.

Step 4: Unit costs

For the purpose of this analysis, “unit costs” means costs of remediation/treatment per relevant unit that remediation/treatment is applied to, such as for example a contaminated site, a water treatment facility, a volume or mass of contaminated material, or a mass of PFAS. These **unit costs will be applied to the number of sites that is determined in the previous steps**.

The unit costs from key sources of previous estimates of PFAS remediation and treatment costs are shown in **Appendix D** to Annex B.

We have compared the most recent and most comprehensive source, Forever Pollution Project (2025)⁸⁶ against the unit costs from the other key sources listed in Appendix D to Annex B to determine the most appropriate unit costs for the analysis. The proposed unit values for the core analysis as well as alternative values for sensitivity analysis are listed in

⁸⁶ *Unaffordable - The absurd cost of 'PFAS as usual'*

the table below. Note that a parallel European Commission study⁸⁷ is currently gathering the latest data on water treatment techniques for PFAS and the associated costs to upgrade water treatment facilities in Europe. It is expected that the results will be available in time to be used in this study, and they will then replace the unit costs from Forever Pollution Project (2025) for water treatment which are largely based on American sources.

⁸⁷ *Analysis of treatment techniques: removal of specific pollutants (PFAS, Bisphenol A, pesticides and their metabolites) and feasibility assessment of an Extended Producer Responsibility system for PFAS.*

Table 3-12 Unit costs proposed for the analysis of remediation/treatment costs

Cost category	Core analysis unit cost	Sensitivity analysis unit cost	Source and justification
Soil remediation	Airports: EUR 7.4 million Industrial PFAS users: EUR 8.0 million Military bases: EUR 36.8 million PFAS manufacturer: EUR 40 million Other: EUR 6 million (all costs per site)	EUR 300,000 – 50 million per site (for all types or sites)	Core analysis: Forever Pollution Project (2025), based on costs for 28 example sites (of which 44 are in the EEA). Unit costs are not explicitly listed in the source, but were calculated by WSP based on the source data provided by the authors in a separate spreadsheet, and the methodology description; costs shown are based on the 75th percentile tonnes of soil per site, and 75th percentile costs per tonne, which were recommended by the authors as the best estimate. These unit costs are well within the range of estimates from other key sources: • Nordic Council of Ministers (2019): EUR 5 million (EUR 300,000 – 50 million) • Wood et al. (2020): EUR 0.42 million to 38 million • See appendix D to Annex B for further details. Exception: The unit cost for PFAS manufacturing sites calculated from Forever Pollution Project (2025) was EUR 868.4 million. This is well outside the range of soil remediation costs per site from other key sources (see above). Furthermore, it appears to be based on only three example sites, one of which one seems to be a duplicate. The results are further skewed through the combination of one site with very high tonnage of soil treated but no total cost, and another site with high cost per tonne of soil treated but only a small tonnage. A cost of EUR 40 million was assumed instead, because this is slightly higher than the estimates derived from Forever Pollution Project (2025) for any other type of sites, and PFAS manufacturing sites are likely to be among the most polluted and therefore most costly to remediate. It is also towards the higher end of the range estimated by Nordic Council of Ministers (2019). Sensitivity analysis: the full range of costs from Nordic Council of Ministers (2019).
Drinking water treatment	Unit costs to be determined by parallel European Commission study. Fallback option: Use the same approach as the Forever Pollution Project (2025), which applies the US EPA PFAS treatment cost model and the Minnesota Pollution Control Agency (MPCA) cost model, with certain adjustments (see Appendix D to Annex B for further details).		

Wastewater treatment	Unit costs to be determined by parallel European Commission study. Fallback option: Use the same approach as the Forever Pollution Project (2025), which applies the cost model developed for the Minnesota Pollution Control Agency (MPCA) (2023), with certain adjustments (see Appendix D to Annex B for further details).		
Landfill leachate	Not applied.	EUR 1.5-65 per m ³ of leachate	Based on Forever Pollution Project (2025). See Appendix D to Annex B for additional assumptions to estimate amount of leachate. Forever Pollution Project (2025) concedes that data on landfills is weak and treatment of PFAS in landfill leachate is an emerging area. Furthermore, no other study was identified to sense-check this cost, and the cost cannot easily be linked to the scenarios (from Task 3). Therefore, it was decided to only apply this cost in the sensitivity analysis in the present study.
Miscellaneous	5% of total remediation / treatment costs	0%-10% (arbitrary range chosen by WSP)	Based on Forever Pollution Project (2025), to account for additional miscellaneous costs not accounted for in the other rows, such as procurement of consultants, design of remediation technology, quality assurance and PFAS monitoring. This seems to be broadly consistent with Nordic Council of Ministers (2019), which included EUR 50,000 (EUR 25,000 - 500,000) per case for monitoring and EUR 1,020 per site for screening. For comparison, 5% of the cost for soil remediation at one airport (EUR 7.4 million) would be equivalent to EUR 370,000.

Step 5: Implications for health and environmental costs

Combining steps 1-4 will yield estimate remediation and treatment costs for each of the pollution scenarios from Task 3, and for different PFAS concentration thresholds defined in step 1. The **interpretation and contextualisation** of quantitative results is an important step for any economic analysis. However, it is particularly important the proposed analysis of remediation/treatment costs, especially because:

- As discussed in step 1, different PFAS concentration thresholds lead to different interpretations of the resulting remediation/treatment cost estimates.
- Related to this, remediation and treatment costs are interrelated with other health and environmental cost categories. They are separate costs in their own right and can be incurred by the same and/or different stakeholders in the EEA. However, they can also overlap with other health and environmental cost categories and can be used to approximate these other health and environmental cost categories (avoided damage cost approach).
- The different scenarios used in the analysis include concentration limits which can trigger additional remediation/treatment costs in order to reduce environmental impacts that could not be quantified. Therefore, such a scenario could appear to lead to higher costs, if unquantified impacts are not adequately discussed. Also, when remediation/treatment costs are used as a proxy for otherwise unquantifiable environmental costs (avoided damage cost approach), these regulatory interventions can appear to make no difference in the quantified environmental costs, if not properly explained.

Therefore, we recommend to present remediation and treatment cost estimates separately from the health cost estimates, and to **explain the relationship between the health cost estimates, remediation/treatment cost estimates, and qualitative analysis of ecosystem service impacts**. This includes qualitatively identifying potential overlaps to account for potential double-counting and highlighting the different extents to which costs are quantified under the different scenarios, and the costs not assessed.

3.3.4. Data inputs required

Direct ecosystem services

Information on:

- The value of the selected ecosystem services in the EEA and their dependence on different species;
- The (eco)toxicological effects from PFAS on the relevant species (mainly from Task 1 but some additional targeted searches will be undertaken); and
- The occurrence of PFAS in these species (biomonitoring/modelling data) or in the relevant environmental compartments across the EEA (based on Task 1, Task 3 and additional targeted data gathering if necessary).

Remediation / treatment costs

The following inputs will be used:

- Relevant regulatory and environmental effects thresholds for concentrations of different PFAS species in different environmental media/compartments: Regulatory thresholds for core analysis are defined in this report; Targeted literature review to select environmental effects thresholds will be undertaken as part of Task 4.
- Remediation and treatment sites: readily available from the CNRS PFAS Data Hub and Forever Pollution Project (2025).
- Task 3 scenario results: projected average concentrations of major groups of PFAS in different environmental media/compartments at the EEA-level.
- Unit costs: based on Forever Pollution Project (2025) and the parallel European Commission study on treatment techniques.

3.3.5. Gaps, assumptions and limitations

Gaps, assumptions and limitations are discussed throughout the section above. However, the key gaps and limitations are summarised below.

The ecosystem service assessment is limited by substantial challenges that we do not think can be overcome to produce a meaningful cost assessment, and therefore a case study / qualitative approach has been proposed. To some extent these costs will be captured by the remediation/treatment cost assessment, which we will need to explain clearly in the final report (see step 5 in section 0).

Key gaps, assumptions and limitations of the remediation/treatment cost assessment include:

- Uncertainty in how well identified concentration thresholds reflect environmental impacts and/or trigger remediation/treatment at specific sites in reality.
- Limitations in the identification of remediation/treatment sites, which are discussed in detail in the sources for the data we propose to use.
- In the absence of detailed site-specific assessments, there is significant uncertainty about the number of sites and extent of remediation/treatment that would be required on a national or international level, so any extrapolation to national or international totals is highly challenging.
- Remediation/treatment can only cover part of the PFAS pollution but does not cover PFAS pollution distributed over larger areas at lower concentrations.
- Modelling the impact of the scenarios on the concentration of individual PFAS species at individual sites throughout the EEA is realistically not feasible, so a simplifying assumption needs to be applied to link the numbers of sites requiring remediation/treatment at certain concentration thresholds to the scenarios (see step 3).
- Uncertainty about unit costs which can vary widely across different sites depending on site-specific criteria.

4. Sensitivity analysis

4.1. Purpose of this section

The purpose of this section is to specify our approach to sensitivity analysis, including a horizontal overview followed by the specification of the analysis that will be undertaken for the health cost and the environmental cost assessments.

4.2. Overview of the horizontal approach

Sensitivity analysis will be conducted on the main estimates produced for the human health and environmental costs of pollution, building on the Commission's Better Regulation Tool #65 'Uncertainty and sensitivity analysis'. The suggested approach will focus on testing the sensitivity of the conclusions to core uncertainties and assumptions identified in the evidence, which are listed in Section 3.

A proportionate number of 'sensitivity scenarios' are specified in the following sections for the human health and environmental cost analysis respectively. These scenarios aim to facilitate the development of conclusions on the likely medium estimate and possible and unlikely low and high estimates of costs on the environment and human health attributable to PFAS exposure under each of the prospective scenarios.

Each of these three broad scenarios (i.e., likely medium, possible but unlikely lower bound, and possible but unlikely upper bound) will consider a proposed assumption for a selection of variables identified as key drivers of uncertainty (e.g., exposure-risk relationships, etc). Generally, the likely medium scenario will be defined based on a value that is between the average and median values in the literature for each of the variables of interest, unless otherwise considered appropriate. The low and upper bounds will be typically based on the 25th and 75th percentiles unless otherwise considered appropriate (e.g., the upper and lower bounds of a 95% confidence interval), offering possible but unlikely lower and upper bounds for each of the variables of interest, and enabling us to test the sensitivity of conclusions to these uncertainties (i.e., total costs of PFAS pollution).

Additional sensitivity scenarios with varying likelihood of occurrence (i.e., additional cases between the lower and upper bounds) have also been considered and specified where useful and proportionate.

The specification of the 'scenarios' and methods is presented in the following subsections, including an outline of the key variables of interest and assumptions that will be tested as part of the sensitivity analyses. Please note that this will be complemented by a consideration of uncertainties associated with the development of prospective PFAS pollution scenarios (Task 3).

4.3. Approach for human health costs

The approach is structured in three parts. Firstly, the variables of interest to test the sensitivity of results to the main assumptions are identified. Secondly, a set of tests are defined and grouped under 'likely medium', 'unlikely lower' and 'unlikely upper' scenarios. Thirdly, the analysis is specified, and suggestions are provided for how to use and contextualise the outputs of the sensitivity analysis.

Variables of interest

A list of variables of interest has been assembled, mirroring the main assumptions required to conduct the human health cost assessment (see Section 3.3.4.), which will be explored in the sensitivity analysis for each of the prospective scenarios.

1. Number of people across population groups (Number of people)
2. PFAS levels in human blood serum ($\mu\text{g/L}$)
3. Health risks included (binary, either included or excluded), which have been assessed in terms of weight of evidence or confidence levels
4. Odds, risk or other ratios, which typically present a central, lower and upper bound within a 95% confidence interval
5. Non-market disease burden value per typical case (EUR/case), which can be estimated with different approaches (VOLY, VSL, etc) and associated with a range of values from willingness-to-pay studies (ECHA, OECD, etc). This also embeds an input assumption on Disability-Adjusted Life Years per typical case (DALY/case).
6. Medical costs per typical case (EUR/case)
7. Sickness absence per typical case (Sick days/case)

Sensitivity scenarios

The sensitivity scenarios are explored to test how the uncertainties in the assumptions and methods might drive differences in the outputs. The lower and upper scenarios capture a range of uncertainties, and thus, it is expected that the deviation in the estimates of human health costs across these scenarios will be large. However, by definition, these scenarios will lead to estimates that are possible but very unlikely to represent the true human health costs of PFAS pollution. In addition, as noted, the literature and evidence available suggests that, due to the lack of coverage of substances and endpoints as a result of a lack of robust scientific evidence, these estimates across the three scenarios will still represent a somewhat lower bound of the true human health cost of PFAS pollution.

The Table below defines the scenarios that we will use to test the sensitivity of results to the main assumptions and methods employed, by specifying how each variable of interest will vary across scenarios.

Table 4-1 Scenarios to test the sensitivities of uncertainty in the assumptions to main results

Variable of interest	Medium scenario	Low scenario	High scenario
1.1. Number of exposed workers ⁸⁸	6.5% of the workers in PFAS- or PFAS-treated product manufacturing	3% of the workers in PFAS- or PFAS-treated product manufacturing	10% of the workers in PFAS- or PFAS-treated product manufacturing

⁸⁸ Goldenman et al. (2019) conducted an analysis of the number of plants and workers in a set of sectors where there could be manufacturing of PFAS or PFAS-treated products. This amounted to around 10.8 million workers or 5% of the total worker population in the EEA. The study assumed that 3% to 10% of these workers could suffer from occupational exposure to PFAS. This assumption is retained, with 6.5% of 10.8 million workers as a central estimate, and 3-10% reflecting the lower and upper bounds.

Variable of interest	Medium scenario	Low scenario	High scenario
1.2. Number of people living near polluted sites ⁸⁹	3% of adults 15+	1% of adults 15+	10% of adults 15+
2. PFAS levels in human blood serum (µg/L)	To be determined based on the outputs of Task 3 and associated analysis, but likely to also have central, lower and upper bound values to test.		
3. Health risks included (binary, either included or excluded)	In: LRTI, low (and very low) birth weight, Maternal hypertensive disorders, hypothyroidism, osteoporosis, high cholesterol, kidney cancer (scores of 3 and 4 with ERFs)	In: LRTI, low (and very low) birth weight, Maternal hypertensive disorders, hypothyroidism (score of 4 with ERFs)	In: LRTI, low (and very low) birth weight, Maternal hypertensive disorders, hypothyroidism, osteoporosis, high cholesterol, kidney cancer, obesity, high blood pressure, CKD, testicular cancer, endometriosis, time to pregnancy/ female infertility
4. Odds, risk or other ratios (ERFs)	Central values	Lower bound	Upper bound
5. Non-market disease burden value per typical case (EUR/case)*	Central values	Lower bound	Upper bound
6. Medical costs per typical case (EUR/case)	Main evidence-based assumption	20% lower (or lower bound)	20% higher (or higher bound)
7. Sickness absence per typical case (Sick days/case)	Main evidence-based assumption	20% lower	20% higher

*This will embed sensitivities concerning both WTP inputs and DALY/case estimates.

Based on our current understanding of the ranging values across the variables, the uncertainties that are expected to have a relatively large impact on results and widen the range of possible estimates for human health costs of PFAS pollution are '3. Health risks included', '4. Odds, risks or other ratios', and '5. Non-market disease burden value per typical case'.

⁸⁹ Goldenman et al. (2019) used a best estimate of 3% of the population exposed to excess levels of PFAS via drinking water, with low and high estimates of 1% and 5% respectively. These assumptions are drawn from Swedish data in Holmström et al. (2014). We propose to double the upper bound for the sensitivity analysis to 10%. This is based on a bottom-up analysis of the number of people who could live within a 5km radius of the 23,000 known contaminated sites identified by the Forever Pollution project, when we assume these might be remote, with an average population density of 5 [2, 20] people per km². This would imply 500 [170, 1,690] people living near each site, or a total of 3% [1-10%] of the EEA population. As of March 2025, the Forever Pollution project does not offer a readily accessible estimate of the population living near contaminated sites, and therefore, a more detailed analysis has not been possible.

We do not think it is possible to test limitations concerning mixture and/or cumulative effects, nor explore uncertainties around the extent to which other, less studied PFAS might contribute with additional human health burden.

Analysis and conclusions

Three broad estimates of human health costs of PFAS pollution will thus be developed to understand the range of possibilities and characterise the uncertainty that exists in the available evidence primarily (and, to a much lower extent, any method-driven uncertainty as well). These estimates will represent the potential health burden that could result from human exposure to five specific substances and the most confident risk associations over time.

We will test the marginal impact on the estimates of the three core variables that might have the most significant impacts on potential variance in the results, that is, '3. Health risks included', '4. Odds, risks or other ratios', and '5. Non-market disease burden value per typical case'. If possible, we will also explore ways to reduce uncertainty and thus variance in outputs, albeit this is unlikely given our understanding of the evidence and the existing limitations.

Finally, we will compare these against the precedent in the available literature, and draw conclusions on:

- The potential scale of human health costs of PFAS pollution in Europe at present, and over time under prospective scenarios
- The main uncertainties and limitations
- Recommendations for further research

4.4. Approach for environmental costs

4.4.1. Direct ecosystem services

As described in section 3.3.2, ecosystem service costs will not be monetised, therefore no quantitative sensitivity analysis will be undertaken. It will be important when describing the potential ecosystem service impacts to emphasise the hypothetical basis for the work and avoid overstating confidence in the evidence that PFAS are causing ecosystem service costs. At the same time, the report should clearly communicate the possible scale of environmental harm that PFAS pollution could be leading to, and as such, careful attention will be paid to the drafting of these sections. Uncertainties, assumptions, and gaps will be clearly highlighted.

4.4.2. Remediation / treatment costs

Four main variables have been identified based on the key assumptions underpinning each step of the method described in section 0. Alternative assumptions will be used to test the sensitivity of results to these assumptions:

- Concentration thresholds (step 1): As explained above, selected regulatory thresholds will be used in the core analysis, preference should be given to thresholds with higher certainty. The sensitivity analysis should test more 'ambitious' thresholds with lower certainty, e.g. addressing additional PFAS species or effects

where the evidence is still emerging. Notably, this will include environmental effects thresholds assessed as part of Task 4 (Sensitivity analysis).

- Remediation and treatment sites (step 2): Sites for which concentration data is available will be prioritised in the core analysis, but the sensitivity analysis will consider contaminated sites identified by the Forever Pollution Project / CNRS where concentration data is not available, in order to account for the possibility that the selected concentration thresholds are also exceeded at those sites.
- Pollution scenarios (step 3): The scenarios and estimates of associated PFAS concentrations in the environment will be developed in Task 3. Any sensitivities tested in Task 3 will also be applied here.
- Unit costs (see step 4 in section 0): As explained above, we propose to use the unit costs from Forever Pollution Project (2025) and water treatment costs from the parallel European Commission study in the core analysis. The sensitivity analysis will test any unit costs from other key sources (as listed in Appendix D to Annex B) that are lower and/or higher.

5. Exposure assessment (Task 3)

5.1. Purpose of this section

This report provides the findings of the work under Task 2, which will form a key component of the next phase of work under Task 3 for exposure scenarios. It also highlights in multiple places the relationship between Task 2 and Task 4 which will implement the methodology set out in this document to quantify the costs of PFAS to society. On that basis the outputs from Task 3 are a key input to that phase of work and therefore Tasks 2 and 3 are deeply intertwined. This section provides an overview of the approach for Task 3 and how it aligns with the phase of work reported in the earlier sections.

5.2. Proposed approach for Task 3

5.2.1. Evolution of approach from proposal

Our proposed approach to Task 3 has followed an iterative discussion with the Commission and evolution based on the requirements of the task. Our original offer (which is also documented in the inception report) intended to use a bespoke mass-flow approach to track use, release, and fate of named PFAS into the environment and expected concentrations in water, food, soil, and air as a means of determining exposure rates, and then scaling factors to determine uptake and therefore blood serum levels. During the inception meeting concerns were raised around using a bespoke methodology and suggestion to explore tried and tested models, particularly EUSES, which also provides similar outputs.

A comparative analysis of the two approaches has been completed and reported within Appendix E to Annex B.

Overall, both approaches have their strengths and weaknesses, with no one method being fully ideal. The bespoke approach would require significant quantities of data (including activity data which we have highlighted is largely absent), and where it is less publicly recognised and accepted could be open to more harsh criticism. The EUSES approach, while having detailed peer reviewed default data to help plug data gaps, is not intended to be used for projections, cannot manage the issue of precursors, and works on a substance-by-substance basis, which may be less helpful given the issues outlined.

The conclusion of the analysis in Appendix E to Annex B was to draw upon the strengths of both approaches and the work completed by Goldman et al (2020) to develop a hybrid approach to tackling the objectives and underlying issues to provide outputs in a useful format for Task 4.

5.2.2. Background context to exposure assessment

As an opening statement data on quantities of named PFAS made and used in the EEA does not readily exist. The REACH Annex XV dossier quantify uses and emissions based on non-polymeric PFAS, polymeric PFAS, and F-gases. This work was largely developed based on key reference sources (particularly Glüege et al, 2020⁹⁰) and stakeholders' consultation where data was fragmented (i.e., industry respondents that span multiple sectors with a single tonnage reported, named substance provided in some cases and not in others, etc). Even the Glüege et al (2020) reference quantifies PFAS as tonnes of polymeric and non-polymeric PFAS. Information on tonnages of named PFAS is largely limited to regulated substances (e.g., PFOS, PFOA, PFHxS etc).

This makes modelling use, emission, and fate of named PFAS extremely challenging. In the case of Goldman et al (2019) the available data largely related to monitoring in different matrices (including blood serum for human health) as a measure of the quantities within the receiving environment or receptor.

This human exposure data formed the basis for how the overall exposure was calculated in the Goldman et al (2019) study based on cohorts in different exposure categories (high, elevated, medium, and low exposure) and geographic distance from exposure sites. Mapping of emissions leading to exposure were not included, nor was modelling of exposure using e.g., EUSES or similar.

5.2.3. Approach

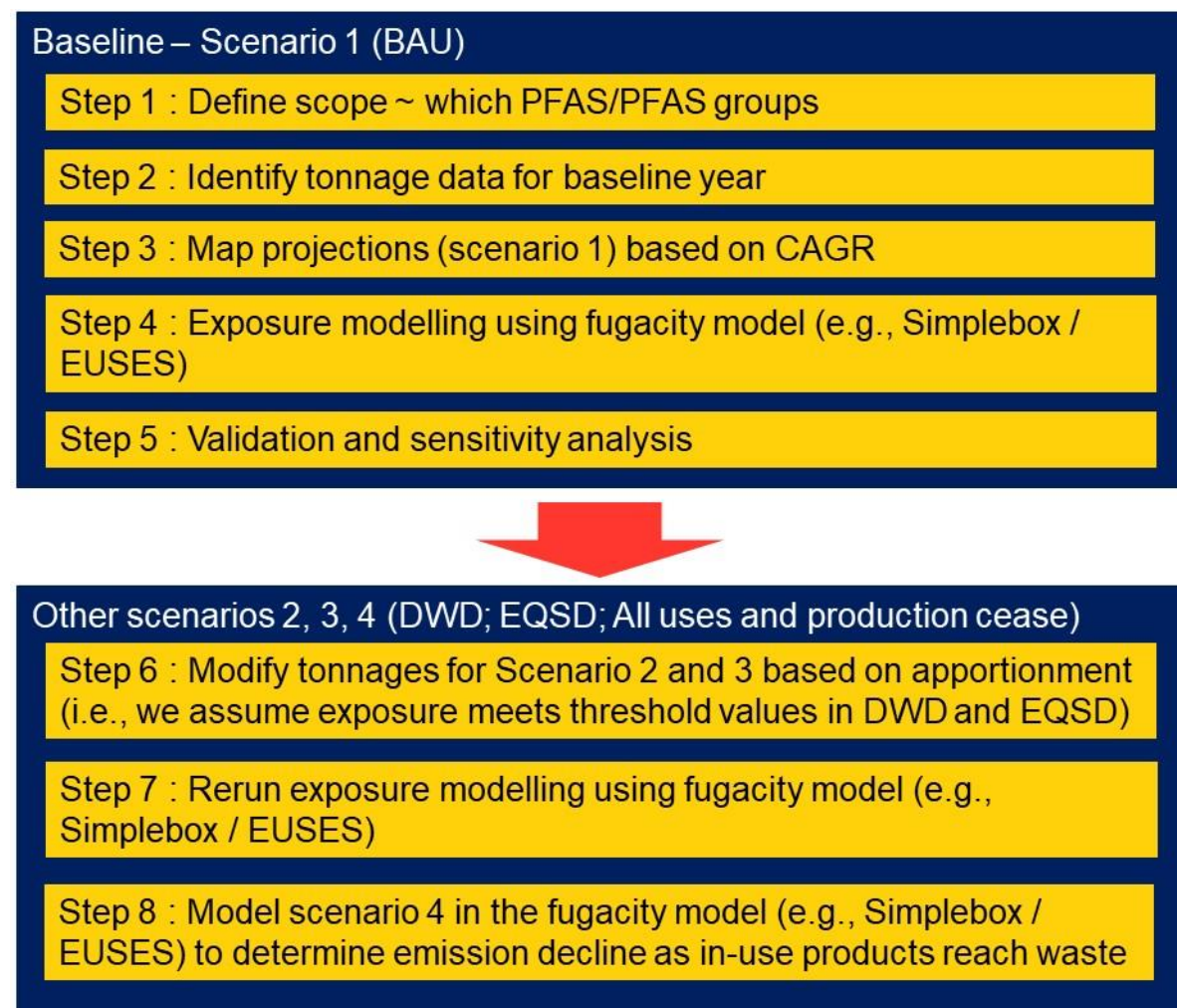
Introduction

As a general comment the work under Task 3 will include the development of four scenarios, 1. A business as usual position assumed to be June 2024 (i.e., no REACH universal PFAS restriction, nor FFF restriction), 2. Implementation of the drinking water directive thresholds ((100 ng/l for the sum of 20 PFAAs) and 500 ng/l for Total PFAS), 3. Implementation of the EQS thresholds for surface water and groundwater, and 4. All uses and production of PFAS are abandoned in EEA. The exposure is expected to be quantified for current year, 2030, 2040 and 2050 based on these scenarios.

⁹⁰ Gluege et al, 2020, An overview of the uses of per- and polyfluoroalkyl substances (PFAS), Journal of Environmental science: processes and impacts.

Figure 5.1 sets out a general workflow to how the exposure assessment will be developed under Task 3.

Figure 5-1 Task 3 work flow



Phase 1 – Development of baseline

The Task 3 approach begins with the development of the baseline scenario, which covers a business as usual position assumed to be June 2024. Once this scenario is fully complete it will be used as the basis to help develop the remaining three scenarios.

Step 1 in the first phase: The development of the baseline scenario begins with determining which PFAS can be included and how they are grouped. As indicated the available data on individual PFAS (which spans thousands of substances) is very limited. The Nordic Council study by Goldman et al (2019) focused only on the C4 – C14 non-polymeric PFAS precursors.

The lists developed under the drinking water directive (Scenario 2) identify 20 perfluoroalkyl acids (PFAAs), while the work to develop lists for the surface EQS and groundwater threshold values identify many of the same substances on the DWD list, there are some additions, with a total of 28 named PFAS spanning the DWD, surface water EQSD and groundwater GWD.

Step 2 in the first phase will involve using available/reported tonnage data for the given PFAS (as both manufacturing and import, and by sector of use). Therefore, we propose that the first two steps are completed together and that the available data on PFAS tonnages will be the driver for which substances are covered and the types of grouping. At this stage, we expect the grouping for PFAS to look like:

- Short chain perfluoroalkyl acids (PFAAs)
- Long chain perfluoroalkyl acids (PFAAs)
- PFAA precursors
- Other non-polymeric PFAS covered by the EQSD.
- Trifluoroacetic acid (TFA) or F-gases as a proxy for TFA with conversion rates.
- Polymeric PFAS.

The specific scope and grouping will be confirmed with the Commission upon completion of the first two steps. But as a minimum it should be assumed that it will cover all the substances on the DWD and EQSD lists, plus TFA as an emerging PFAS of concern.

We will use the REACH Annex XV dossier as the most comprehensive and complete resource on baseline tonnage data, with further literature review to supplement this data source.

Further note that where Task 1 has identified blood serum concentration trends from the 1990s and 2000s for a selected number of PFAS (PFOS, PFOA, PFHxS, PFNA, PFPeA), we will also endeavour to identify usage and tonnage data for these substances over that time range. This will allow to test the fugacity modelling approach to see if similar trends can be created within the model compared to the blood serum data. This will provide useful context for human exposure rates in terms of concentrations consumed in drinking water and food versus concentrations within bodily fluids.

The **third step** in the first phase will be to create projections of future manufacture and use based on a baseline year. To do this we propose to use the same approach used in the REACH universal PFAS restriction. This uses compound annual growth rates (CAGR) to determine future demand and consumption. This approach will provide year on year tonnage data for named PFAS groupings, including disaggregation by manufacture, import, and types of use. This set of data will then form the basis of input data for a fugacity model, along with other physical property data gathered from literature.

We will then make use of a fugacity model, such as simplebox⁹¹, which underpins the mechanics of the EUSES model. This helps determine the fate of substances, based on use and emission. It allows users to apply the EUSES default settings and EEA scale to assess behaviour of chemicals. Based on the tonnage data and PFAS grouping, Simplebox will be used to predict concentrations in drinking water, surface water, groundwater, soil, and food. This will provide data as local, regional and continental scale.

Where the tonnage data gathered is at EU level without disaggregation to country level, the values generated within Simplebox provide estimates for the near field (site level), regional and continental level. As we are applying EU total data into the model to map environmental release and distribution it will be important to select the correct geographic level to determine what EU average concentrations in different compartments look like.

⁹¹ [SimpleBox / RIVM](#)

Simplebox will be used to develop the exposure outputs (including the projections for future years) based on the data collected in steps 1 to 3.

Once outputs have been created, it will be critical to sense check the results against real world data. We therefore propose that the **concluding step** of the first phase will be to make use of monitoring data from literature to sense check the results of the fugacity model for the baseline year. Depending on how well the results correlate, further amendments and alterations may be needed, as well as analysis to determine why any large discrepancies exist.

As a caveat, we do not expect the outputs of the fugacity model to match perfectly with monitoring data. However, the same orders of magnitude / broad agreement⁹² on the typical concentrations seen in drinking water, surface water, groundwater, soil, and food should be possible to give confidence that the tonnages manufactured and used, and resulting emissions modelled with Simplebox mirror real-life.

Details of this validation and sensitivity analysis will be documented in the Task 3 report, along with any necessary modifications and best attempts to explain any possible discrepancies.

Phase 2 – Other scenarios

The finalised baseline scenario will be used as the basis to develop the other three scenarios. Where Scenario 2 and 3 work to set thresholds in drinking water and surface/groundwater respectively, we will use an apportionment approach which assumes full compliance with the Directives. This will mean that the tonnage data is amended to help achieve compliance, and the fugacity model is then rerun with the new tonnage data. This will help determine what kind of reduction is needed at source to achieve compliance in drinking water, surface water and groundwater.

For Scenario 4, which assumes all use is abandoned we would assume that this relates to all 'new' use, and that for products and articles treated with PFAS already in use, that use is allowed to continue. This creates a declining emission over time as in-use articles finally reach waste. To model this aspect, we propose to use EUSES which has a service life function to track year on year emissions during use.

Service life data for the sectors included in the model will come from the literature review, largely based on the universal REACH restriction.

Further details for each scenario are provided below:

Scenario 2 DWD thresholds

The analysis from the parallel study on drinking water techniques has determined that average EU drinking water concentrations (post treatment) are between 10 and 40 ng/l (noting the 100 ng/l threshold). This means that the majority of EU drinking water treatment works will not need to implement additional measures. However, based on the

⁹² As an example of what we mean here, the data from Member State authority monitoring programs (collected and collated by the JRC) suggests that for the sum of EQSD PFAS substances concentrations in surface water could be expected to be in the 10s to 100s of ng/l. If the results of the modelling broadly sit in this order of magnitude, then we can assume a good agreement. If the results of the modelling suggest concentrations in the hundreds of picograms/l or 10s to 100s of µg/l then this would suggest a significant divergence that needs review.

minimum and maximum concentrations we do expect that there will be areas that are above the 100 ng/l threshold. Additionally, based on application of the CAGR, the concentrations under BAU may exceed the 100 ng/l in the future.

Therefore, this scenario will aim to determine for both the present year and future years the reduction in human health exposure and environmental exposure when compliance to DWD is achieved everywhere compared to the BAU scenario. This assumes that achieving compliance will be through a combination of drinking water treatment, and source control for specific industries. Assessment of TFA concentration (although not listed under the DWD thresholds) will also be included.

Scenario 3 EQS thresholds

The monitoring data provided by member states to the JRC for surface water, along with the forever pollution project for surface and groundwater monitoring already provides some steer on minimum, maximum, and median concentrations. Based on the target thresholds proposed under the surface water and groundwater EQS directives it is possible to calculate the short fall. We propose to use a similar method to Goldman et al (2019) for the Nordic Council study and the Forever Pollution project data set to define groupings of water bodies at set concentration levels based on the monitoring data. This will define the scale of the shortfall and the reduction in human health exposure and environmental exposure when compliance to EQS is achieved everywhere.

Scenario 4 All uses and production of PFAS are abandoned in EEA

The full abandonment of manufacture and use of PFAS will apply to new uses. This means in-use articles can continue to be used and corresponding PFAS emitted to environment for the remainder of their service life, which, for some items (e.g., sofas) can have a service life of 20+ years, this means that emissions do not immediately stop but will decline over time. It also poses difficult questions for landfill and landfill leachate.

5.2.4. Data input requirements

To help develop the exposure scenarios we will need a range of data, primarily drawn from Task 1 and supplemented by other major references. This includes:

- Monitoring data across a range of environmental compartments and geographies.
- Activity data (tonnages) drawn from Glüge et al (2019), the REACH Annex XV restriction, and other literature for regulated PFAS.
- Physical properties for PFAS drawn from ECHA and literature sources (needed by simplebox)
- Locations of contaminated sites drawn from Forever Pollution project.

5.2.5. Gaps, assumptions, and limitations

The proposed approach will provide a high-level set of estimates at an EEA scale to help feed into the cost analysis for Task 4. In developing this approach there are a few key gaps and weaknesses, as well as assumptions that should be recognised. These are briefly summarised below:

- The business-as-usual scenario draws upon pre-existing monitoring data to determine what average concentrations in different environmental compartments look like today. This may mean using limited sampling data to map large areas of

territory that misses localized issues. We also note as with the Forever Pollution project dataset that concentrations in Central and Eastern Europe look considerably lower than western Europe (with Belgium having the highest concentrations in Europe). It is unclear whether this is a genuine environmental artefact or a methodological / sampling issue (i.e., fewer sampling campaigns with higher limits of detection). Therefore, gaps in data will apply EEA-averages which could over/under estimate the real-world situation.

- The calculations to develop tonnages of PFAS made and used require a series of assumptions, particularly for precursors. We recognise that this issue is potentially an area of high uncertainty but is necessary given the importance of the data for the approach detailed.
- The fugacity model, simplebox, which underpins EUSES is designed to be tailored to specific world conditions. To do this it is necessary to have additional data on e.g., rain fall, soil type, climate conditions etc. Applying this at a pan European scale means it is not possible to build in this fine detail within the schedule of the project. Switching to default EUSES settings provides useable results. But the data will be generic and may not consider the specific situation of a specific EEA geography.
- Where the projections are planned to stretch 25 years into the future, as with any projections there are limitations to the reliability of the estimate. The projection is completed in isolation and assumes real-world events (e.g., natural disasters, wars, economic crashes, pandemics, etc) will not occur. Therefore, it is not intended that the projection is a real-world estimate of concentrations in 2050, but rather an indicative picture of what the situation could look like, and the magnitude of difference that the difference policy scenarios may have on that future.

Appendices to Annex B

A. Brief comparative analysis of different valuation methods

A range of market-based and non-market valuation methods have been identified in the literature, which are briefly outlined below for reference.

- **Cost-based methods** use market data to value health impacts. This includes methods such as the cost of illness (COI) method, human capital approach and the present value of lifetime earnings (PVLE).
- **Avoided damage methods:** A cost-based approach used to estimate the economic value of preventing negative health outcomes, that is, the market and/or non-market costs that would have been incurred if the health damage had not been prevented.
- **Revealed preferences methods** use observed behaviours and market transactions by market actors to estimate the economic value of health outcomes. This includes Hedonic Pricing method, Travel cost method and the averting behaviour method.
- **Stated preferences methods** are used to estimate the economic value of health outcomes based on individuals' expressed preferences in hypothetical scenarios, generally summarised in terms of their willingness to pay to avoid years of life lived with disability and/or lost. These methods are particularly useful when market data is unavailable or insufficient. This group includes Contingent Valuation (CV), which appears predominant in the literature as well as employed by the European Chemicals Agency and the Organisation for Economic Cooperation and Development, and Discrete Choice Experiments (DCE).
- **Benefit Transfer methods** can also be employed, which draw on valuation data gathered in one situation and applying it, with adjustments, in a similar situation to a population with similar attributes and suffering from similar burden of disease. This method is used frequently as it limits the need for primary valuation studies.

Each of these methods requires different types and depths of data, varies in boundaries or scope of the values or impacts captured (e.g., includes indirect non-market value of health or not), and can often be used as complementary methods in a valuation exercise. The Table below provides a summary of the key strengths and weaknesses of a range of valuation methods that have been considered as part of the methodological development for this study.

Table 0-1 Strengths and weaknesses of valuation methods

Method	Strengths	Weaknesses
Direct costs or Costing Methods (Market-based)	- Methods use actual market prices and represent accurate values for provisioning services. - They reflect real economic trade-offs individuals make, making the data highly relevant for policy and decision making.	- Methods do not account for indirect, or non-use values associated with health. - Requires detailed and accurate data on market transactions and behaviours, which may not always be available. - They may not fully capture externalities.
Avoided damage costing methods	- This method is relatively straightforward and can be easier to apply compared to other valuation methods. It uses existing data on costs, making it less resource intensive. - It provides concrete estimates of economic benefits by focusing on actual costs avoided, such as medical expenses and lost productivity.	- This method only captures the costs that are directly avoided and may miss broader economic and social benefits of improved health. - It relies on the assumption that the costs avoided are a good proxy for the value of health improvements, which may not always be accurate. - The accuracy of this method depends heavily on the availability and quality of data on health costs and outcomes.
Revealed preferences methods	- These methods use actual behaviour and market data, which can provide more accurate and reliable estimates compared to hypothetical scenarios. - They offer insights into how people value health-related goods and services based on their real-world decisions. - The results can be directly applicable to policymaking as they reflect actual consumer behaviour and preferences.	- The availability and quality of data can be a significant limitation. Not all health benefits are traded in markets, making it difficult to capture their full value. - They may not capture non-market values, such as the intrinsic value of health improvements or the broader social benefits.
Stated Preference methods (WTP)	- These methods can be applied to a wide range of health outcomes and scenarios, including those not traded in markets. - By directly asking individuals about their preferences, these methods can provide insights into the value people place on health improvements and risk reductions.	- The availability and quality of data can be a significant limitation. - Responses may be influenced by the hypothetical nature of the questions, leading to over- or under-estimation of true values. - Respondents might provide biased answers if they believe their responses will influence policy decisions or if they do not fully understand the scenarios presented.
Benefit transfer methods	Increased availability of evidence to draw from without the requirement for primary research and/or valuation studies	Limitations in accuracy, relevance and/or validity of the value being transferred (i.e., the value might not be as applicable to the situation to which it is being transferred)

B. Reference willingness-to-pay values of disease burden associated with chemical exposure

This Appendix summarises key inputs underpinning our proposed unit monetary values for the non-market disease burden, healthcare costs and economic productivity costs (EUR₂₀₂₄/ case).

Non-market disease burden

ECHA, the EEA, the OECD (SWACHE) and other institutions conduct research and set guidelines for the **valuation of non-market health and wellbeing impacts**, especially drawing on contingent valuation methodologies. In 2023, ECHA published reference willingness-to-pay (WTP) values for monetising health impacts of chemical exposure⁹³, which complements previous publications⁹⁴, which together contain reference values for averting the following cases of ill health and/or conditions: skin sensitisation, dermatitis, fertility, cancer, adult asthma, childhood asthma, chronic kidney disease, very low birth weight, and birth defects. In addition, a valuation of a statistical pregnancy was also conducted. Finally, a reference value of a statistical life (VSL), equivalent to the WTP for averting a premature death, is also presented. These are summarised in the Table below.

Table 0-2 Non-market disease burden or reference WTP values for various health endpoints

Specific health risk/ endpoint in scope	Non-market disease burden (EUR ₂₀₂₄ / case)
Premature death or VSL	4,700,000 ⁹⁵ - 6,600,000
Cancer (morbidity, generic)	540,000
Statistical pregnancy	29,000 - 54,000
Statistical case of infertility	41,000 - 74,000
Very low birth weight	531,000 - 1,000,000
Minor birth defects	5,700 - 57,000
External birth defects	35,000 - 439,000
Internal birth defects	170,000 – 946,000
Dermatitis (mild, acute)	330
Dermatitis (severe, chronic)	2,700 - 16,000
Adult asthma	40,000 - 243,000
Childhood asthma	61,000 - 338,000
Chronic Kidney Disease	175,000 - 648,000

⁹³ ECHA (2023). Reference willingness-to-pay values for monetising chemicals health impacts. Available at: https://echa.europa.eu/documents/10162/17229/seac_reference_wtp_values_en.pdf/403429a1-b45f-4122-ba34-77b71ee9f7c9

⁹⁴ ECHA (2016). Valuing selected health impacts of chemicals. Summary of the results and a critical review of ECHA study. Available at: https://echa.europa.eu/documents/10162/17228/echa_review_wtp_en.pdf/dfc3f035-7aa8-4c7b-90ad-4f7d01b6e0bc

⁹⁵ Lower values tend to be based on the median and higher values of the mean (these are typically not lower and upper bounds of the available evidence).

These monetary values can capture a range of direct and indirect health and wellbeing implications associated with each endpoint. For example, for low birth weight, the valuation appears to capture the knock-on implications and attributable impacts associated with neurosensory problems, behavioural and social competence problems, and intellectual and learning disability. Thus, it does not appear necessary to separately consider and evaluate the intellectual and learning disability risks associated with low birth weight.

In 2011, ECHA published research on the 'quantification and valuation of the human health impacts of chemicals based on quality and disability-adjusted life-years'⁹⁶, among other relevant considerations, arguing that 'DALYs [might be] more appropriate [way to assess reductions in burden of disease within society] in the context of REACH...', primarily because it evaluates the existing or projected burden that REACH or other interventions seek to address.

In this context, it is useful to refer to monetary values of the value of a life year (VOLY), which could be used to monetise the welfare losses attributable to disease burden and/or the potential welfare gains from preventing such burden. In ECHA (2016) 'Valuing selected health impacts of chemicals'⁹⁷ refers to the VOLY implied by the NewExt study⁹⁸ equivalent to 64,000 euros (median) and 144,000 euros (mean) in 2012 prices, which price-adjusted using the EU-27 GDP deflator⁹⁹ would be equivalent to 83,000 and 187,000 euros in 2024 prices respectively, rounded to the nearest '000 euros.

Studies for DG Employment¹⁰⁰ collecting evidence and analysing the health, socio-economic and environmental impacts in connection with workplace exposure to harmful substances use a monetary value of a DALY of 100,000 euros.

VOLY values can also be derived from the implicit value placed to one year of life in VSL estimates (or willingness-to-pay to prevent a statistical death). This is also explored in ECHA (2016), which presents a method to calculate an 'annuity' equivalent of VSL over the number of years of remaining life expectancy of the person considering a statistical death. That is:

$$VOLY = r \times \frac{VSL}{[1 - (1 + r)^{-LE}]}$$

Where:

VSL refers to the value of a statistical life, which is estimated to range between 4,700,000-6,600,000 in the EU-27, as highlighted previously.

r refers to the real social discount rate, assumed at a level of 3% in line with the Commission's Better Regulation Guidelines. International guidelines and good

⁹⁶ ECHA (2011). *Quantification and valuation of the human health impacts of chemicals based on quality and disability-adjusted life-years*. Available at: https://echa.europa.eu/documents/10162/17231/report_quality_daly_en.pdf/f8c20060-8e7d-4b87-9e0c-64ba2999e63d

⁹⁷ ECHA (2016). *Valuing selected health impacts of chemicals. Summary of the results and a critical review of ECHA study*. Available at: https://echa.europa.eu/documents/10162/17228/echa_review_wtp_en.pdf/dfc3f035-7aa8-4c7b-90ad-4f7d01b6e0bc

⁹⁸ NewExt (2003). *New Elements for the Assessment of External Costs from Energy Technologies. Final report*. Available at: http://www.ier.uni-stuttgart.de/forschung/projektwebsites/newext/newext_final.pdf

⁹⁹ Multiplied by a factor of 1.3 (Source: ECB)

¹⁰⁰ For example, Garrett S., Vencovsky D., Collins H. (2021). *Study on collecting information on substances with the view to analyse health, socio-economic and environmental impacts in connection with possible amendments of Directive 98/24/EC (Chemical Agents) and Directive 2009/148/EC (Asbestos)*. Available at: <https://op.europa.eu/en/publication-detail/-/publication/03b0cc5a-5e22-11ec-9c6c-01aa75ed71a1/language-en>; and the methodological note, available at: <https://op.europa.eu/en/publication-detail/-/publication/371c9593-5e1f-11ec-9c6c-01aa75ed71a1/language-en>

practice suggest the use of lower discount rates discounting health impacts (e.g., 1.5%)^{101,102}.

LE refers to the remaining life expectancy at the age of statistical death, which for a typical cancer case is assumed to be around 30 years (comparing age of statistical cancer death between 45-65 years when compared to a life expectancy of 80.6 years).

This suggests implicit VOLY values ranging from 240,000-340,000 euros.

Moreover, the valuation of non-market health impacts, i.e., the non-market effects of exposure to harmful chemicals on the quality and years of life of people living in the EU, can be approached in different ways, each with their own limitations.

Therefore, and since ECHA's and the OECD's publications do not provide reference monetary values for all endpoints covered in this study, different approaches were considered to estimate proposed monetary values for a typical case of ill health across each of the endpoints in scope to select a reasonable scale that can be used to monetise the attributable impacts of human exposure to PFAS. In particular, the following were calculated and/or compared:

- Study references: ECHA (2023) and Garrett S., Vencovsky D., Collins H. (2021) reference monetary values for the non-market disease burden estimated across each endpoint.
- VOLY-based: Direct, intangible costs of a typical case of ill health, based on ECHA (2016)'s the mean VOLY value (187,000 euros) and estimated DALY/case.
- VSL-based: Direct, intangible costs of attributable statistical deaths, based on an implicit estimate associate with the Years of Life Lost expected from each case of ill health, and ECHA (2023)'s lower VSL estimate (4,700,000 euros).

DALY/case or and attributable statistical deaths were estimated by endpoint based on baseline evidence from IHME. Total estimated DALYs attributable to a given endpoint (disease or risk factor) were divided by incident cases and adjusted to isolate the burden of disease that could be attributable to prevalent cases, where relevant and applicable. Evidence of DALYs/case for hypothyroidism was based on Obsekov, Kahn and Trasande (2023).

The results of these analysis are presented in the Table below, as well as the proposed selection, for coherence and consistency. In general, it is considered that the scale of impacts is broadly aligned across approaches (see below).

¹⁰¹ European Comission (2023). Better Regulation Toolbox Chapter 8 Tool 64. Available at: https://commission.europa.eu/document/download/0d32ee11-92da-434d-9c86-fd4579d95dc6_en?filename=BRT-2023-Chapter%208-Methodologies%20for%20analysing%20impacts%20in%20IAs%20evaluations%20and%20fitness%20checks_0.pdf

¹⁰² UK His Majesty's Treasury (2022). Green Book. Available at: <https://www.gov.uk/government/publications/the-green-book-appraisal-and-evaluation-in-central-government/the-green-book-2020>

Table 0-3 Selection of monetary values for non-market disease burden per health endpoint, in alphabetical order

Specific health risk/ endpoint in scope	References from recent studies (EUR ₂₀₂₄ / case)	DALY-based (EUR ₂₀₂₄ / case)	VSL-based (EUR ₂₀₂₄ / case)	Selected value (EUR ₂₀₂₄ / case)
Chronic kidney disease	175,000 - 648,000	40,000	48,000	175,000
Endometriosis	-	123,000	130	123,000
Maternal hypertensive disorders	6,000**	2,000	850	6,000
High LDL cholesterol	-	5,000	8,000	5,000
High systolic blood pressure	6,000**	32,000	47,000	32,000
Hypothyroidism	-	3,500	3,500	3,500
Kidney cancer	540,000*	626,000	994,000	626,000
Low (and very low) birth weight	531,000 - 1,000,000	624,000	523,000	624,000
Obesity	-	7,000	11,000	11,000
Osteoporosis	-	15,000	0	14,000
Lower respiratory tract infection	-	75,000	125,000	75,000
Testicular cancer	540,000*	198,000	265,000	198,000
Time to pregnancy/ female infertility	41,000 - 74,000	1,000	0	41,000

*Cancer morbidity 'generic'; **Price adjusted from Garrett S., Vencovsky D., Collins H. (2021); rounded to the nearest '000 euros.

In general, all estimates were revised and considered. The order of magnitude of the values for each endpoint across methods tended to be similar. In general, the DALY-based approach was selected, to maintain consistency across endpoints, except for the endpoints CKD, maternal hypertensive disorders, and time to pregnancy/female infertility. References studies were used for these given the differences in order of magnitude. The cancer morbidity reference value is generic, and thus, for testicular cancer, given the lower rate of mortality and associated burden of disease, a DALY-based approach was considered more reasonable.

Healthcare costs

Healthcare costs are defined as the expenses associated with medical care required to treat a typical case of ill health across the prioritised endpoints. This includes the costs associated with appointments or consultations, diagnoses, treatment, procedures, prevention, and/or management of diseases and conditions. This study relies on assumptions of the medical costs of typical cases of ill health by endpoint based on available secondary sources to provide a sense of scale. Most of these costs are borne by public authorities or public health

systems across the EU, albeit a small proportion might be funded out of pocket. The table below summarises the evidence underpinning the assumptions developed for healthcare costs per typical case by endpoint.

Table 0-4 Healthcare costs associated with a 'statistical' case of ill health (EUR₂₀₂₄/case), by endpoint in alphabetical order, and rounded to the nearest '000 euros

Specific health risk/ endpoint in scope	Healthcare costs (EUR ₂₀₂₄ / case)	Commentary
Chronic kidney disease	5,000	Balducci <i>et al.</i> (2024) ¹⁰³ estimated the annual medical costs of CKD of EUR 4,478 ± 9,804 in 2024. An approximate value of EUR 5,000 was selected for the study.
Endometriosis	4,000	Simoens <i>et al.</i> (2011) ¹⁰⁴ estimated the healthcare costs to be EUR 3,000 per case in 2012. These costs were adjusted to 2024 values using evidence from the GDP deflator.
Maternal hypertensive disorders	4,000	Fox <i>et al.</i> (2017) ¹⁰⁵ estimated the average cost of a pregnancy complicated by preeclampsia was EUR 3,596 – EUR 6,890 in 2016. These costs were adjusted to 2024 values using evidence from the GDP deflator.
High LDL cholesterol	5,000	Allahyari <i>et al.</i> (2020) ¹⁰⁶ found that the annual cost of PCSK9 inhibitors (alirocumab 75 mg/150 mg, evolucumab 140 mg) is EUR 4,500. These costs were adjusted to 2024 values using evidence from the GDP deflator.
High systolic blood pressure	900	This value was taken from Garrett, Vencovsky, Collins (2021)'s methodological note, table 3-14, price adjusted using the GDP deflator.
Hypothyroidism	1,000	The costs of treatment (levothyroxine) are around EUR 2-5/month or up to EUR 60/year (Source: EURIPID). ¹⁰⁷ Radioiodine therapy and thyroid surgery can cost thousands of euros; however, they are not common (see Møllehave <i>et al.</i> , 2018 ¹⁰⁸). Based on this, an assumption of up to EUR 1,000 has been assumed.

¹⁰³ Balducci *et al.* (2024). Healthcare costs in relation to kidney function among older people: the SCOPE study. *Eur Geriatr Med*. Available at: <https://doi.org/10.1007/s41999-024-01086-8>

¹⁰⁴ Simoens *et al.* (2011). Endometriosis cost assessment (the EndoCost study): a cost-of-illness study protocol. *Gynecologic and obstetric investigation*, 71(3), 170–176. Available at: <https://doi.org/10.1159/000316055>

¹⁰⁵ Fox *et al.* (2017). Estimating the Cost of Preeclampsia in the Healthcare System: Cross-Sectional Study Using Data From SCOPE Study (Screening for Pregnancy End Points). *Hypertension (Dallas, Tex. : 1979)*, 70(6), 1243–1249. Available at: <https://doi.org/10.1161/HYPERTENSIONAHA.117.09499>

¹⁰⁶ Allahyari *et al.* (2020). Application of the 2019 ESC/EAS dyslipidaemia guidelines to nationwide data of patients with a recent myocardial infarction: a simulation study, *European Heart Journal*, Volume 41, Issue 40, 21, Pages 3900–3909. Available at: <https://doi.org/10.1093/eurheartj/ehaa034>

¹⁰⁷ <https://ppri.goeg.at/euripid>

¹⁰⁸ Møllehave *et al.*, (2018). Trends in Costs of Thyroid Disease Treatment in Denmark during 1995–2015. *European Thyroid Journal*.

Specific health risk/ endpoint in scope	Healthcare costs (EUR ₂₀₂₄ / case)	Commentary
Kidney cancer	18,000	Buja <i>et al.</i> (2022) ¹⁰⁹ estimated that the average per patient cost incurred during the first-year post-diagnosis amounted to EUR 17,210. These costs were adjusted to 2024 values using evidence from the GDP deflator.
Low (and very low) birth weight	23,000	Cavallo <i>et al.</i> (2015) ¹¹⁰ estimated the mean cost of the hospitalisation for the very low birth weight infants (VLBWIs) was EUR 20,502. These costs were adjusted to 2024 values using evidence from the GDP deflator.
Obesity	800	The European Food Information Council's 'Europe's Obesity Statistics: Figures, Trends & Rates by Country' ¹¹¹ , estimates the total direct medical costs in Europe of EUR 141 billion, which divided by people suffering from high body-mass index and obesity is equivalent to a round 800 euros/case.
Osteoporosis	2,000	The International Osteoporosis Foundation's 'Key Statistics for Europe' ¹¹² dated 2021 estimated the total direct cost of osteoporotic fractures at EUR 56.9 billion and the cost of pharmacological intervention (assessment and treatment) at EUR 1.6 billion in 2019. Given an estimated 32 million individuals aged 50+ had osteoporosis in 2019, the cost per case is estimated as $\frac{(56.9+1.6) \text{ billion}}{32 \text{ million}}$, equal to EUR 1,800 in 2019. These costs were adjusted to 2024 values using evidence from the GDP deflator.
Lower respiratory tract infection	200	Oppong <i>et al.</i> (2010) ¹¹³ found that the mean cost of treating acute cough/LRTI in Europe was EUR 116.47 in 2010.
Testicular cancer	8,000	This value was assumed based on evidence of cancer costs, albeit these are not specific to testicular cancer, from Garrett, Vencovsky, Collins (2021)'s methodological note, table 3-14, and Schlueter <i>et al.</i> (2020) ¹¹⁴ .

¹⁰⁹ Buja *et al.* (2022). Renal cell carcinoma: the population, real world, and cost-of-illness. *BMC Urol* 22, 206. Available at: <https://doi.org/10.1186/s12894-022-01160-y>

¹¹⁰ Cavallo *et al.* (2015). Cost of care and social consequences of very low birth weight infants without premature- related morbidities in Italy. *Ital J Pediatr* 41, 59. Available at: <https://doi.org/10.1186/s13052-015-0165-z>

¹¹¹ European Food Information Council (2024). Europe's Obesity Statistics: Figures, Trends & Rates by Country. Available at: <https://www.eufic.org/en/healthy-living/article/europes-obesity-statistics-figures-trends-rates-by-country>

¹¹² International Osteoporosis Foundation (2021). Key Statistics for Europe. Available at: <https://www.osteoporosis.foundation/facts-statistics/key-statistic-for-europe>

¹¹³ Oppong *et al.* (2011). Resource use and costs of treating acute cough/lower respiratory tract infections in 13 European countries: results and challenges. *Eur J Health Econ* 12, 319–329. Available at: <https://doi.org/10.1007/s10198-010-0239-1>

¹¹⁴ Schlueter *et al.* (2020) The cost of cancer – A comparative analysis of the direct medical costs of cancer and other major chronic diseases in Europe. *PLoS ONE* 15(11): e0241354. Available at: <https://doi.org/10.1371/journal.pone.0241354>

Specific health risk/ endpoint in scope	Healthcare costs (EUR ₂₀₂₄ / case)	Commentary
Time to pregnancy/ female infertility	8,000	Bourrion <i>et al.</i> (2022) ¹¹⁵ estimated the average infertility related expenditure per woman at EUR 6,996 in 2022. These costs were adjusted to 2024 values using evidence from the GDP deflator.

Please note that these figures are rounded to the nearest '000 or '00 euros where relevant.

¹¹⁵ Bourrion *et al.* (2022). *The economic burden of infertility treatment and distribution of expenditures overtime in France: a self-controlled pre-post study.* *BMC Health Serv Res* 22, 512. Available at: <https://doi.org/10.1186/s12913-022-07725-9>

Economic productivity costs

Each case of ill health might also be associated with attributable sickness absence from work, directly (if a worker gets ill) and/or indirectly (if a person cared by a worker gets ill). In addition to the lost marginal productivity, employers might have to incur temporary costs during a period. These are considered additional costs attributable to the illness that can result from human exposure to PFAS.

In the EU, overall absenteeism from work due to illness appears to be around 12.5 days per worker.¹¹⁶ However, not all employees take time off from work due to illness each year. It was not possible to find studies estimating in detail the proportion of workers taking sick leave in a typical year, but available evidence suggests that this might be around half of all employees. Within the half taking some time off work due to illness, some employees may suffer very large period of absence, whereas others might take a few days at most.

Hourly labour costs are considered a reasonable reference value to monetise the marginal productivity costs associated with absenteeism, at least to estimate an order of magnitude of the cost (31.8 euros per hour¹¹⁷). This is further uplifted to account for the increased costs incurred by the employer in the EU, paying for employees a proportion of their salaries for a period (65% of labour costs for a maximum of an assumed 45 days or no more than 7,440 euros¹¹⁸).

Productivity losses due to mortality have not been considered due to potential overlaps with non-market disease burden estimates and the challenge of managing these overlaps. A more in-depth review and assessment of the evidence would be necessary to comfortably add this as part of the assessment that is considered out of scope and not proportionate for this project.

¹¹⁶ WHO. Absenteeism from work due to illness, days per employee per year. Available at: https://gateway.euro.who.int/en/indicators/hfa_411-2700-absenteeism-from-work-due-to-illness-days-per-employee-per-year/#id=19398

¹¹⁷ Eurostat. Hourly labour costs. Available at: https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Hourly_labour_costs

¹¹⁸ Assumptions based on EurDev's 'Sick Leaves in Europe 2022', available at: <https://www.eurodev.com/blog/sick-leaves-in-europe-2022>

Table 0-5 Economic productivity costs associated with a 'statistical' case of ill health (EUR₂₀₂₄/case)¹¹⁹, by endpoint in alphabetical order

Specific health risk/ endpoint in scope	Sickness absence (No. of days/ case)	Productivity Costs (EUR ₂₀₂₄ / case)	Commentary
Chronic kidney disease	30	13,000	Evidence-based assumption that a typical case result in around 30 days of sickness absence (or a fourth of the days of absence from a cancer case).
Endometriosis	-	8,000	Sourced from Simoens <i>et al.</i> (2012) ¹²⁰ , price adjusted using the GDP deflator.
Maternal hypertensive disorders	25	10,000	This is based on the understanding that women diagnosed with preeclampsia may require extended maternity leave, often starting earlier than usual due to the need for medical monitoring and rest, which can range from several weeks to a few months.
High LDL cholesterol	6.25	3,000	Based on Leynen <i>et al.</i> (2016) ¹²¹ and the assumption that attributable sickness absence might be up to 6.25 workdays (or no more than half 12.5 days, or the average days of absenteeism per employee in Europe based on WHO evidence).
High systolic blood pressure	6.25	3,000	Based on Leynen <i>et al.</i> (2016) and the assumption that attributable sickness absence could be up to 6.25 work-days.
Hypothyroidism	6.25	3,000	Based on Nexø <i>et al.</i> (2014) ¹²² and the assumption that attributable sickness absence could be up to 6.25 workdays.
Kidney cancer	75-120	32,000	Based on the assumption that cancer patients might typically take around 75-120 days off work, although acknowledging this will depend on the type of cancer (developed based on a study from Reframe Cancer 2024 ¹²³ and breast cancer evidence in Drolet <i>et al.</i> , 2005 ¹²⁴).

¹¹⁹ All monetary values are presented in 2024 euros, having adjusted data from secondary sources using evidence from the GDP deflator where necessary. See Appendix B.

¹²⁰ Simoens *et al.* (2012). Endometriosis cost assessment (the EndoCost study): a cost-of-illness study protocol. *Gynecologic and obstetric investigation*, 71(3), 170–176. Available at: <https://doi.org/10.1159/000316055>

¹²¹ Leynen *et al.* (2006). Increased absenteeism from work among aware and treated hypertensive and hypercholesterolaemic patients. Available at: <https://pubmed.ncbi.nlm.nih.gov/16575282/>

¹²² Nexø *et al.* (2014). Increased Risk of Long-Term Sickness Absence, Lower Rate of Return to Work, and Higher Risk of Unemployment and Disability Pensioning for Thyroid Patients: A Danish Register-Based Cohort Study. Available at: <https://academic.oup.com/ijcm/article/99/9/3184/2538008?login=false,%20costs>

¹²³ Reframe (2024). The Employee Experience report: Living and working with cancer. Available at: https://www.reframe.co.uk/hubfs/eBooks%20and%20whitepapers/Reframe_The%20Employee%20Experience%20Report-Living%20and%20Working%20with%20Cancer%202024.pdf

¹²⁴ Drolet *et al.* (2005). Work absence after breast cancer diagnosis: a population-based study. Available at: [https://pmc.ncbi.nlm.nih.gov/articles/PMC1216317/#:~:text=Interpretation,average\)%20after%20receiving%20the%20diagnosis.](https://pmc.ncbi.nlm.nih.gov/articles/PMC1216317/#:~:text=Interpretation,average)%20after%20receiving%20the%20diagnosis.)

Specific health risk/ endpoint in scope	Sickness absence (No. of days/ case)	Productivity Costs (EUR ₂₀₂₄ / case)	Commentary
Low (and very low) birth weight	24	10,000	Based on the assumption that one parent may take up to 24 additional days off work, due to additional care/hospitalisation of their newborn/infant (developed based on evidence from Mehretie <i>et al.</i> , 2024 ¹²⁵).
Obesity	-	1,800	Based on the European Food Information Council's 'Europe's Obesity Statistics: Figures, Trends & Rates by Country', updated in 2024.
Osteoporosis	8	3,000	Based on the assumptions that, on average, an osteoporosis patient may take up to 8 days of attributable sickness absence. This is based on evidence that 5% of people with osteoporosis may suffer fractures could cause 40 sickness days or more ¹²⁶ , the rest (95%) might only take a few of days a year.
Lower respiratory tract infection	7	3,000	Based on the assumption that, on average, a LRTI patient (and a guardian with the patient, where relevant) may take up to a total 7 days of attributable sickness absence (drawing also on Fisman <i>et al.</i> , 2024 ¹²⁷).
Testicular cancer	75-120	32,000	Based on the assumption that cancer patients might typically take around 120 days off work, although acknowledging this will depend on the type of cancer (developed based on a study from reframe cancer 2024 ¹²⁸ and on breast cancer evidence in Drolet <i>et al.</i> , 2005).
Time to pregnancy/ female infertility	7	3,000	Based on the assumptions that, on average, a typical infertility patient (and partner, where relevant) may take up to a total 7 days of attributable absence from work (drawing on the typical length of infertility treatment cycles and associated care commitments ¹²⁹).

Please see Appendix B to Annex B for underpinning evidence/sources and the analysis undertaken to conclude on these proposals. In addition, please note that these figures are rounded to the nearest '000 euros, or '00 where relevant

¹²⁵ Mehretie *et al.* (2024). Length of hospital stay and factors associated with very-low-birth-weight preterm neonates surviving to discharge a cross-sectional study, 2022. Available at: <https://bmcpediatr.biomedcentral.com/articles/10.1186/s12887-024-04532-5>

¹²⁶ CDC (2017). National Health Statistics Report. Available at: <https://www.cdc.gov/nchs/data/nhsr/nhsr103.pdf>

¹²⁷ Fisman *et al.* (2024). Absenteeism and Productivity Loss Due to Influenza or Influenza-like Illness in Adults in Europe and North America. Available at: <https://www.mdpi.com/2079-9721/12/12/331>

¹²⁸ Reframe (2024). The Employee Experience report: Living and working with cancer. Available at: https://www.reframe.co.uk/hubfs/eBooks%20and%20whitepapers/Reframe_The%20Employee%20Experience%20Report-Living%20and%20Working%20with%20Cancer%202024.pdf

¹²⁹ For example, <https://guysandstthomasspecialistcare.co.uk/news/what-are-the-stages-of-ivf-treatment/>

'Price' adjustments

Prices were adjusted to constant 2024 euros using data from the ECB¹³⁰ of the GDP deflator.

¹³⁰ https://data.ecb.europa.eu/data/datasets/MNA/MNA.Q.Y.I9.W2.S1.S1.B1GQ_Z_Z_Z.IX.D.N

C. Ecosystem services potentially affected by PFAS and how they will be considered in Task 4

The table below describes the relevant (eco)toxicological evidence, potential implications on ecosystem services, and a proposal for how these will be considered in Task 4.

Table 6 Ecosystem services which may be impacted by PFAS based on the available (eco)toxicological evidence, and how we suggest considering these in Task 4

(Eco)toxicological evidence	Potential implications on ecosystem services	Further steps for analysis in Task 4
Impacts of PFAS on primary producers – some PFAS are toxic to algae and some may be toxic to plants.	1. Cascade effects (multiple ecosystem services) – primary producers are at the foundations of food-webs across ecosystem types, and therefore, negative impacts on primary producers have the potential to ripple through ecosystems via ecological interactions. These cascade effects could result in the disruption of a wide range of ecosystem services. 2. Climate regulation – primary producers play a key role in carbon sequestration. 3. Food and other biomass provisioning – if toxic effects occur in plants involved in food provisioning (crops) or other biomass provisioning (e.g. trees and cotton plants), there could be economic losses from reduced yields. Impacts may also arise due to health protection goals (described below this table). 4. Water quality regulation – toxic effects in algae could disrupt water quality as algae play a role in water quality regulation.	1. Describe only at a high level. The general takeaway message is that there could be implications for all types of ecosystem services. It is unlikely to be fruitful to further investigate the ecological interactions. 2. Include in a case study. This will involve qualitatively explaining the potential impacts and gathering additional information to explain the logic and state of evidence on the potential effects of PFAS on this service. E.g. looking into the value of algae in carbon sequestration could contextualise the potential cost implications. Algae have been reported to be very sensitive to PFAS so it may be useful to look at concentrations in EEA surface waters (Task 3) and concentrations in studies (whilst also considering the limitations noted in the Task 1 report, e.g. related to mixtures, bioaccumulation potential, and long-term exposure). 3. Exclude from analysis. The evidence of toxicity of PFAS to plants is very sparse

(Eco)toxicological evidence	Potential implications on ecosystem services	Further steps for analysis in Task 4
		and even a qualitative description would lack references. 4. Exclude from analysis. (see row below on water quality impacts)
Impacts of PFAS on pollinators – there is evidence of toxicity of some PFAS to pollinators.	1. Crop pollination – toxic effects in bees and other pollinators could lead to a decline in natural pollination of crops. This could be significant as the crop pollination ecosystem service in the EU has been valued at EUR 4,517 million.¹³¹ 2. Other pollination services – A large proportion of flowering plants rely on pollinators, and as such, pollinators are essential for biodiversity. Harm to pollinators could lead to harm to primary producers and have cascade effects (similar to those mentioned above).	1. Include in a case study. This will include a more detailed description of the risks of PFAS to pollinators. The value of crop pollination to the EEA could be investigated in more detail, e.g. to see if there is data on which pollinator species are most critical, and which of those have been studied for PFAS effects. 2. Describe only at a high level. This impact might be relatively significant, however, describing it clearly is unlikely to be possible.
Impacts of PFAS on birds - there is evidence of toxicity of some PFAS to birds.	1. Food provisioning – birds contribute to pest control and seed dispersal which could benefit arable farming, however, birds also interact negatively with agricultural systems, e.g. through direct consumption of produce.	1. Exclude from analysis. The interactions between birds and agricultural productivity are complicated. We suggest avoiding this complexity.
Impacts of PFAS on soil quality – there is evidence of toxicity of PFAS to some soil-dwelling organisms.	1. Cascade effects (multiple ecosystem services) – terrestrial primary producers, and consequently entire food webs, rely on healthy soil for nutrients and water. Harm to soil-dwelling organisms can result in damage to soil structure and function. This	1. Describe only at a high level. There could be overlaps looking at agricultural productivity with the category evidence on (eco)toxicity in primary producers.

¹³¹ Eurostat (2021) Accounting for ecosystems and their services in the European Union, Final report from phase II of the INCA project aiming to develop a pilot for an integrated system of ecosystem accounts for the EU. Available at: <https://ec.europa.eu/eurostat/web/products-statistical-reports/-/ks-ft-20-002>

(Eco)toxicological evidence	Potential implications on ecosystem services	Further steps for analysis in Task 4
	could impact agricultural systems and other ecosystem services.	
Impacts of PFAS on aquatic species - there is evidence of toxicity of PFAS to fish, mussels, and crustaceans.	1. Food provisioning – if toxic effects occur in aquaculture-related species involved in food provisioning, there could be economic losses from reduced yields. Marine fish capture in the EU has an estimated value of EUR 1.04 million. ¹³²	1. Include in a case study. There are several references looking at the effects of PFAS in fish and other aquatic organisms. More details on the food provisioning ecosystem services related to aquatic species for which there is evidence of effects of PFAS could be interesting.
Impacts of PFAS on livestock and poultry – there is evidence of toxicity of PFAS to chickens and some mammals.	1. Food provisioning — if toxic effects occur in livestock and poultry, there could be economic losses from reduced yields. Impacts may also arise due to health protection goals (described below this table).	1. Include in a case study. Targeted searches to identify evidence of PFAS effects on farm animals (in addition to the evidence already gathered in Task 1) may be useful.
Impacts of PFAS on water quality	1. Water quality regulation – contamination of water with PFAS may counteract the water purification processes that occur in wetlands (pollutant immobilisation, retention, and removal). The water purification ecosystem service in the EU has an estimated value of EUR 55,576 million. ¹³³ 2. Other ecosystem services – PFAS can lead to reduced growth of microalgae, which play an important role in climate regulation and could have cascade effects on food webs in ecosystems that could ultimately affect a	1. Exclude from analysis. As discussed in Task 1, there is insufficient data to quantify the extent to which these ecosystem services are affected by PFAS.

¹³² Eurostat (2021) *Accounting for ecosystems and their services in the European Union, Final report from phase II of the INCA project aiming to develop a pilot for an integrated system of ecosystem accounts for the EU*. Available at: <https://ec.europa.eu/eurostat/web/products-statistical-reports/-/ks-ft-20-002>

(Eco)toxicological evidence	Potential implications on ecosystem services	Further steps for analysis in Task 4
	potentially wide range of ecosystem service impacts.	

Some types of ecosystem service impacts have been deliberately excluded from the table above, either due to large uncertainties on economic significance or because the ecosystem service impacts are only indirectly related to (eco)toxicological effects. The excluded impacts include:

- **Recreational and cultural ecosystem services.** These include recreational fishing (if fish growth / population sizes are affected by PFAS), activities related to birds (e.g. bird watching, if bird populations are affected by PFAS), and outdoor swimming (if potential bathing waters are contaminated with PFAS). Cultural and recreational ecosystem services are generally difficult to monetise and conceptualise in economic terms. **It is suspected that the potential impacts of PFAS on cultural and recreational ecosystem services are less significant and more indirect than other ecosystem service impacts and we do not recommend including them in the final report for this project.**
- **Human use of ecosystem services impacted by health and environmental protection goals.** These impacts fall in a similar category to remediation and water treatment costs as they represent costs to avoid risks/damage, however, they have not been as widely studied in the literature. We will describe these costs only qualitatively in the final report, due to data gaps. These cost types include:
 - **PFAS regulatory limits in food and effects on food provisioning ecosystem services:** Commission Regulation 2022/2388/EU sets maximum levels for PFAS (PFOS, PFOA, PFNA, PFHxS, individually and as a cumulative sum) in certain foodstuffs (eggs, seafood, and livestock produce),¹³⁴ which are likely to affect the use of the food provisioning ecosystem services. The limits range from 0.2 to 50 µg/kg wet weight. It is unlikely that data on the concentrations and distribution of PFAS in foodstuffs is available across Europe.
 - **PFAS limits in waste and material provisioning ecosystem services:** The POPs Regulation sets concentration limits for certain PFAS in waste. This can lead to the diversion of waste from recycling or reuse to incineration (in order to irreversibly destroy PFAS), resulting in a loss of material value, hence increasing demand for new materials and possibly putting more pressure on ecosystems for provision of these new materials. However, data on the value of waste diverted from recycling to incineration due to PFAS contamination is not available and approaches to comply with the regulation are expected to differ between EU countries.

¹³⁴ Commission Regulation 2022/2388/EU on maximum levels of PFAS in certain foodstuffs. Available at: <https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32022R2388>

- **PFAS limits in soil and land use ecosystem services:** Some Member States have soil limit values for PFAS¹³⁵, which could prevent the use of land for economic activities that would otherwise take place. However, soil limit values and soil risk assessment methods vary across the EU, meaning that detailed data gathering would be needed to understand the number / area of PFAS contaminated sites where PFAS contamination is preventing economic activity.
- Other provisioning ecosystem services limited by health protection goals, e.g. the loss of clean water provisioning due to contamination of surface water. **Water treatment costs will be assessed in the section below.**

¹³⁵ E.g. in Germany there are limits for PFOA (0.1 µg/l), PFBA (10 µg/l), and PFOS (0.1 µg/l) under the Federal Soil Protection Ordinance, a federal regulation under the German Soil Protection Act - <https://www.jonesday.com/en/insights/2023/07/new-german-regulation-imposes-thresholds-for-pfas>

D. Remediation and treatment costs – literature overview

Source	Cost category (e.g. soil remediation, drinking water treatment, wastewater treatment)	Description of costed activities	PFAS species/groups	Unit cost	Unit (e.g. Euro per site, Dollar per kg)	What are the unit costs applied to, to calculate totals (e.g. what types of sites, or tonnes of emissions)	What triggers remediation/treatment (e.g. concentration threshold)	Other key assumptions	Other notes
(Column A)	(Column B)	(Column C)	(Column D)	(Column E)	(Column F)	(Column G)	(Column H)	(Column I)	(Column J)
Ling, A.L. (2024). Estimated scale of costs to remove PFAS from the environment at current emission rates. https://doi.org/10.1016/j.scitotenv.2024.170647 (full PDF available at https://papers.ssrn.com/sol3/Delivery.cfm?abstractid=4718530)	Removal and destruction of PFAA from drinking water, wastewater effluent, landfill lechate, and wastewater biosolids	"Costs estimated in this analysis are intended to reflect present value, life-cycle project costs for PFAS remediation projects over a 20-year service life, including equipment costs, direct costs, indirect costs, and operation and maintenance (O&M) costs"	PFAAs	USD 0.9 million - 67 million	USD per kg PFAA removed and destroyed	Global emission rate (mass/year) of PFAAs	n/a		"Costs to remove and destroy PFAS from environmental soils, sediments, atmosphere, or biota remain either poorly characterized or impractical, and are thus not included in this analysis." "PFAS such as TFA and f-gases do not currently have viable treatment techniques [...] and thus do not have established cost estimates for environmental remediation." "Total PFAS production, including fluorotelomers, fluoropolymers, and fluorinated gases, is estimated to be 10 to 10,000 times higher than PFAA production."
Forever Pollution Project (2025). Unaffordable - The absurd cost of 'PFAS as usual'. https://foreverpollution.eu/lobbying/the-cost-of-remediation/ and https://foreverpollution.eu/lobbying/the-cost-methodology/	Soil remediation	"The majority of cost estimates used to establish soil remediation costs assumed management using either direct transport to landfills (dig and dump) or ex-situ soil washing with transport of rinsate to landfills." "For the legacy scenario, this cost estimate did not include PFAS destruction methods associated with the landfill leachate produced by landfilled soils [...] It also excludes costs of PFAS destruction for soil washing" "For the emerging scenario that also considers (ultra-)short-chain PFAS where GAC are not effective and ion-exchange resins less effective, destruction of PFAS was accounted for."	Legacy PFAS (long-chain PFAS such as PFOS and PFOA) and emerging PFAS (TFA and other short and ultra-short chain PFAS)	Airports: EUR 7.4 million, Industrial PFAS users: EUR 8.0 million, Military bases: EUR 36.8 million, PFAS manufacturer: EUR 868.4 million, Other: EUR 6 million (Costs calculated by WSP based on the source data provided by the authors in a separate spreadsheet, and the methodology description; costs shown are based on the 75th percentile tonnes of soil per site, and 75th percentile costs per tonne, which were recommended by the authors as the best estimate)	EUR per site	Commercial airports, military bases, PFAS producers, PFAS users, and a small share (10% of those listed in the database) of manufacturers of paper and paperboard products assumed to be making or to have made PFAS-coated products, such as grease-proof wrapping paper. Calculation: "The statistical distribution of costs per ton of soil remediated was established from the sites described above as cost source data and used for the calculation. The statistical distribution of tons of soil per site for each type of site was established for use in the calculation. For each country and type of site, the statistical distribution of costs for that country/site type was estimated by multiplying the number of that type of site by the tonnes per site number and the cost per tonne number. For example, Austria has eight airport sites. The 10th percentile cost for airports in Austria was estimated as 8 times the 10th percentile tonne/site for airports (5,372 tonnes/site) times the 10th percentile cost/ton (101 EUR/tonne). For each country, total costs for each percentile were summed across all site types For each percentile considered (10th, 25th, 50th (median), 75th, and 90th), the total estimated costs for all countries and site types considered were summed for an all-EU cost for that percentile. 75th percentile costs were assumed as best-guess costs to account for contingencies not included in these cost estimates."	Shortlisted around 1,800 sites from CNRS "PFAS data hub" (based on Forever Pollution Project), because of their typical levels of contamination and proximity to humans and vital resources, and based on data availability on remediation costs for these categories of sites.	"Only the most contaminated soils at site are treated; lesser contaminated soils are not accounted for in the cost estimates (a conservative assumption), but would need to be managed (e.g. with in situ stabilisation, monitoring) The distribution of costs for soil remediation at a category of sites based on available data (e.g. airport, military sites, PFAS production facility) are similar for other sites The number of sites included in the cost estimate are all that were identified in the Forever Pollution database for commercial airports, military bases, PFAS producers, PFAS users, and a small share (10%) of manufacturers of paper and paperboard The reported tonnes of soil remediated per site that we could collect are reflective of typical site sizes for a given category (for example, the median amount of soil remediated per airport sites where a remediation activity occurred, based on the remediated airport sites we had data for, would be similar to the median amount of soil that should be/should have been remediated in other airport sites). Similarly, the costs per tonne of soil remediation for landfilling or soil washing for sites for which we have data, have the same statistical distribution for costs per tonne in sites for which we do not have data. It is assumed that typical costs are in the 75th percentile of our cost distribution (low end 50% and high end 90%) to account for not considering unknown sites (only sites with a high likelihood of requiring remediation and not potential sites) It is assumed that reported costs per tonne are reflective of costs available for the timeframe in which remediation would occur and that the treatments included would be reasonable for the scenarios outlined here. For the legacy scenario only, it is assumed that PFAS emissions stop shortly, such that remediation of existing contamination is sufficient, and that additional sites will not be added to the list, nor existing sites made larger."	"range of typical costs per category of site, based on scientific literature, available commercial figures, and a collection of costs gathered by our partners" (provided in separate spreadsheet, see also calculation in column G) "Things not included in the cost estimate Firefighting sites and training sites that are not in airports or military bases Infrastructure decontamination (relevant at many sites). Currently, there is little data on the costs of remediating PFAS-polluted buildings which can be found at PFAS-contaminated soil sites (e.g. contaminated airport hangers, sprinkler systems). Currently, there is a lack of general full-scale technology and data about the costs of remediating such sites. For these reasons, the "legacy" scenario is a conservative one, and, therefore, the high-end estimates are more likely to represent the costs of remediation considering the several sites that could not be included. Additional or alternate technology used for PFAS destruction General remediation of diffusely polluted sites, like ambient surface waters, groundwaters, or soils outside known hotspots, many of which have levels of PFAS in them that can exceed country-specific threshold values. Those sites are not practical or affordable to treat and result in lower health impacts due to the low background concentrations present. Costs to update/provide PFAS destruction infrastructure, Costs to implement source controls at industrial facilities through wastewater and air emission treatment Infrastructure costs to add high-temperature incineration or GAC reactivation capacity, including any air emission control equipment (for disposal of solids or some liquids) In case partners didn't ask for corrections on updated sources, the number of PFAS users per country, collected for the Forever Pollution Project, is underestimated."
Forever Pollution Project (2025). Unaffordable - The absurd cost of 'PFAS as usual'. https://foreverpollution.eu/lobbying/the-cost-of-remediation/ and https://foreverpollution.eu/lobbying/the-cost-methodology/	Drinking water treatment	"GAC with high-temperature incineration of spent media was assumed for use in the legacy scenario. [...] RO was assumed for the emerging scenario because it can separate TFA from water. However, RO produced a large volume of brine ("waste" liquid concentrated with filtered PFAS), requiring management (assumed to be 3% for this analysis). We assumed that the brine would be treated with an emerging PFAS destruction technology designed to handle liquids, such as supercritical water oxidation (SCWO), electrochemical oxidation (ECO), or hydrothermal alkaline treatment (HALT)." Includes capital costs and operating costs.	Legacy PFAS (long-chain PFAS such as PFOS and PFOA) and emerging PFAS (TFA and other short and ultra-short chain PFAS)	General unit cost not specified in source, but cost for each site provided in separate spreadsheet (based on EPA PFAS treatment cost models and the Minnesota Pollution Control Agency (MPCA) cost models, with certain adjustments)	EUR per drinking water treatment plant	No full list of DW supplies in Europe, so they used the list of "large drinking water supply zones (provide either more than 1,000m3 drinking water per day as an average or serve more than 5,000 people)"-estimated that there must be one facility per zone (conservative) under the DWD. Calculation: "Collect data on large water zones (treating more than 5,000 residents or 1,000 cubic meters per day) in EU countries. Some countries reported zones smaller than those thresholds: we set a minimum value to 500 cubic meters per day (difficult to properly assess costs under this threshold due to economies of scale). Estimate flow treated for each, in m3/day In some cases, this was provided.	"Assumes that all large supply zones would need PFAS treatment and does not account for any treatment plants that currently remove PFAS with existing levels of treatment."	"Assumes that PFAS treatment technologies would be applied by large supply zones as if each supply zone is one facility. Each supply zone can actually contain several facilities. This work estimated costs for one theoretical facility per zone instead of each actual facility, resulting in an underestimate in cost due to economies of scale of the treatment effort. Assumes that all large supply zones would need PFAS treatment and does not account for any treatment plants that currently remove PFAS with existing levels of treatment. In some cases, additional data cleaning was done to establish m3/year treated based on population and reported water use rates for each country. Assumes the use of technologies listed per scenario, including specified	"Things not included in the cost estimate Reporting small drinking water supply zones is not mandatory. It means that even in the emerging scenario, our calculated costs do not include the treatment of all drinking water and are thus underestimated. Exact number of facilities per supply zone. There can be more than one per zone, which means costs would increase. Infrastructure costs to add high-temperature incineration or GAC reactivation capacity, including any air emission control equipment (for disposal of solids or some liquids). Infrastructure costs to add liquid destruction capacity, for example, SCWO (for disposal of liquid residuals)."

Source	Cost category (e.g. soil remediation, drinking water treatment, wastewater treatment)	Description of costed activities	PFAS species/groups	Unit cost	Unit (e.g. Euro per site, Dollar per kg)	What are the unit costs applied to, to calculate totals (e.g. what types of sites, or tonnes of emissions)	What triggers remediation/treatment (e.g. concentration threshold)	Other key assumptions	Other notes
(Column A)	(Column B)	(Column C)	(Column D)	(Column E)	(Column F)	(Column G)	(Column H)	(Column I)	(Column J)
						Some countries (IT and NL) seemed to be reporting in m3/year not m3/day based on scale, so flow rates were adjusted accordingly. In other cases, it was missing and estimated from reported L/person/day usage in those countries from the EurEau dataset (UK, NO), from other parts of the same country (DE, FR), or from neighbouring countries (DK, SE) Apply treatment costs summarised above to estimate capital and annual O&M costs for each large drinking water zone. Legacy scenario – GAC with high-temperature incineration, then multiply total costs by 0.05 to reflect treating only 5% of plants (consistent with how many currently exceed the EU drinking water directive in Germany) Emerging scenario – RO with emerging liquid destruction technology for brine management for all large drinking water zones Estimate 20-year present value cost for each large drinking water zone For each country, sum up 20-year present value costs for each scenario and divide by 20 for annualised costs"		drinking water quality and PFAS fate outcomes: For the legacy scenario, assume adding GAC treatment in pressurised vessels to the end of the treatment plants, with spent GAC routed to GAC reactivation facilities. Cost inclusions match the EPA model linked above, including the assumption that GAC is changed out after 50,000-bed volumes of water pass through. For the emerging scenario, assume that all reported water supply zones add RO to the back end of the plant, with RO concentrate/brine and the PFAS in it routed to PFAS destruction treatment at a cost of 8 EUR/m3. Cost inclusions match the EPA model linked above, including no fees for discharge. Assumes 97% recovery of RO, with 3% of initial volume routed to brine and disposal. Also assumes that liquid destruction technologies would be widely available at a total cost of 8 EUR/m3 of brine disposed of. Assumes treatment needs per scenario as follows: For the legacy scenario, assume that 5% of large supply zones exceed the EU drinking water directive and would require treatment to remove long-chains. This is based on available literature and measurements, especially watched samples in Germany showing a rapid rise of the share exceeding the European Drinking Water Directive of 0.1 µg/L for the sum of 20 PFAS (3.8 % in 2023, 4.1% in 2024) and the fact that not all of Europe's supply zones are included in our data. We chose 5% as a conservative value, knowing that the number of zones to treat will probably be much higher in case countries adopt stricter rules, as is the case in Germany: according to the latest data, the local norm set at 20 ng/L for the sum of 4 PFAS would imply the need to treat 20% of the zones. For the emerging scenario, assume that all water supply zones have TFA over some undefined threshold, and, thus, all would require treatment if some future TFA target would need to be met. Assuming discount rate of 5.0% for net-present value calculations Assuming a USD/EUR conversion rate of 1.1 USD to 1.0 EUR"	
Forever Pollution Project (2025). Unaffordable - The absurd cost of 'PFAS as usual'. https://foreverpollution.eu/lobbying/the-cost-of-remediation/ and https://foreverpollution.eu/lobbying/the-cost-methodology/	Wastewater effluent	"The method most currently applicable for removing short-chain PFAS is pretreatment to reduce organics and solids low enough to be fed into RO and GAC vessels (<1 mg/L each COD and TSS or <5 mg/L BOD or includes sand or other filtration), followed by RO membranes, with brine sent to GAC adsorption, then anion exchange, and high-temperature incineration of spent GAC and anion exchange media. For WWTPs in the source data reporting, either "advanced" treatment or effluent water quality meeting the above guidelines, pretreatment costs were not included. Pretreatment costs were based on estimated costs for retrofitting a conventional activated sludge system with a membrane bioreactor (MBR) system for improved water quality." Includes capital costs and operating costs.	Emerging PFAS (TFA and other short and ultra-short chain PFAS)	General unit cost not specified in source, but cost for each site provided in separate spreadsheet (based on cost models developed for the Minnesota Pollution Control Agency (MPCA) (2023), and certain adjustments)	Combination of EUR per wastewater treatment plant and EUR per m3 of water	Using the UWWTD and the data which MS have to provide (including listing urban wastewater treatment plants and wastewater treatment from certain industrial sectors and their associated flows). Calculation: "Estimate flow treated for each wastewater plant, in m3/day. In some cases, this was provided. In other cases, it was missing and estimated from reported m3/p.e./day usage in those countries from other parts of the same country (SE) or assuming a value of 0.3 m3/p.e./day (PT, IS, NO, UK, CH). Filter to only include WWTPs greater than 4 000 m3/day. This is meant to reflect only large WWTPs with mechanical treatment. Apply treatment costs summarised above to estimate capital and annual O&M costs for each large WWTP. Emerging scenario – RO with brine treated by GAC and anion exchange with high-temperature incineration of spent media, including pretreatment capital costs for those without advanced treatment to low organics and solids. Estimate 20-year present value cost for each large WWTP. For each country, sum up 20-year present value costs for each scenario and divide by 20 for annualised costs."	"WWTPs greater than 4 000 m3/day. This is meant to reflect only large WWTPs with mechanical treatment"	"Assuming that provided data for "wwwWasteWater Treated" = m3/year treated at that plant. In some cases, additional data cleaning was done to establish m3/year based on reported person equivalents treated per day or on reported person equivalent plant capacity. Assuming that plants without "advanced treatment", reported filtration process, or effluent water reporting <1 mg/L BOD or TSS or < 5 mg/L COD would require pretreatment before GAC. Assuming that the costs estimated in the US in 2023 are valid, and all those assumptions are accurate enough for costs to be similar. From https://www.pca.state.mn.us/sites/default/files/c-plc1-26.pdf Assume that water quality of WW effluent is similar enough to the MPCA report that the media use rates are comparable. Assumes breakthrough and media changeout at about 5,000-bed volumes for GAC and about 50,000-bed volumes for anion exchange. Range of PFAS concentrations in wastewater effluent consistent with studies cited in Thompson, 2022 article cited above, ranging from 40 to 570 ng/L WW effluent. This range reflects the 10th and 90th percentile of studies that measured at least 4 PFAS in WW	"Things not included in the cost estimate Costs do not include efforts or expenses by municipal wastewater plants to reduce or manage upstream PFAS. Costs do not include efforts or expenses by industrial wastewater plants to reduce or treat PFAS prior to discharge to municipal wastewater sewers. Wastewater treatment plants that are not reported to the European Union and couldn't be retrieved locally, and probably some industrial sectors that treat their wastewater autonomously. Additional O&M costs for any pretreatment added to prepare WWTP effluent for RO and GAC treatment. We only kept the biggest plants (treating over 4,000 cubic meters per day) for our "emerging" scenario and did not consider wastewater treatment plant treatment in our "legacy" scenario. Costs do not include any treatment that would occur at plants treating less than 4,000 cubic meters per day. The assumption here is that treating PFAS at those plants would be prohibitive from an affordability standpoint. We did not estimate the cost of TFA removal because the technical and financial implications of such treatment in wastewater treatment plants are unrealistic under known circumstances.

Source (Column A)	Cost category (e.g. soil remediation, drinking water treatment, wastewater treatment) (Column B)	Description of costed activities (Column C)	PFAS species/groups (Column D)	Unit cost (Column E)	Unit (e.g. Euro per site, Dollar per kg) (Column F)	What are the unit costs applied to, to calculate totals (e.g. what types of sites, or tonnes of emissions) (Column G)	What triggers remediation/treatment (e.g. concentration threshold) (Column H)	Other key assumptions (Column I)	Other notes (Column J)
								effluent. Assuming discount rate of 5.0% for net-present value calculations. Assuming a USD/EUR conversion rate of 1.1 USD to 1.0 EUR."	The RO system proposed for the emerging scenario could remove some, but will probably not remove all TFA because TFA breaks through media relatively quickly, requiring high O&M costs for media changeout and renewal. Infrastructure costs to add high-temperature incineration or GAC reactivation capacity, including any air emission control equipment (for disposal of solids or some liquids)."
Forever Pollution Project (2025). Unaffordable - The absurd cost of 'PFAS as usual'. https://foreverpollution.eu/lobbying/the-cost-of-remediation/ and https://foreverpollution.eu/lobbying/the-cost-methodology/	Wastewater biosolids	"The most established method currently used is pyrolysis of sludge with thermal oxidation of produced syngas to facilitate PFAS destruction." Net present value. "The low end reflects costs for a site treating 10 dry tonnes per day, and the high end of costs reflects a site treating 1 dry tonnes per day."	Emerging PFAS (TFA and other short and ultra-short chain PFAS)	EUR 1,160 - 3,380 (based on sludge pyrolysis cost models developed for the Minnesota Pollution Control Agency (MPCA))	EUR per dry tonne of sludge	"total sludge disposal per country, in thousands of tonnes of dry substance, for "urban" wastewater treatment plants and "other" wastewater treatment plants" (according to Eurostat "Sewage sludge production and disposal") Calculation: "From source data, estimate total wastewater sludge sent to fields as the total mass per year for each country multiplied by the sum of percents to agriculture, compost, and "other". Multiply by the range of costs stated above for pyrolysis for high end and low end costs. The high end costs here were used, because more facilities are expected to be in the range of 1 dry tonne per day than 10 dry tonnes per day."	n/a (estimate for all sludge currently routed to compost + agriculture, with a range of 70%-150% around this to account for uncertainty)	"Assume that all sewage sludge production is reported for all the countries listed (no data for Iceland) and that the breakdown between agricultural application, compost, and other routes is accurate. Pyrolysis/gasification costs estimates were based on facilities managing at least 1 dry tonne per day. Costs for smaller sites may be underestimated and the upper end of costs was used as the "best guess" cost. Costs to dot include any pretreatment (anaerobic digestion, dewatering, etc.) required prior to pyrolysis treatment of sludges. Range of PFAS concentrations in wastewater biosolids consistent with studies cited in Thompson, 2022 article cited above, ranging from 60-600 ng/g biosolids. This range reflects the 10th percentile and 90th percentile of data listed from three studies that each measured at least 10 PFAS, including perfluoroalkyl sulfonamides (a type of PFAS that is usually present in high concentrations in biosolids). Assuming discount rate of 5.0% for net-present value calculations."	"Things not included in the cost estimate Any amount of sludge routed to fields that is not reported in the source database is not considered in this cost estimate. Costs do not include final management of biochar produced from the pyrolysis, which could be an added cost or could potentially be marketed and sold as a product. Switzerland has stopped applying sewage sludge in its fields since 2006 and is thus not included in these estimates."
Forever Pollution Project (2025). Unaffordable - The absurd cost of 'PFAS as usual'. https://foreverpollution.eu/lobbying/the-cost-of-remediation/ and https://foreverpollution.eu/lobbying/the-cost-methodology/	Landfill lechate	"The legacy scenario uses foam fractionation for the treatment of landfill leachate, with the destruction of foamate liquid using high-temperature incineration. [...] The emerging scenario assumes use of RO with SCWO or other destruction of brine."	Legacy PFAS (long-chain PFAS such as PFOS and PFOA) and emerging PFAS (TFA and other short and ultra-short chain PFAS)	Legacy: EUR 1.5 - 24; Emerging: EUR 5 - 65	EUR per m3 of leachate	Eurostat "number and capacity of recovery and disposal facilities" Calculation: "Estimate total landfill capacity per country. In some cases, this was provided. In other cases, it was missing and estimated from reported m3/person in similar or nearby countries (BG, HR, EE, FI, LV, PO, IS, CH). Apply assumption for percent of capacity in use (70%) to estimate used landfill volume per country. Apply assumed depth of landfill (10m) to estimate used landfill area per country. This is needed, because leachate is more a function of area than volume, partly due to rainfall. Apply assumed range of leachate production per area (100 to 300 gallons per acre per day) to estimate annual volume of leachate currently produced in each area. Apply treatment costs in EU/m3 for legacy and emerging scenarios. Both will end up with a range reflecting low end (low leachate * low costs) to high end (high leachate * high costs). The best guess cost was assumed to be half of the high end cost estimated here."	n/a (Includes treatment of 50% to 100% leachate from all reported landfills from "Eurostat" for each country)	"Assumes average landfill depth of 30 metres. Assumed flow of leachate per cubic metre of landfill capacity, leachate production rates of 100 to 300 gallons per day per acre-feet from https://www.sciencedirect.com/science/article/pii/S2352340923000793 . Assumed 50% to 100% leachate for landfills listed is available for treatment. Assumed percent of "rest" capacity actually in use (assumed to be 70%). Assuming discount rate of 5.0% for net-present value calculations."	"Things not included in the cost estimate A lot of landfills are completely off the radar in Europe. Our estimates do not account for unreported closed or illegal landfills. Costs to retrofit unlined landfills to collect leachate. Infrastructure costs to add liquid destruction capacity could be SCWO (for disposal of liquid residuals)."
Forever Pollution Project (2025). Unaffordable - The absurd cost of 'PFAS as usual'. https://foreverpollution.eu/lobbying/the-cost-of-remediation/ and https://foreverpollution.eu/lobbying/the-cost-methodology/	Consulting and monitoring	procurement of consultants, design of remediation technology, quality assurance and PFAS monitoring over the lifetime of the remediation action	Legacy PFAS (long-chain PFAS such as PFOS and PFOA) and emerging PFAS (TFA and other short and ultra-short chain PFAS)	5%	percent of remediation/treatment costs	Total remediation/treatment costs	n/a		
Nordic Council of Ministers (2019). The cost of inaction. https://norden.diva-portal.org/smash/get/diva2:1295959/FULLTEXT01.pdf	Upgrading water treatment works	Providing a new pipeline to bring in clean water from other areas, capital cost of upgrades, and maintenance cost over 20 years. Net present value.	C4-14 non-polymer fluorosurfactants	New pipeline: EUR 800 (EUR 500-1,500) Upgrading water treatment works (capital): EUR 300 (EUR 18-600) Upgrading water treatment works (maintenance): EUR 19 (EUR 8-26)	EUR per person	1% - 5% (best estimate 3%) of the population are exposed to excess levels of PFAS via drinking water	Swedish National Food Agency's limit value for PFAS in drinking water of 0.09 µg/l (90 ng/l)	"Best estimate assumptions 1. Assumed 3% of the population are exposed to excess levels of PFAS via drinking water. 2. Assume 20 year maintenance programme for treatment works, based on best estimate. 3. Assume best estimate cost per case for water treatment. 4. Assume 4% discount rate on future maintenance costs. Low estimate assumptions 1. Assumed 1% of the population are	Pipeline cost: This is dependent on the no. people affected, the distance new piping is required and the complications in laying piping (e.g. geology). Upgrading of water treatment plant: "the cost range is again broad, EUR 8 to EUR 2,200 when normalised against population (the "high" estimate is notably the supposed cost of the temporary solution at Hoosick Falls). Excluding the two highest and lowest values gives a reduced range of EUR 18 to EUR 940/person, with remaining values spread rather evenly over this range. Taking the mean of the 9 data

Source	Cost category (e.g. soil remediation, drinking water treatment, wastewater treatment)	Description of costed activities	PFAS species/groups	Unit cost	Unit (e.g. Euro per site, Dollar per kg)	What are the unit costs applied to, to calculate totals (e.g. what types of sites, or tonnes of emissions)	What triggers remediation/treatment (e.g. concentration threshold)	Other key assumptions	Other notes
(Column A)	(Column B)	(Column C)	(Column D)	(Column E)	(Column F)	(Column G)	(Column H)	(Column I)	(Column J)
								exposed to excess levels of PFAS via drinking water. 2. Assume 20 year maintenance programme for treatment works, based on best estimate. 3. Assume low estimate cost per case for water treatment. 4. Assume 4% discount rate on future maintenance costs. High estimate assumptions 1. Assumed 5% of the population are exposed to excess levels of PFAS via drinking water. 2. Assume 20 year maintenance programme for treatment works, based on best estimate. 3. Assume high estimate cost per case for water treatment. 4. Assume 4% discount rate on future maintenance costs."	points excluding the highest and lowest gives a best estimate of EUR 300/person. " Maintenance-For maintenance costs, there are four estimates for which normalisation against population has been performed, from EUR 8/person/year to EUR 30/person/year. The range is adopted from these studies and the best estimate (EUR 19) is taken as the midpoint. About half of the data that has been collected comes from the USA, raising questions about its transferability to Europe.
Nordic Council of Ministers (2019). The cost of inaction. https://norden.diva-portal.org/smash/get/diva2:1295959/FULLTEXT01.pdf	Soil remediation	Excavation and soil treatment	C4-14 non-polymer fluorosurfactants	Excavation and treatment of soil: EUR 5 million (EUR 300,000 - 50 million)	EUR per case (EUR per kg of PFAS also cited but not used, see column J)	10-30% (best estimate 20%) of airports and PFAS manufacturing sites, and 0.1-1% (best estimate 0.5%) of other facilities	n/a (see column G)	"Best estimate assumptions 1. Assumed 20% of airports and PFAS manufacturing sites require remediation. 2. 0.5% of other facilities require remediation. 3. Best estimate of costs adopted. Low estimate assumptions 1. Assumed 10% of airports and PFAS manufacturing sites require remediation. 2. 0.1% of other facilities require remediation. 3. Low estimate of costs adopted. High estimate assumptions 1. Assumed 30% of airports and PFAS manufacturing sites require remediation. 2. 1% of other facilities require remediation. 3. High estimate of costs adopted. "	Soil remediation unit costs (excavation and treatment of soil) are also provided on a per kg of PFAS basis: EUR 280 000 (EUR 100,000 - 1 million) per kg of PFAS. However, these don't seem to have been used in the calculations.
Nordic Council of Ministers (2019). The cost of inaction. https://norden.diva-portal.org/smash/get/diva2:1295959/FULLTEXT01.pdf	Monitoring	Estimated costs for monitoring at sites where significant PFAS contamination has been found	C4-14 non-polymer fluorosurfactants	EUR 50,000 (EUR 25,000 - 500,000)	EUR per case	10-30% (best estimate 20%) of airports and PFAS manufacturing sites, and 0.1-1% (best estimate 0.5%) of other facilities	n/a (see column G)	"Best estimate assumptions 1. Assumed 20% of airports and airfields (as in Sweden) and PFAS manufacturing sites require monitoring programme, using best estimate cost/case for monitoring. 2. 0.5% of other facilities require monitoring. 3. Best estimate of costs adopted. Low estimate assumptions 1. Assumed 10% of airports and PFAS manufacturing sites require monitoring programme, using low estimate cost/case for monitoring. 2. 0.1% of other facilities require monitoring. 3. Low estimate of costs adopted. High estimate assumptions 1. Assumed 30% of airports and PFAS manufacturing sites require monitoring programme, using high estimate cost/case for monitoring. 2. 1% of other facilities require monitoring. 3. High estimate of costs adopted. "	
Nordic Council of Ministers (2019). The cost of inaction. https://norden.diva-portal.org/smash/get/diva2:1295959/FULLTEXT01.pdf	Screening	Costs of a basic screening programme to assess PFAS levels.	C4-14 non-polymer fluorosurfactants	Not specified in source, but can be calculated from totals as EUR 1,020 per site	EUR per site	All airports and PFAS manufacturing sites, and 1%-10% (best estimate 5%) of other facilities (fire stations, waste water treatment works, large and small supplies, hazardous and MSW landfills)	n/a (see column G)	"Best estimate assumptions 1. All airports and PFAS manufacturing sites are screened, assume 3 samples, using best estimate of cost/sample for monitoring; 2. 5% of other facilities are screened (fire stations, waste water treatment works, large and small supplies, hazardous and MSW landfills), assume 3 samples; 3. Best estimate of costs adopted. Low estimate assumptions 1. All airports and PFAS manufacturing sites are screened, assume 3 samples, using low cost/sample for monitoring. 2. 1% of other facilities are screened (fire stations, waste water treatment works, large and small supplies, hazardous and MSW landfills), assume 3 samples. 3. Low estimate of costs adopted.	

Source (Column A)	Cost category (e.g. soil remediation, drinking water treatment, wastewater treatment) (Column B)	Description of costed activities (Column C)	PFAS species/groups (Column D)	Unit cost (Column E)	Unit (e.g. Euro per site, Dollar per kg) (Column F)	What are the unit costs applied to, to calculate totals (e.g. what types of sites, or tonnes of emissions) (Column G)	What triggers remediation/treatment (e.g. concentration threshold) (Column H)	Other key assumptions (Column I)	Other notes (Column J)
								High estimate assumptions 1. All airports and PFAS manufacturing sites are screened, assume 3 samples, using low cost/sample for monitoring. 2. 10% of other facilities are screened (fire stations, waste water treatment works, large and small supplies, hazardous and MSW landfills), assume 3 samples. 3. High estimate of costs adopted."	
Wood et al. (2020). The use of PFAS and fluorine-free alternatives in fire-fighting foams. Report produced for European Commission DG Environment / European Chemicals Agency (ECHA). https://echa.europa.eu/documents/10162/6755610/pfas_flourine-free_alternatives_fire_fighting_en.pdf/d5b24e2a-d027-0168-cdd8-f723c675fa98	Soil remediation	"capping" (lower estimate), or excavation and incineration (higher estimate)	PFAS used in firefighting foams, i.e. non-polymeric PFAS	EUR 0.42 million to 38 million	EUR per site	Only an order of magnitude estimate of the EU total is provided. Number of sites not quantified.	n/a (see column G)	Several additional technical assumptions (see pages 101-105)	Costs for one contaminated site may involve any combination of soil remediation, groundwater treatment, and/or drinking water treatment.
Wood et al. (2020). The use of PFAS and fluorine-free alternatives in fire-fighting foams. Report produced for European Commission DG Environment / European Chemicals Agency (ECHA). https://echa.europa.eu/documents/10162/6755610/pfas_flourine-free_alternatives_fire_fighting_en.pdf/d5b24e2a-d027-0168-cdd8-f723c675fa98	Groundwater treatment	"pump and treat"	PFAS used in firefighting foams, i.e. non-polymeric PFAS	EUR 1.2 million to 30.3 million	EUR per site	Only an order of magnitude estimate of the EU total is provided. Number of sites not quantified.	n/a (see column G)	Several additional technical assumptions (see pages 101-105)	Costs for one contaminated site may involve any combination of soil remediation, groundwater treatment, and/or drinking water treatment.
Wood et al. (2020). The use of PFAS and fluorine-free alternatives in fire-fighting foams. Report produced for European Commission DG Environment / European Chemicals Agency (ECHA). https://echa.europa.eu/documents/10162/6755610/pfas_flourine-free_alternatives_fire_fighting_en.pdf/d5b24e2a-d027-0168-cdd8-f723c675fa98	Drinking water treatment	Reverse osmosis	PFAS used in firefighting foams, i.e. non-polymeric PFAS	EUR 2.9 million to 39.8 million	EUR per site	Only an order of magnitude estimate of the EU total is provided. Number of sites not quantified.	n/a (see column G)	Several additional technical assumptions (see pages 101-105)	Costs for one contaminated site may involve any combination of soil remediation, groundwater treatment, and/or drinking water treatment.

E. Modelling prospective scenarios to feed into the cost assessments (Task 3)

During the inception meeting the Commission asked WSP to review the proposed methodology (which was on the basis of a bespoke material flow and exposure estimation) and assess whether a more recognised methodology, such as **EUSES** would be a better option.

Following the discussion a comparative analysis was developed by WSP and provided to the Commission in the form of a technical note. The Commission subsequently reviewed and commented on the technical note. This Appendix provides the updated technical note following comments received by WSP.

Table 1 (below) provides the comparison of these two approaches and their strengths and weaknesses.

Table 1. Comparison of EUSES versus Bespoke approach

EUSES tool approach

Overview:

EUSES is a harmonised quantitative risk assessment tool developed within the EU chemicals legislation (REACH) by ECHA. It is designed to determine the release and environmental exposure of named chemical substances* within named emission scenarios, based on a lifecycle approach.

*As a comment here, the data disaggregation for volumes of use per individual PFAS is poor. Quantitative data on the use of PFOA and PFOS is relatively well defined (albeit older, i.e., pre-2015), for other PFAS substances, existing data more typical references all non-polymeric PFAS, side-chain fluoropolymers, fluoropolymers, and F-gases. In this case if not possible to quantify on a substance-by-substance basis, it would be necessary to either:

a) equally divide all non-polymeric PFAS into major family groups with key marker substances. Assuming such data exists to support that work.

b) Use a range of PFAS substances to define “averaged” physical properties, or lower/upper/average of those properties (e.g., melting point, volatility, log octanol, mass).

In this respect, the grouping approach under the bespoke tool could arguably be more appropriate but has the same issues in terms of determining the ‘average’ physical properties. See also Section 5, which in part supersedes this.

The EUSES tool can be used to determine release and exposure within the near field and

Bespoke tool approach

Overview:

Proposed bespoke excel spreadsheet approach mapping material flow from production, use, and waste including import/export.

This would likely take a time-series based approach with year-on-year manufacture and use of PFAS in industrial settings. It would use quantified data from the REACH Annex XV universal restriction proposal, literature, and data gathered as part of Task 3 to determine volumes of use per sector, per year. It would then apply emission factors based on a literature review or supplemented by Environmental Release Codes (ERCs) where data was lacking.

It would further apply mass-balance approaches for volumes of precursor converted from specific forms of PFAS (e.g., various telomers (phosphates, phosphonates, phosphate esters, sulphides, sulphonates, amides, and alcohols) into perfluoroalkyl acids.

It should also be possible to gather data from literature and Eurostat to determine losses from landfill.

For drinking water, a mass balance approach could determine quantities emitted to environment and held within compartments which are then used for drinking water sources. This would require further validation based on drinking water monitoring data and information from sources such as the forever pollution project and Forever Pollution project maps of PFAS contamination.

Determination of human exposure would be developed using scaling factors. This could be tailored further to consider possible at-risk

long-range release of chemicals, environmental distribution and transport and predicted environmental concentrations (PECs).

Outputs for consumer exposure and worker exposure are given in the form of risk ratings (RCRs).

Pros:

- Formally recognised and robust exposure tool which has been used within REACH for many years which builds confidence and comparability.
- Provides a powerful engine to model apportionment and environmental distribution (e.g., PNECs vs PECs), including releases from wastewater treatment works, and a range of different industry sectors within the same run.
- Makes use of a wide range of data metrics in the calculations. However, where it is data heavy the tool does also provide a comprehensive set of default values which could be useful to fill critical data gaps.
- Tool allows for import and export stages, so does have a lifecycle element to the way it works, including breakdown of emissions from production, use and waste.
- Data can be exported from the tool in excel and word for further data analysis/work.
- Tool can be further modified and tailored by expert users to give it additional functionality. This is relatively specialist, but possible.

Cons:

- Very substance specific, including phys-chem properties, meaning that individual PFAS would need to be included in separate runs, potentially dozens if not 100s of runs (assuming data is available, which is unlikely). The more likely scenario would be the two approaches outlined on the previous page (a) divide total use equally by major family with marker substances, or b) define an "average" PFAS using min/max/averaged physical properties such as melting point.
- Not possible to complete projections in the model. Would have to map growth in a separate sheet and do repeat model runs for each time segment (100s of runs)
- For legacy pollutants (e.g., PFOS that was largely withdrawn in 2002) could use the "service life" function to help model some of the fate between 2002 and 2025, but it was not designed to work in this way and results could be dubious and widely open to criticism.

cohorts (e.g., workers, pregnant women, children etc.).

Would likely take a grouping approach to PFAS (e.g., all perfluoroalkyl acids) rather than substance by substance. Overall estimates would be more high level at compartment (e.g., all surface fresh water; EUSES is more granular than this which could be valuable).

Pros:

- Greater flexibility for specifically which aspects are retained and used in the emission and distribution calculations.
- Greater transparency of how the input data is manipulated to produce outputs.
- Option for time-series data to map emission trends which then become environmentally distributed based on literature data for retention times and final distribution.
- Possibility to include some considerations around environmental fate and metabolites. E.g., 50% of PFOA concentrations comes from pre-cursors.
- Possibility for future update of the spreadsheets. Possibility to link the activity data to EU statistics such as Eurostat to demonstrate data in a granular way (e.g., number of companies, number of factories etc). Note this could still be done for EUSES as a separate document detailing the input data. But this approach would house all information in one document.

Cons:

- Bespoke tools can be riskier and more uncertain as they are not publicly recognised and that leaves you open to greater scrutiny and possible criticism from stakeholders.
- The approach detailed here requires two steps, one documenting emissions and then scaling factors for exposure based on the data gathered as part of Task 2. In this respect EUSES is a more neat and integrated approach.
- This approach is likely to suffer from the same sort of general data gaps which will affect the EUSES based approach. The EUSES tool makes use of defaults which have been through their own peer review process. As a possible caveat, we could make use of some of the default values from EUSES to plug gaps in the bespoke approach. However, it is likely that at least some expert judgment or extrapolation would be needed. Again, this can leave you open to criticism by stakeholders.
- We would propose a grouping approach to mapping PFAS material flow, while this does things in a single run-through per major

- Requires detailed information spanning many different metrics to provide a fully tailored response.
 - Not possible to trace the individual calculations or steps between calculations to determine how the inputs become the outputs.
 - Provides outputs as PECs for local and regional level (including surface water, groundwater, and drinking water). But it is not specific to geographic regions (e.g., Belgium). May mean we need multiple runs map things at a national level. Depending on the data available. Analysis of the data held by Forever Pollution project suggests Belgium, Germany, and Finland have the highest surface water concentrations. But unclear if that is an artefact of less data from other parts of Europe, particularly eastern Europe.
 - EUSES itself provides results as environmental distribution not direct expose (i.e., man via the environment). Would need to use EUSES in combination with e.g. EASE or CHESAR to map worker exposure.
 - Care needed in how runs are put together. The model allows you to use specific emission factors if you have that data available, otherwise it reverts to default factors based on the choice of industry activity. In the lowest tier basic model (which is the easiest and least labour intensive to program), the model can overwrite the specific values for defaults if it disagrees. It is also possible if runs are being copied (i.e., we take the model run for 2025 as the basis for 2030) it can overwrite the specific values with defaults between runs. This affects continuity and means the new run is redundant and has to be run again. As a minimum to avoid this issue, the model needs to be run at intermediate complexity, which makes the process more labour intensive.
 - No uncertainty analysis in results, requires further interpretation and care when assessing and sense-checking the outputs.
 - Not possible to take monitoring data and back-calculate tonnages using EUSES.
- category defined (e.g., all PFAAs, etc) which makes the results easier to incorporate. The EUSES substance by substance approach could be valuable to gain greater granularity at the substance level. That could also be important, and a possible way around the legacy vs ongoing gap.
- The EUSES tool has been through an intensive development phase. The bespoke approach does not exist yet but can be expected to be complex in its own right. Arguably, EUSES would require far less QA/QC of the calculations themselves, and without a thorough and intensive QA/QC by expert staff there is a risk of errors in the calculations with any kind of bespoke approach.

Summary:

The biggest plus points for a EUSES style approach are that the tool is already well established and recognised, including a library of default emission factors which could be valuable to manage data gaps. It is also very comprehensive in its coverage of endpoints.

Summary:

The biggest plus point for a bespoke approach is that it can be tailored to our exact needs, and the calculations can be viewed easily to track how inputs become outputs.

The biggest weaknesses are that bespoke tools require more effort and care in their development (QA/QC) than off the shelf tools

The biggest weaknesses are that it cannot do projections, it will struggle to manage the issues around legacy pollutants, it cannot manage issues related to precursors, and the outputs may not be in a form that easily supports Task 4. In effect this is a risk model to determine PNEC vs PEC based on current use today. The remit of Task 3 is significantly different to this remit.

There are elements of the EUSES style approach that are valuable and could be worth implementing, in particular there is the fugacity model (simplebox) which underpins EUSES as a spreadsheet tool. That could keep some of the key functionality and be more readily modified than EUSES itself. But the overall wholesale use of the model is likely to be very labour intensive (assuming 400 model runs + analysis could equate to 40 days of staff time as a minimum), and the results may not be as hoped for.

Would urge caution before adopting this approach without significant modifications.

and are open to greater scrutiny / criticism because they are not well established.

For the current study determining what environmental fractions come from legacy PFAS vs ongoing use is likely important. The time-series element of things could therefore be very valuable. But that does assume and rely on a good foundation of body of data to help drive the calculations in the first place. That may be the determining step.

Overall, there are elements here that are very valuable to tailor the response in the way we need. However, the level of QA/QC rigour and potential scepticism from stakeholders should not be underestimated.

Summary and next steps

Overall, there are positive and negative elements to both approaches. The ideal solution would be to follow a EUSES style methodology (which is well recognised and documented) but build in the additional elements from the bespoke approach to further tailor it to the needs of Task 3. A fugacity model (Simplebox) will be used to help model environmental distribution and exposure, but it will be absolutely critical to sense check the results of the model against real-world monitoring data. If the results of the model show significant deviation from real-world monitoring data, additional steps will be needed to understand and correct the model to bring it into alignment. See Section 5 for further details of the method.

Annex C – Exposure scenario modelling

Annex C1 – Task 3 report

1. Introduction	4
1.1. This report.....	4
1.2. Project context	4
1.3. Task 3 purpose, scope, and method.....	5
1.3.1. Introduction.....	5
1.3.2. Exposure scenarios	6
1.3.3. How Task 3 relates to the other tasks.....	7
2. Methodology	8
2.1. Overall approach.....	8
2.2. Development of baseline year (2024).....	9
2.2.1. Developing cohort groups	9
2.2.2. Developing environmental concentrations	17
2.2.3. Blood serum concentrations.....	21
2.2.4. Developing ratios.....	27
2.2.5. Developing emission projections	29
2.3. Development of Scenarios	30
2.4. Assumptions and consideration of weaknesses.....	33
2.4.1. Assumptions.....	33
2.4.2. Considerations of weaknesses.....	35
3. Results	37
3.1. Introduction	37
3.2. Scenario 1 – Business as usual for emissions without intervention	37
3.2.1. Introduction.....	37
3.2.2. Environmental exposure.....	37
3.2.3. Human exposure.....	39
3.2.4. Summary.....	41
3.3. Scenario 2 – Drinking Water Directive (DWD) thresholds.....	41
3.3.1. Introduction.....	41
3.3.2. Environmental exposure	41
3.3.3. Human exposure.....	42
3.3.4. Summary.....	43
3.4. Scenario 3 – Environmental Quality Standards	43
3.4.1. Introduction	43
3.4.2. Environmental Exposure	44

3.4.3. Human exposure	45
3.4.4. Summary	45
3.5. Scenario 4 – Total stop of production and uses of PFAS.....	46
3.5.1. Introduction.....	46
3.5.2. Environmental Exposure.....	46
3.5.3. Human exposure.....	47
3.5.4. Summary.....	48
3.6. Trifluoroacetic acid (TFA) (case study)	49
3.6.1. Introduction.....	49
3.6.2. Results.....	50
3.6.3. Summary.....	53
3.7. Comparison of results across scenarios	53
3.7.1. Changing area of contamination and cohort size.....	53
3.7.2. Environmental and blood serum concentrations	56
3.7.3. Occupational cohort (size and mixture).....	59
4. Sensitivity analysis.....	61
4.1. Introduction	61
4.2. Approach	61
4.3. Outcome	62
4.3.1. Sensitivity on the level of the emission projections	62
4.3.2. Sensitivity on the number of sites stemming from the Forever Pollution Project data.....	69
4.3.3. Varying the drinking water mixture (ground/surface water contribution)	70
4.3.4. Scenario 4 – Sensitivity analysis on the length of the service life of consumer goods remaining in use	71
4.3.5. Environmental concentrations set to minimum and maximum	73
4.3.6. Blood serum concentrations set to minimum and maximum.....	75
4.3.7. Summary.....	76
5. Conclusions	79
6. References	82
Appendices to Annex C1	87
A. Step-by-step approach used in this study	88
B. Input data for calculations.....	103
C. Environmental monitoring data.....	109
D. Methodology for TFA case study	121
TFA calculations	122

E. Additional sensitivity analysis for drinking water – Advanced treatment.....	126
Scenario 2 – Drinking Water Directive thresholds.....	127
F. Additional graphs.....	129
G. Original proposed methodology.....	133
G.1. Context and approach to date.....	134
G.1.1 Introduction.....	134
G.1.1.1 Gathering data for use in fugacity model.....	134
G.1.1.2 Developing data for projections.....	137
G.1.1.3 Development of approach to determine blood serum concentrations.....	137
G.1.1.4 Model runs and outputs.....	138
G.2. Emission release categories (ERCs) and emission factors used with EUSES approach.....	139

1. Introduction

1.1. This report

WSP and Ricardo are supporting DG ENV with a **study on the cost of PFAS pollution for our society**¹ under framework contract ENV.01/FRA/2023/0006 *Economic analysis of environmental policies and analytical support in the context of Better Regulation* led by Trinomics B.V.

This document presents the **'Task 3 Report'**, which provides an analysis for four prospective scenarios covering hypothetical future PFAS pollution levels in the European Economic Area (EEA). The report details the approach to correlate emissions, environmental concentrations, and blood serum concentrations in the European population, starting from a baseline year, 2024² to the year 2050 (2020, 2024, 2030, 2040 and 2050). The four option scenarios explore a business-as-usual situation (i.e., extending trends from a situation set at June 2024), as well as three hypothetical scenarios reflecting thresholds set under the drinking water directive, the proposed environmental quality standards for surface water and groundwater, and a full stop of PFAS use and production.

1.2. Project context

The objective of this study is to complement and update the existing sources of information (such as the Goldenman (2019) study for the Nordic Council of Ministers) on the overall external costs of PFAS pollution in the EU and in the EEA. More specifically, the objective of this contract is to present information on all components of the societal costs of PFAS pollution, expressed in monetary terms and based on an up-to-date list of impacts of PFAS on the environment and human health. This assessment will describe not only the cost of current pollution but also the future costs under a defined number of prospective scenarios representing hypothetical future developments, hence showing the current and future costs of inaction under various situations.

The project is organised in the following tasks:

- Task 1: Literature review of existing studies on the costs of PFAS pollution and identification of possible knowledge gaps.
- Task 2: Development of a methodology to update and expand the existing knowledge on societal costs of current and future PFAS pollution in the EEA.
- Task 3: Development of 4 prospective scenarios representing hypothetical PFAS future pollution levels in the EEA.
- Task 4: Assessment of the societal costs of current and future PFAS pollution (up to 2050, under hypothetical future scenarios).

¹ Specific Contract No 090202/2024/924706/ENV.B2

² Note that the Task 2 report uses the year 2024 as its baseline. For Task 3 the emission estimates and projections from the REACH Annex XV dossier are critical, with the estimates based on two rounds of stakeholder consultation in 2020 and 2021. Therefore, the Task 3 estimates commence from 2020, but will retain 2024 as the baseline year. This provides reported estimates for one interval before the baseline, and three intervals after the baseline.

1.3. Task 3 purpose, scope, and method

1.3.1. Introduction

The purpose of Task 3 is to develop data on current and future levels of PFAS pollution in the European Economic Area (EEA). This includes concentrations within surface water, groundwater, soil, and food, as well as blood serum concentrations from citizens exposed to PFAS through consumption of food and water, or occupational settings.

As PFAS is a family of chemicals that spans approximately 10,000 substances, it is not possible to study their effects individually, and some **grouping of PFAS** is necessary. The grouping of PFAS applied in this study is summarised in the table below. Further explanation is provided below the table.

Table 1-1 Overview of PFAS grouping applied in this study

PFAS group	Notes
PFAAs and PFAA precursors	Includes side-chain fluorinated polymers.
Fluoropolymers	Focuses on the use of non-polymeric PFAS based processing aids.
TFA	Based on data from fluorinated gases, and fluorinated pesticides

This grouping is based on the following pieces of (future) legislation:

- The proposed universal PFAS restriction under REACH, which broadly groups PFAS into four categories:
 - perfluoroalkyl acids (PFAA) and PFAA precursors,
 - side-chain fluorinated polymers³,
 - fluoropolymers,
 - fluorinated gases (F-gases).
- The Drinking Water Directive (DWD), which focuses on 20 PFAAs
- The European Commission's 2022 proposal to amend the Groundwater Directive (GWD) and the Environmental Quality Standards Directive (EQSD) , adding EQS for 24 PFAA and PFAA precursors.

Two adjustments to these groupings have been made in this study. Firstly, for fluoropolymers, the use of non-polymeric PFAS as a processing aid for the production of fluoropolymers (and subsequent emissions) is calculated as a sector to determine relative importance for inclusion within the PFAAs and PFAA precursors . Secondly, trifluoroacetic acid (TFA) has been included as a different PFAS group, as a substance of emerging concern, linked to use and emission of fluorinated gases and fluorinated pesticides. Additionally, note that the Task 1 report (Table 3-2) identified data on blood serum concentrations for different cohort and age group types (occupational, elevated, “background”, adults, and children) primarily for four PFAS: perfluorooctane sulphonic acid (PFOS), perfluorooctanoic acid (PFOA), perfluorononanoic acid (PFNA) and

³ Side-chain fluorinated polymers are treated differently from fluoropolymers in the REACH restriction proposal. This is because the sidechains can break, releasing non-polymeric forms of PFAS. In emission estimates for the baseline year (in Annex B of the restriction proposal), side-chain fluorinated polymers are therefore included as part of the total emissions of PFAAs and PFAA precursors. In the present report, side-chain fluorinated polymers have therefore also been included as part of the group of PFAA and other PFAA precursors.

perfluorohexane sulphonic acid (PFHxS) collated over the time range 2019 to 2024. The same analysis identified more incomplete data available for a further 11 PFAS substances⁴, with the most complete dataset covering adults within the “background” exposure cohort. This data has been included in the analysis to support estimates for PFAA exposure covering 20 PFAA substances for drinking water, and 24 PFAA and PFAA precursor substances in surface water and groundwater.

The **geographic scope** is the European Economic Area (EEA), with some population grouping. The assessment does not attempt to track blood serum concentrations for specific individuals over time. The outputs of Task 3 estimate geographic areas at different concentration levels of pollution, as well as human exposure grouped by age (adults and children) and by exposure cohort (general population exposed to only “background”⁵ concentrations, population living near sites of PFAS production and use, and occupational exposure).

During the development of the methodology multiple approaches were explored, including the use of the fugacity model EUSES⁶. The preliminary attempts to explore the use of EUSES proved unsuccessful due to a combination of the complexity of the issue presented by PFAS and the lack of granular data to fully drive the fugacity model to achieve outputs consistent with real world monitoring. Further details of this approach and why it was unsuccessful are documented in Appendix G to Annex C1.

As part of the approach to develop a methodology, consultation and feedback was also sought with two experts (Hans Peter Arp, Norwegian University of Science and Technology (NTNU) and Alison Ling, University of St. Thomas, USA).

1.3.2. Exposure scenarios

Task 3 provides four scenarios with estimates including a baseline year (2024), plus estimates for 2020, 2030, 2040, and 2050. The four scenarios include:

- **Scenario 1** – A business-as-usual situation for emissions without further intervention. This is based on the legislative situation as of June 2024 (hence with no implementation of the proposed universal PFAS restriction, nor the restriction on PFHxA and its salts (effective from September 2024) nor the restriction on use in firefighting foams). Note that thresholds for the DWD come into force from January 2026. In order to test the effects of these thresholds under scenario 2 (below), scenario 1 focuses on the emissions only, which are under the REACH restriction dossier, predicted to increase in absence of any further intervention.
- **Scenario 2** – Full compliance with the DWD thresholds of 100 ng/l for the sum of 20 PFAAs and 500ng/l for “Total PFAS”. TFA will fall into this latter bracket, with concentrations which already meet or exceed the 500ng/l on its own. Therefore, to track TFA we have used the Total PFAS as the guiding limit..

⁴ Perfluoropentanoic acid (PFPeA), Perfluorohexanoic acid (PFHxA), perfluoroheptanoic acid (PFHpA), perfluorodecanoic acid (PFDA), Perfluoroundecanoic acid (PFUnDa), Perfluorododecanoic acid (PFDoDA), Perfluorotridecanoic acid (PFTTrDA), Perfluorohexadecanoic acid (PFHxPA), perfluorobutane sulphononic acid (PFBS), perfluoroheptane sulphononic acid (PFHpS), and perfluorodecane sulphononic acid (PFDS)

⁵ Clarifying note: Under the Water Framework Directive, “background concentrations” are a defined term relating to natural background concentrations, i.e., concentrations in water of named substances that occur naturally due to e.g., geological conditions, such as metals. In this report, ‘background concentrations’ and ‘background cohort’ have been used to align with the terminology presented in Goldenman et al. (2019) as the key reference used to help guide the methodology. PFAS are man-made chemicals and do not naturally occur. Therefore, some care is needed not to misinterpret or conflate ‘background concentrations’ with the WFD use of terminology.

⁶ European Union System for the Evaluation of Substances tool.

- **Scenario 3** – Full compliance with the proposed quality standard of 4.4 ng/l PFOA-equivalent for the sum of 24 PFAS under the EQSD and GWD for surface water and groundwater, respectively⁷.
- **Scenario 4** – A total stop of production and uses of PFAS. It is assumed that certain uses will cease immediately, while others are phased out gradually as a complete and immediate cessation is realistically not feasible for many uses that would require product re-calls (e.g., all sports clothing and outdoor wear, all sofas and soft furnishings, all cars and road vehicles, all x-ray and scanning medical equipment, complete replacement of all plumbing parts in domestic and commercial settings, etc.). Therefore, scenario 4 covers a total stop of production and new uses; but uses of articles already in use are assumed to continue until their end of life.

As a clarification, the four scenarios are presented as hypothetical ‘what if’ cases in isolation to determine the effect of a given measure. In reality it should be understood that things may be more complex. For example, scenario 3 looks at the role of the proposed EQS thresholds, assuming full compliance. In reality we respect that achieving full compliance would only be possible through a combination of regulatory controls (bans), improved abatement for source and end-of-pipe control, and possible remediation efforts. These aspects are excluded from the scope to focus on the specific target of the ‘what if’ scenario.

1.3.3. How Task 3 relates to the other tasks

Task 3 draws upon the outputs of Task 1 (literature review of existing studies) and 2 (development of a methodology to expand upon existing knowledge). In particular, this includes the data identified for environmental concentrations and blood serum concentrations. It builds on the methodologies identified, in particular the work of Goldenman et al. (2019) for the Nordic Council to inform the approach that has been adopted for delivery of Task 3. The Task 3 outputs will in turn provide the primary information for the cost calculations that will be completed as part of Task 4.

⁷ As a clarifying note: At the time of writing (October 2025) the EQS legislative process has reached a trilogue agreement on the amendment of surface water and groundwater quality legislation. This agreement amends the original proposals submitted to the parliament. The study presented here commenced work before the agreement was reached and is based on the original proposals for a threshold of 4.4 ng/l for the sum of 24 named PFAS expressed as PFOA-equivalents based on their relative potency factor (RPF). The primary differences are as follows:

The co-decision notes that for surface water the threshold of 4.4 ng/l is now applied to the sum of 25 PFAS, which includes TFA as an addition to the 24 named PFAS from the original proposal. The groundwater threshold for the sum of PFAS dynamically linked to the DWD (i.e. it will automatically be updated if the threshold in the DWD is changed). Currently, the DWD threshold is 0.1 ug/L, for 20 PFAS (not including TFA). However, TFA is considered as a relevant metabolite of pesticides in groundwater (so already in the provisions of the current Groundwater Directive). The agreement also empowers the Commission to revise the list of PFAS and define TFA limit value. In addition, the sum of four PFASs (PFHxS, PFOS, PFOA, PFNA) are among the substances to be added to the groundwater list with the strict quality standard originally proposed by the Commission (4.4 ng/L).

2. Methodology

2.1. Overall approach

The overall step-by-step approach used for the development of a baseline year (2024) and projections out to 2050 for scenarios 1 – 4 is provided in Appendix A to Annex C1. During the development of the methodology and unsuccessful approach using the EUSES fugacity model, one of the issues that appeared most problematic was the highly variable nature of environmental concentrations, for a variety of reasons (e.g., type of source that created emissions, the volume of the emissions, emission pathway, type of PFAS, type of geography and environmental transport, etc). During the interviews with the two experts, this issue was discussed as well as the concepts of what was described by Hans Peter Arp as “hot-spot” and “not-hot-spot”, reflecting the variation in concentrations closer to point of release and further away from it).

The study by Goldenman et al. (2019) identifies the same phenomenon (but termed “elevated” and “background”), which was used to create three population cohort groups, as follows:

1. Those who live far from the point of release and contamination, termed ‘background’ cohort (see clarifying note on terminology on page 9).
2. Those who live close to sites of production and use of PFAS, termed the ‘elevated’ cohort,
3. Those who work directly in facilities producing and/or using PFAS where exposure occurs as part of their occupation (termed the ‘occupational’ cohort).

To keep continuity with Goldenman et al. (2019), the same terminology has been used in this study.

To determine the proportions of EU citizens in each cohort, Goldenman et al. (2019) used a series of case studies based on sampling and analysis of known sites. Two case studies in particular (one for Sweden (Holmstrom, 2014) and one in the US (GWA, 2017)) indicated that 3% and 4.5% of the population respectively were exposed to elevated levels of PFAS through air, drinking water, and food, based on proximity to contaminated sites. Goldenman et al. (2019) uses the 3% of population value as a proxy applied to each Member State to extrapolate the EU level of exposure for the elevated cohort.

Goldenman et al. (2019) states that accurately calculating the number of workers in the occupational cohort is particularly challenging due to the lack of data. The estimates by Goldenman et al. (2019) are based on a series of case studies to determine the average number of workers per facility, and the number exposed, and extrapolated by the estimated number of facilities. Those not in the occupational or elevated cohort were assumed to be in the “background” cohort.

Based on the methodologies assessed under Task 1 and 2, Goldenman’s approach was considered the best approach to replicate in this study. There have however been two further significant developments since the publication of the Goldenman et al. report in 2019. Firstly, in March 2023 the universal PFAS restriction dossier under REACH was

published⁸, including detailed emission estimates for different sectors and emission projections to 2050 as a business-as-usual scenario. Secondly, in November of 2023, the Forever Pollution project (FPP) published a map of Europe detailing the best estimates for known and presumptive locations (which is the terminology used in the FPP reporting) for manufacture and use of PFAS, most recently updated in November 2024. This details the location for manufacture and use of PFAS leading to potential hotspots described by Goldenman et al. (2019).

The approach adopted in this study has aimed to align as closely as possible with Goldenman's approach but incorporating these two new data sources to develop the unconstrained emissions and projections for scenario 1, with amendment to develop scenarios 2 to 4. The following sections outline the approach in more detail, with further considerations of limitations detailed at the end of the Section (see Table 2.8).

2.2. Development of baseline year (2024)

2.2.1. Developing cohort groups

Cohort groups are developed using the following main steps:

- Identify population and area of the elevated cohort
- Split elevated cohort into high and low
- Identify occupational cohort population
- Identify "background" cohort population
- Project future population

Each step is explained in further detail below.

Identify population and area of the elevated cohort

To determine the elevated exposure cohort, data from the FPP covering PFAS production sites, known PFAS users, and presumptive PFAS users have been identified. The full details for types of sites and numbers per country are provided in Appendix B to Annex C1. Where PFAS is known to be manufactured and used, it is reasonable to assume environmental concentrations in the immediate vicinity of the site will be elevated, well above "background" concentrations. The same logic can be conferred to presumptive sites (albeit with less confidence). While the data on presumptive sites is less certain, it still provides a key overview of the possible scale of PFAS pollution for the wider elevated cohort. The FPP authors define presumptive sites based on the work by Salvatore et al. (2022), which has the following definition:

"Salvatore et al. (2022) defined presumptive PFAS contamination sites as locations where high-quality testing for PFAS is not available, but which can be presumed to be contaminated on the basis of scientific investigations and expert advice. We based our research on the same methodology and three categories: (1) fluorinated aqueous film-forming foam (AFFF) discharge sites; (2) certain industrial facilities; and (3) sites related to PFAS-containing waste.

⁸ An update of the Background Document underpinning the universal PFAS restriction proposal was published in late August 2025. The methodology and calculations presented here commenced before that date and are based on the March 2023 version of the universal PFAS restriction.

- AFFF discharge sites include military bases, air bases, airports, training camps, NATO bases, and other related sites (based on open-source intelligence (OSINT) data), commercial civilian airports (excluding small airports and heliports), and firefighting training sites (based on a few country-specific databases, where available).
- Industrial facilities were identified based on Salvatore et al. (2022), who developed a set of 38 NAICS codes (North American Industry Classification System) using 11 regulatory or academic lists linking PFAS contamination with specific facility types. The Forever Pollution Project then matched these codes to 18 industrial sectors in the E-PRTR, using Glüge et al. (2020) on PFAS uses and Goldenman et al. (2019) as confirming documentation.
- Sites related to PFAS-containing waste cover wastewater treatment plants (WWTPs) treating a minimum average of 3700 m³ per day, and landfills for non-hazardous and hazardous waste.”

The study by Goldenman, (2019) estimated that 3% of the population of Sweden was in the elevated cohort exposed to the highest concentrations based on drinking water, food, and air and proximity to contaminated sites. In our study, this value of 3% of the population in the elevated cohort has been retained for Sweden specifically and then extrapolated to the rest of the EEA based on the number of PFAS manufacturing and use sites. This has been undertaken using the following approach: the elevated cohort population from Sweden is divided by the national average population density taken from Eurostat NUTS3 data to derive a total area corresponding to the elevated cohort in Sweden. This area is then divided by the number of known and presumptive manufacturing/use sites in Sweden from the FFP dataset to determine a radius per site (31km²).

For all other countries, the number of manufacturing/use sites (known + presumptive) is multiplied by this radius (computed for Sweden) to determine the area corresponding to the elevated cohort. This area is then multiplied with the national average population density to determine the population of the elevated cohort⁹.

An information box is provided on the next page to give a worked example of how these calculations have been performed for Sweden.

⁹ As a point of reference, we note that potential sites of contamination could be based in either urban or rural areas where population varies, in particular industrial sites closer to urban hubs will have population density far greater than the national average. However, we also note that the derived radius for each site of contamination is a physically large area (31km²), e.g., for example the total radius of Bruges, Belgium is 30km². This means that the population density within the contaminated area is likely to vary significantly, and that by using national average we make use of a recognised metric. The infobox on the next page illustrates that this approach provides similar population estimates to what Goldenman, 2019 estimated.

Information box – worked example for cohort calculations in Sweden

Population of Sweden (2024) based on Eurostat data was 10,550,000. Based on Goldenman et al. (2019), it is assumed that 3% of this population (316,500) are in the elevated cohort. Using the national average population density for Sweden (NUTS3) of 25 people per km² allows to determine the area corresponding to elevated cohort in Sweden:

$$316,500 \text{ (population)} / 25 \text{ (population density)} = 12,660 \text{ km}^2 \text{ (area)}$$

The latest FPP data identifies, for Sweden, 1 known PFAS user, plus 407 presumptive users (55 airports, 309 industrial sites, 19 military sites, and 24 waste sites). This allows to determine the average area with high pollution concentration around each polluting site:

$$12,660 \text{ km}^2 \text{ (area)} / 408 \text{ (known + presumptive sites)} = 31 \text{ km}^2$$

One potential issue with this approach is that population density can vary between urban and rural areas. However, a spatial analysis of the population density around thousands of contaminated sites in the EEA would be a complex exercise that is not possible within the scope of the current study. To assess the impact of this possible limitation, the results of the approach in the current study has been sense-checked against the results of Goldenman et al. (2019):

- Goldenman et al. (2019) applied a standard 3% of population per country to determine the elevated cohort.
- The current study derives the area corresponding to the elevated cohort (based on the number of sites identified in the FPP), and this area is then multiplied by population density to derive population in the elevated cohort.

The table below presents on the right-hand side, the elevated cohort computed as 3% of the population (in 2024) for the Nordic council countries, hence mimicking Goldenman's approach. The left-hand side uses 3% by area as a proxy and multiplies this area by the national average population density, to obtain another estimate of the elevated cohort. The two orange-shaded columns show that both approaches provide broadly similar numbers. This should reflect that the average population density can be used as a reasonable value when specific details of urban/rural are not fully known.

Country	Geographic area km ²	3% of geographic area (km ²)	Average population density	Population in "elevated cohort" in this study	Total Population (2024)	Population in "elevated cohort" as in Goldenman et al. (2019), based on 3% of total population
Sweden	447,424	13,423	25	335,575	10,550,000	316,500
Norway	324,220	9,727	15	145,905	5,550,000	144,926
Finland	338,363	10,151	18	182,718	5,600,000	182,716
Denmark	42,925	1,288	139	179,032	5,960,000	178,997
Iceland	103,125	3,094	4	12,375	380,000	11,756

Split elevated cohort into high and low

As discussed above, Goldenman et al. (2019) applied three broad cohorts to simplify the varying levels of exposure and associated health effects for the EEA population. In reality, concentrations in the environment and in drinking water typically decline gradually the further away from the point of release. Moreover, the magnitude of emissions varies substantially across different sites. Therefore, the concentrations of PFAS that the population in the elevated cohort is exposed to is also likely to vary substantially. To manage this issue within the current study, the elevated cohort has been further divided into two sub-cohorts:

- *Elevated – high*, for those populations living the closest to production/use sites and exposed to concentrations of $\geq 100\text{ng/l}$ (referred to as “hotspots” by FPP 2023 as discussed below); and
- *Elevated – low* for those living further away but still within the area of elevated concentrations (i.e., exposed to concentrations above “background”).

The share of the elevated cohort that is assigned to the “elevated – high” sub-cohort is identified using monitoring data collected by FPP, which identifies *2,300 ‘hotspots’ where concentrations exceed 100 ng/l*” (FPP, 2023). The specific location and details of these 2,300 sites cannot easily be derived from the FPP dataset which includes 1.1 million monitoring data-points. However, it has been assumed that there is significant overlap between these 2,300 hotspot sites and the sites of PFAS manufacture and use.

The number of sites (of manufacture and use) vary per country, with some countries having high numbers of sites (e.g., Germany (2406 sites), France (1538 sites) and Italy (1229 sites) and others having low numbers of sites (e.g., Bulgaria (140 sites), Ireland (52 sites), Slovenia (41 sites). Given the potential overlap between the highly contaminated sites (2,300 sites) and total number for production and use (11,471), without knowing the specific details, it is logically to assume a country with a higher number of production and use sites would also have a higher number of highly contaminated sites. Therefore, for the “elevated – high” cohort, the 2,300 sites identified by the FPP are shared proportionately per country based on the total number of known and presumptive manufacturing/use sites. These hotspot sites are then multiplied by the same radii (31KM²) to determine what fraction of the elevated cohort is high, and therefore the remainder being low.

Elevated cohort results and discussion

Table 2-1 provides the results of these calculations and comparison to the outputs of the work by Goldenman et al. (2019) (see far right-hand column). This illustrates that using the FPP data (for manufacturers, known users, and presumptive users) indicates a more significant number of people in the elevated cohort overall (61 million using FPP data vs 12.5 million under Goldenman et al. (2019)). However, when considering the “elevated – high” sub-cohort, there is much closer agreement (12.3 million people in “elevated – high” compared to 12.5 million in the Goldenman et al. (2019) study). This should also recognise that research has continued since 2019, and the extent of the pollution is likely more greatly known now.

This suggests that the “elevated-high” sub-cohort mirrors the levels of exposure and environmental concentrations indicated by both the FPP and Goldenman et al. (2019), i.e., this is the population subject to the highest levels of exposure and contamination which the FPP describes as concentrations $\geq 100\text{ ng/l}$ (drinking water). The “elevated – low” sub-

cohort captures a population exposed to levels in between the highest concentrations and “background” concentrations. This “elevated – low” sub-cohort makes up around 10% of the EEA population.

A key difference between Goldenman et al. (2019) and the present study illustrated by Table 2-1 is that the 2019 study assigned the same share of the population to the elevated cohort (3% of population for Sweden) for every country. The use of the FPP data allows us to estimate variations across countries. For some countries, the share of the population in the elevated exposure cohort is very small, e.g., 2% in Croatia, Ireland, Latvia and Romania (with <0.5% in the “elevated – high” cohort) and 1% in Iceland (with 0.1% in the “elevated – high” cohort). For other Member States, particularly Belgium, Germany, Italy, and the Netherlands, much higher proportions of the population are in the elevated cohort, including the “elevated-high” sub-cohort. This reflects the distribution of sites manufacturing and the use of PFAS across countries and therefore likely reflects better the reality.

However, it is important to note that this approach could lead to an overestimation for some countries. To determine the area of the elevated cohort, a 31km² radius per PFAS manufacturing/use site is calculated based on the elevated cohort population, population density, and number of sites in Sweden (see info-box on previous page). This calculation might reflect some degree of overlap between the radii of two or more sites when they are closer to one another than 31km², or sites that are closer to an international border than 31km². For countries with a higher density of PFAS manufacturing or use sites than Sweden or a higher share of sites closer to their borders, there might be more overlap between the areas contaminated by each site or with other countries, and so applying the same radius of 31km² to those countries leads to an overestimation. This is most clearly seen for Belgium and Malta where the calculations determine more than 100% of the population within the elevated cohort¹⁰. The figures have been amended to cap the elevated cohort at a maximum of 100% of the population.

Identifying the varying degrees of overlap for each country would require more complex calculations and use of geographic information systems (GIS) to map all locations and potential overlaps. This was not feasible in the present study. However, the issue is relatively contained to those cases with a higher density of sites than Sweden (e.g., Belgium and the Netherlands), and countries with a higher share of sites close to their borders than Sweden.

Moreover, overlap is less likely for the “elevated – high” sub-cohort, due to the smaller area of this cohort. The “elevated – high” sub-cohort is likely to be linked to more significant costs of PFAS pollution due to the higher concentrations in this cohort, so any overestimation due to overlap between radii is not very likely to significantly affect the cost results in Task 4.

¹⁰ As a worked example: Malta has a geographic area of 316km² and population of 560,000. The FPP identifies 13 presumptive sites (3 airports, 5 industrial sites, 2 military sites, and 3 waste sites). 13 x 31km² (per site) is a total area of 403km², which more than exceeds the area (and by proxy) the population of Malta. However, eight of these sites form 4 sets of overlapping pairs: Two waste sites near Maghtab, an airport and a waste site near Xewkja, an airport and military site in Valetta, and a military site and waste site near Marsa. If it is assumed that the radii of these four pairs of sites overlap fully, the total of sites would be reduced from 13 to 9, to eliminate the double counting. This would yield 9 x 31km² = 279km², or 88% of the total area of Malta within the elevated cohort (not including the disaggregation for elevated-high and low). It is considered that the only way to solve the issue in a more precise manner would have been to use GIS mapping, which was not possible given the constraints of the project.

In conclusion, the estimates for population per country and aggregated to EEA level should be used as indicative and an estimate for the order of magnitude in terms of populations within different cohorts and sub-cohorts. However, the estimates from Goldenman et al. (2019) (which span 3% of the population per country) are in the same order of magnitude of the results for the “elevated – high” sub-cohort of this study, based on the number of “hotspots” derived from FPP data.

Table 2-1 Overview the data developed for this study, based on the Forever Pollution Project and Goldenman et al. 2019 – all populations in thousands

Country	Population in the elevated - high sub cohort	Population in the elevated – low sub cohort	Population in the elevated cohort (Total)	Percentage of population in the elevated cohort (elevated - high in brackets)	Goldenman et al. 2019 extrapolated for Population in 2024
Austria	190	757	947	10% (2%)	275
Belgium	2,369	9,451	11,820*	100% (20%)	355
Bulgaria	55	218	273	4% (1%)	194
Croatia	15	60	75	2% (0.4%)	116
Cyprus	15	62	77	8% (1.5%)	29
Czechia	196	784	980	9% (1.8%)	327
Denmark	218	868	1,086	18% (4%)	179
Estonia	7	30	37	3% (0.5%)	41
Finland	32	130	162	3% (0.6%)	168
France	1,013	4,041	5,054	7% (1.5%)	2,054
Germany	3,513	14,015	17,528	21% (4%)	2,504
Greece	56	222	278	3% (0.5%)	312
Hungary	147	586	733	8% (1.5%)	287
Iceland	0.4	1.6	2	1% (0.1%)	11
Ireland	23	93	116	2% (0.4%)	161
Italy	1,535	6,123	7,658	13% (2.5%)	1,769
Latvia	6	24	30	2% (0.3%)	56
Liechtenstein	0	0	0	0% (0%)	1
Lithuania	24	97	121	4% (1%)	87
Luxembourg	37	149	186	28% (6%)	20
Malta	112	448	560*	100% (20%)	17
Netherlands	1,442	5,756	7,198	40% (8%)	538
Norway	46	182	228	4% (0.8%)	167
Poland	426	1,700	2,126	6% (1.2%)	1,099
Portugal	121	482	603	6% (1.1%)	319
Romania	73	290	363	2% (0.4%)	572
Slovakia	40	158	198	4% (0.7%)	163
Slovenia	26	106	132	6% (1.2%)	64
Spain	589	2,351	2,940	6% (1.2%)	1,459
Sweden	64	253	317	3% (0.6%)	317
Total	12,390.4	49,437.6	61,828	13.5% (2.7%)	13,479

* The estimate exceeds 100% of the population. Population has been capped at 100% of the country's population.

Identify occupational cohort population

To determine the occupational exposure cohort, the same approach as Goldenman et al. (2019) has been used, complemented with new data from the FPP. Goldenman et al. (2019) estimates that there were 12-20 PFAS producing facilities in the EEA with 500 workers each. Additionally, they estimated, based on case studies, that there are 352,000 small plants (with an estimated 30 workers each) and 780 large plants (with 300 workers each) in other relevant sectors in the EEA that may use PFAS. For these small and large plants, Goldenman estimated between 3 and 10% actually use PFAS. This equates to 10,600-35,350 plants with 335,000-1.1 million workers in the occupational cohort.

The number of installations actually manufacturing and using PFAS can now be estimated with more certainty using the FPP dataset, which identifies 17 PFAS producers, along with a total 11,454 sites using PFAS in the EEA. This is at the lower end of the range of plants manufacturing/using PFAS estimated by Goldenman et al. (2019). The FPP value has been used within the current study without further extrapolation (to use published values as far as possible).

The remainder of the approach follows Goldenman et al. (2019), using the same proportions for number of large and small plants (99.8% small, 0.2% large, based on Eurostat data) and the same number of workers per plant (300 workers at the large plants and 30 workers at the small plants). Applying these to the FPP data yields that the identified 17 PFAS producers, 23 large PFAS using plants and 11,431 small PFAS using plants employ a total of 358,000 workers, who make the occupational cohort. This estimate sits within the range quoted by Goldenman in her study (335,000 – 1.1 million workers), but at the lower end.

This study has also included calculations to account for retired workers, in order to allow for more accurate results for the dynamic assessment involved by the scenarios developed for the future up to 2050. It assumes that, as workers retire, they are replaced in the workforce, but their blood serum concentrations do not immediately decline, based on years of occupational exposure. The Eurostat labour report (2022) and European Commission ageing report (2024) indicate that around 0.86% of the EU labour force retires each year. However, the ageing report also highlights that the age 55 – 67 group is the fastest growing one and that retirement rate is expected to increase to 1.1% by 2030, and 1.25% before 2035. A flat rate of 1.25% has been applied across the entire time-series on the basis that the rate post-2035 is not known. This likely overestimates the rate of retirement before 2030 and potentially underestimates the rate after 2030. The life expectancy in the EU27 varies by gender and geographical area, with an average value of 81.4 years used for the calculations. This means that each year, $1/15.7^{\text{th}}$ (reflecting the 15.7 years from retirement at 65.7 to life expectancy at 81.4) of the retired pool is expected to reach life-expectancy and pass away. The size of the retired former occupational set is determined by the rate of retirement from current workers vs the rate of retirees reaching life expectancy and passing away.

For the first year of estimates (2020) it was necessary to determine the size of the retired worker pool at that time. This recognises that the calculations determine how many

Information box – worked example for determining the initial size of the retired cohort.

In order to complete the calculations for the full timespan (2020 – 2050, including 2024 as a baseline year), it is necessary to calculate how many retired workers existed in the first year of the calculations.

The FPP data on the number of PFAS manufacturing and using sites (also referred to as “companies” in Goldenman et al. 2019 and below) and an assumed number of workers per company type (from Goldenman et al, 2019) have been used to estimate the number of active workers exposed to PFAS in 2020. Note that the FPP data are assumed to reflect the number of sites in the baseline 2024 year, and the emission estimates from the universal PFAS restriction have been used to extrapolate the number of companies in 2020 (as discussed in section 2.2).

Company type	Number of companies	Number of workers per company	Total Number of workers
Producer	17	500	8,500
Large (user)	22	300	6,600
SME (user)	11,146	30	334,380
Total			349,480

Based on the labour statistics, we assume 1.25% of the current work force retires per annum:
 $349,480 \times 1.25\% = 4,369$ in 2020.

To determine the size of the retired cohort for year 1, we multiply the retirees that year by the remaining life expectancy (81.4 years (life expectancy EU average) – 65.7 years (retirement age EU average) = 15.7 years).

$4,369 \times 15.7 = 68,593$ retired workers.

Note however, this now includes those who will reach life expectancy in the same year and pass away. This means 4,369 needs to be subtracted from 68,593 = 64,224.

The size of the retired cohort as of 1 January 2021 will be 64,224 before that year’s retirees join the retired worker cohort.

retirees enter the retired cohort pool per annum, but that this cohort existed before the first year of the study calculations, and that those individuals would have already been exposed to PFAS in the years pre-2000. Given the estimated life expectancy of 15.7 years after retirement and knowing how many workers retired in 2000; in lieu of better data, it is assumed that the size of the worker pool at the start of the calculations is 15.7 x the number of workers who retired in 2000. The infobox below provides further details of how these numbers have been calculated.

Identify background cohort population

The text thus far has detailed the approach to calculate the number of people within the elevated cohort (including the high and low sub-cohorts) and workers (including retired

workers). The remaining cohort is the “background” cohort population. This is calculated based on the total EEA population minus elevated and worker cohorts.

This means that the remaining population is assigned to the “background” cohort, making up 393,000,000 citizens. **The study estimates that 86% of the EEA population is in the “background” cohort, 14% in the elevated cohort (11% in the elevated-low; and 3% in the elevated-high), and 0.1% in the occupational cohort.**

Table 2-2 Population cohort tables as of 2024*

	Occupational	Elevated (total)	Elevated (high)	Elevated (low)	Background
Total population	423,000**	61,700,000	12,400,000	49,400,000	393,100,000
Adults	423,000**	52,700,000	10,600,000	42,100,000	335,500,000
Children aged 14 or under	-	9,100,000	1,800,000	7,300,000	57,700,000
Total EEA population					455,222,000

*Numbers in the table are rounded to the closest 100,000. **Includes retired workers.

Project future population

In terms of population changes between 2020 and 2050, we have used the compound annual growth rates (CAGR) identified in the Task 1 report, which includes -0.3% year on year for adults, and a weighted value¹¹ of -0.58% year on year for children. As a further clarification, the baseline year 2024 uses published population statistics from Eurostat, with CAGR to calculate both backwards (2020-2023) and forwards (2025-2050). This indicates that the EEA population will decline by 9% over 30 years (equivalent to 39.7 million people). For each time segment (2020, 2024, 2030, 2040, 2050), the population of the elevated cohort is calculated based on the proportion of geographic area of the elevated cohort, average population density (assumed constant over time), and the proportional change in EEA population. The occupational cohort is calculated based on the current number of workers and the proportional change in EEA population plus retired workers, and the “background” cohort is calculated based on the total population minus the population of the elevated and occupational cohorts.

2.2.2. Developing environmental concentrations

Overview

To support the analysis, PFAS monitoring data (for selected PFAS) was gathered as part of Tasks 1 and 2. This includes concentrations in surface water, groundwater, drinking water, soil, and food. As blood serum concentrations (see next section) are not available systematically, it sometimes needed to be inferred from environmental concentrations

¹¹ The CAGR table provided in the Task 1 report includes different compound growth rates by age group, 0 years, 1-4 years, 5-14 years, and 15-19 years. The calculations here present Children in total 0-14 years of age. Therefore, based on the proportionate numbers in each age group for 2024 a weighted CAGR was calculated.

that have been developed for areas corresponding to the “background” and elevated¹² cohorts.

The major references used to help compile this data for environmental concentration came from:

- The consolidated dataset of monitoring data in surface water, groundwater, and drinking water collected by the FPP
- The Member State monitoring data in surface water submitted to and collated by the Joint Research Centre as part of the work to develop a priority substance dossier
- Data gathered by Aqua Publica Europea based on monitoring at drinking water and wastewater works
- Monitoring conducted by the NORMAN network for surface water
- The EFSA (2020) PFAS risk assessment for presence of PFAS in food
- Studies by UBA (2021, and 2023) for environmental concentrations of TFA
- Arp et al. (2024) review of TFA
- Brusseau et al. (2021) review paper for PFAS concentrations in “background”, elevated, and hotspot sites

The details of this research are provided in Appendix C to Annex C1.

Where blood serum data did not span the whole relevant PFAS spectrum (data collated on blood serum collected as part of Task 1 from NHANES and the EU’s human biomonitoring program primarily focussed on four specific PFAS (PFOA, PFOS, PFNA, and PFHxS) while blood serum data was also available for a further 11 key PFAS of interest but to a lesser extent with a more incomplete dataset), this study has aimed at isolating information on these specific PFAS from environmental monitoring data to allow greater cross comparison with blood serum data.

In some cases, e.g., for surface water and drinking water monitoring, sufficient data exists for all or almost all 20 PFAAs identified under the DWD. For example, the Member State surface water monitoring data provided to the JRC spans 17 PFAS. In other cases, the number of substances is more limited, for example soil data largely spans only PFOA and PFOS. Besides these two PFAS, monitoring data on TFA in soil has appeared more recently as a new set of data for a chemical of emerging concern.

The data from the FPP draws on over 100 different datasets based on environmental monitoring by academic researchers, public bodies, and water companies, with the number of PFAS and specific identity of PFAS varying significantly. To ensure comparability, this study had to extrapolate¹³ in cases where fewer PFAS substances were included in datasets, so that it could estimate the sum of 20 PFAAs when not all of them were included in the monitoring.

¹² The monitored data has been used to determine the highest environmental concentrations and rates of exposure for the elevated-high sub-cohort. The environmental and blood serum values for the elevated-low cohort are based on the mid-values between elevated-high and background.

¹³ The approach to extrapolation was determined based on the number of substances and quality of the data. For example, in the case of the data compiled by the JRC from Member State monitoring of surface waters, the data spans 17 out of the 24 identified by the EQSD proposed threshold. An average for one PFAS (e.g., concentration for sum of 17 PFAS / 17) was determined and then multiplied for the number of missing PFAS (e.g., in this case $x \text{ ng/l} \times 7 \text{ missing substances}$) and added to the sum of the known substances. In other cases where the number of substances was too few to make a reasonable extrapolation, e.g., the data on soils by Brusseau et al. (2021) covers only PFOS and PFOA, no extrapolation is attempted, and the data is presented only for these substances. In all cases, it is made clear whether extrapolation has been made, and what proportion of the estimate is extrapolated (i.e., number of substances with monitoring data vs number of substances where the concentration was extrapolated).

Table 2-3 provides the environmental concentration data used in the calculations for this study. As far as possible, published and referenced monitoring data has been used (primarily from the sources in the bullet points above). In the cases where further calculations were needed, the value is identified with an asterisk.

For **drinking water**, in particular the data from the FPP and Aqua Publica Europea surveys indicate that **“background” concentrations** (as the sum of 20 PFAS) can be expected to be between 10 and 50 ng/l. The aggregated average values from the monitored data results in a concentration of 22 ng/l. For the **elevated cohort**, the concentrations are more variable depending on the specific location and circumstances, and values identified ranged from around 75 ng/l to 500 ng/l. In this case a more cautious approach has been adopted assuming that, for the “elevated – high” sub-cohort, the concentration is close to or at the 100 ng/l quoted in the DWD. The justification for this approach is two-fold. Firstly, the FPP in their estimates which refer to the most contaminated sites, indicate that these are at or above 100 ng/l. We propose to use this value for the entire radius of the hotspot, based on the understanding that concentrations within the immediate site (first 1 – 2 km²), may be close to 500 ng/l, but at the outer rim (of the 31km²) may be below the 100 ng/l and closer to the 75 ng/l quoted, noting that 31km² is a physically large area. Secondly, the 500 ng/l is the upper bound of the identified concentrations likely representing a worst-case situation. For the FPP identified sites it is likely that many of them do not reach the upper bound concentration. Note the sensitivity analysis (see section 4) specifically covers the use of the high and low concentration values and the potential impacts of that.

For the “elevated – low” cohort, the mid-value between the elevated - high and “background” cohorts has been used (61ng/l).

Monitoring data for drinking water from the FPP datasets provides concentrations for 12 of the 20 PFAS identified under the DWD, and the relative importance of individual PFAS within the mixture (i.e., which substances dominate the monitoring value)¹⁴. For the *background concentration*, collated values for the most data-rich substances (including PFOS, PFOA, PFHxS and PFNA) have been used directly from the FPP and Aqua publica monitoring data. For the sum of 20 PFAS, where data is either not available for specific substances, or is weak (i.e., <20 samples) an extrapolation approach has been used. This determines the average concentration for a ‘hypothetical’ PFAS substance (i.e., sum of the concentrations for known substances divided by the number of substances). This average concentration is then applied to each missing PFAS substance to aggregate known and extrapolated concentrations towards an overall aggregated total for the group. For the environmental concentrations corresponding to the “*elevated – high*” sub-cohort, where the concentrations range more widely (75 – 500 ng/l), a value of 100 ng/l has been assumed (as explained above).

Given the links to the blood serum data which specifically covers four PFAS substances (PFOS, PFOA, PFNA, and PFHxS), the drinking water values assigned for the substances that are also specifically covered in the blood serum data are 8.8 ng/l for PFOS, 9.9 ng/l for PFOA and PFNA, and 27.5ng/l for PFHxS, based on the consolidated data from the FPP.

¹⁴ This shows that the shorter chain PFAS C4 – C8 PFCAs and PFSAs have higher concentrations than the longer chain ≥C9 PFCAs and PFSAs.

For **surface water**, monitoring data from the Member States showing minimum and maximum concentrations has been used to define the concentrations corresponding to the “background” and elevated exposure cohorts.

For **groundwater**, the concentrations used for the “background” cohort have been estimated from the data collated by the FPP in a similar fashion to drinking water. Examples of elevated concentrations in contaminated zones were less easily identified. Therefore, values for the elevated concentrations in groundwater were calculated based on the same proportionate difference between “background” and elevated concentrations in surface water. This approach has been taken based on the following justifications: 1. Hydrological connectivity between surface water and groundwater means concentrations may be similar; 2. The role of a consistent source emitting to environment means an increase in that source’s emissions would increase both surface water and groundwater concentrations; 3. Using a ratio based on the average concentrations rather than real-world monitored values per location will help mitigate variations in localised issues that may affect the wide range in concentrations at a pan-European level.

For **food**, the EFSA (2020) risk assessment is based on four named PFAS (PFOA, PFOS, PFNA, and PFHxS) with average concentrations based on hundreds of samples. However, monitoring beyond these four substances was not included and therefore the total concentration of 20 PFAS has been extrapolated based on the average of the four multiplied by 20. This method of extrapolation carries considerable uncertainty, as concentrations of individual PFAS can vary widely across different environmental media. However, the authors of this study have made the decision to use extrapolation, despite its shortfalls in this specific situation, to allow a fair comparison between intake of PFAS via drinking water and via food. Indeed, drinking water and food are two key pathways to exposure and therefore mapping them independently is crucial for the analysis, particularly to judge the impacts of the DWD under Scenario 2. Without extrapolation, the effects of reducing exposure to the 20 PFAS in drinking water could not be weighted against the effects of increases in exposure to the 4 PFAS in food. The limitations of this approach are however well acknowledged.¹⁵

¹⁵ To be noted that the authors did also consider another approach: The monitoring data for surface water, groundwater and drinking water provides some steer on which PFAS substances are the most dominant within the mixture for a given matrix (i.e., within the overall aggregation certain PFAS have higher concentrations than others, with a pattern that mirrors across water compartments). This could be used to determine a weighted average and that could be used as part of the extrapolation to offset the issue of using PFAS which are more likely to be dominant in a given mixture. This approach was not used on the basis that the environmental and biological processes between water compartments and food are different and likely mean non-comparable results.

Table 2-3 PFAS mean average concentrations used for elevated and background cohorts in countries in the European Economic Area (EEA) (based on monitoring data except for values with * that have been calculated)

Compartment	PFOS	PFOA	PFNA	PFHxS	Sum of 20 PFAS	TFA
Drinking water (all values as ng/l)						
Background	0.9	1.6	0.4	1.8	22	700
Elevated	8.8*	9.9*	9.9*	27.5*	100*	3,900
Surface water (all values as ng/l)						
Background	10	16.5	4	11.9	201	4,700
Elevated	108	49	6	24	1,006	23,900
Groundwater (all values as ng/l)						
Background	3.7	7.6	2.4	2.8	99	300
Elevated	19*	38*	12*	14*	496*	3,200
Soil (all values as µg/kg)						
Background	22	18				0.2
Elevated	680	38				2
Hotspot	8722	83				
Food (all values as ng/g)						
Red meat	0.1	0.1	0.07	0.05	1.6*	
Fish	19.71	6.99	5.43	4.85	184.9*	
Vegetables	0.08	0.08	0.06	0.05	1.35*	
Fruits	0.14	0.13	0.09	0.09	2.3*	
Dairy (incl. milk)	0.07	0.07	0.05	0.05	1.2*	

Decay of environmental concentrations

The emission projections aspect of the study determines the rate of new emissions to environment alongside the monitored environmental concentrations to support the baseline year (2024). In the cases where emissions in future years decline it could be expected that environmental concentrations decline through a process of natural attenuation. Note that within this task no consideration is given to remediation activities or anthropogenic intervention.

The universal REACH restriction dossier for PFAS highlights the very long-lived nature of PFAS (hence the term forever chemicals), with environmental decline through degradation processes likely to take between decades and hundreds of years.

On that basis within the 30-year period of the study focus (2020 to 2050) it could be expected that there would be little to no decline in environmental concentrations through natural attenuation.

2.2.3. Blood serum concentrations

General approach

Blood serum data was collated as part of Task 1. This included different cohorts (e.g., adults, children, pregnant women, workers, people living near industrial sites). The data spans approximately a dozen PFAA substances, including the four key substances also identified by US research under NHANES (PFOA, PFOS, PFNA, and PFHxS). For each of the three major cohorts identified for this study ("background", elevated, and occupational), the monitoring data for adults and children (age ≤14 years of age) has been used.

To maintain continuity with the environmental monitoring data, the values have been extrapolated to provide concentrations as the sum of 20 PFAAs¹⁶. For different cohort groups and age groups the available blood serum concentrations span between 10 and 12 PFAAs, noting no specific data for children in the elevated cohort (data has been extrapolated based on the ratio of blood serum concentrations between adults and children in the “background” cohort). The available concentration data by substance and cohort is provided in Table 2-4. For each cohort and age group combination, the sum of the known concentrations for PFAS species where data was available was used to derive an average concentration per substance. This average was then used to extrapolate for the missing fraction (i.e. other PFAS species out of the 20 PFAAs for which no data was available). For children in the “elevated – high” sub-cohort where blood serum data was not available, the ratio between adults and children in the “background” cohort has been applied to the concentrations for adults in the elevated cohort.

While this approach was necessary to maintain continuity between the number of substances considered in concentrations in environmental compartments and the number of substances considered in blood serum concentrations, the authors acknowledge that certain degree of uncertainty remains, given the different metabolism rates, physical properties, and initial exposure.¹⁷ However, as the aim of the analysis is not to determine blood serum concentration to exact decimal places, but rather to determine indicative levels of exposure and how they compare between different cohort groups, this approach has been adopted nonetheless to meet the needs of the objectives of this study in the absence of specific data and given the complexity of the subject matter.

Table 2-4 provides an overview of the blood serum concentrations used for the baseline (2024) year in the current study. Table 2-5 provides the data from Goldenman et al. (2019) for comparison.

One further issue needs to be raised regarding the data in Table 2-4 and how it has been used in the model. The data collated from literature (as part of Task 2) provides that data as a range. The values repeated in Table 2-4 present the mid-value of that range. In the case of the elevated cohort (people living near to sites of use) and occupational cohort the mid-value is lower for the occupational cohort than the elevated cohort. This is a result of the occupational cohort having a wider range of blood serum concentrations depending on the specific use, release, abatement and PPE, and length of exposure. In practice, we would expect workers (from the occupational cohort) to live near to their place of work (i.e., they live in the elevated cohort area). It is therefore unrealistic that their blood serum concentration would be lower than the elevated cohort. Therefore, we assume that the occupational cohort has the same blood serum concentrations as the elevated – high cohort in our calculations, instead of using the data shown in Table 2-4 for the occupational cohort.

¹⁶ Depending on the specific cohort and age group, monitoring data reflecting different numbers of PFAS species were available. For adults in occupational settings and background settings, this spanned 12 out of 20 PFAAs. For adults in the “elevated – high” sub-cohort, this spanned 11 out of 20 PFAAs. For children in the background cohort, this spanned 10 of 20 PFAAs, and for children in the “elevated – high” sub-cohort, no data was identified. In this case, the ratio for adults in “elevated – high” and background cohorts was used to calculate the sum of 20 PFAAs from the blood serum concentrations of children in the background cohort.

¹⁷ As discussed for the environmental compartments, an alternative approach could have been to use proportionate relationship between different substances (i.e., some have higher concentrations than others). This could be used to develop a weighted approach to determine the missing fraction. However, it is unclear how justifiable and proportionate such a weighted approach would be in practice for blood serum concentration and was not used.

Table 2-4 Blood serum concentrations used in this study (values with * have been calculated)

PFAS	Adults	Children n	Adults	Children	Adults
	Background	Background	Elevated - high	Elevated - high	Occupational**
Values used in the current study extrapolated as the sum of 20 PFAAs					
PFAAs (total)	15.6	10.4	56.4	37.5*	37.9
Values from Table 3-2 of the Task 1 report used to extrapolate the values above					
PFOA	1.8	0.75	19.5	1.84*	2.37
PFOS	5.04	1.76	5.65	2.1*	17.43
PFNA	0.77	0.33	0.5	0.35*	0.43
PFHxS	0.68	0.37	1.91	0.83*	0.75
PFPeA	-	0.04	0.5	-	0.4
PFHxA	-	0.07	0.5	-	0.3
PFHpA	-	0.02	0.5	-	0.2
PFDA	0.3	0.09	0.5	-	0.2
PFUnDA	0.21	0.02	0.5	-	0.15
PFDODA	0.04	-	0.5	-	0.2
PFTTrDA	0.05	-	-	-	-
PFBS	0.02	-	0.5	-	0.1
PFHpS	0.2	0.02	-	-	0.23
PFDS	0.06	-	-	-	-
PFHxPA	0.18	-	-	-	-

Notes:

Cells where no values are presented this reflects a lack of data, not that the concentration was zero.

*) Calculated based on ratio of adults elevated - high and adults “background”, applied to children “background”.

**) The values shown in this column reflect averages of wide ranges reported in the literature. However, as discussed above the table, in our calculations we assume that the values from the elevated-high cohort also apply to the occupational cohort, because workers would be expected to live near PFAS manufacturing and using sites, i.e. in the elevated cohort.

Table 2-5 Blood serum concentrations taken from Goldenman et al. (2019)

PFAS	Italy	Norway	Sweden	Belgium	Spain	Germany	Greece	USA
Year of study	2018	2009	2004	2004	2007	2008	2008	2018
Background level concentrations								
PFOA	1.64	2.7	5.0	4.1	3.4	13.7	2.05 (male) 1.92 (female)	3.07
PFOS	5.84	12	34.2	17.2	15.2	5.7	13.6 (male) 9.3 (female)	4.99
PFNA	0.6	0.6	-	-	-	-	-	0.7
PFHxS	2.5	1.4	3.0	1.3	5.8	-	-	1.35
PFDA	0.3	0.2	-	-	-	-	-	0.2
PFUnDA	0.2	0.2	-	-	-	-	-	-
PFDoDA	0.04	-	-	-	-	-	-	-

Blood serum – trends

The data produced in Table 2-4 above is based on the mid-values of the 2019 – 2024 data set. However, the data collated as part of Task 2 included data for four named PFAS (PFOA, PFOS, PFNA, and PFHxS) over a longer period of time, spanning 2001 to 2024. This longer period of time does allow for a trend analysis, which shows for PFOA, PFOS, PFHxS and PFNA a declining trend over time as regulatory enforcement takes effect. The trends over the time-series are assumed to continue to apply from the baseline year 2024 until the end of the assessment period. However, where named PFAS like PFOA were banned, they have been replaced at least in part by other related PFAS. This means while these four specifically may have a declining trend, other PFAS, particularly shorter chain are likely to have an increasing blood serum concentration. The baseline year (2024) blood serum levels are determined on the basis of all PFAAs as an aggregated group, and future blood serum levels determined based on their relationship with emissions of PFAAs also as a group.

Therefore, the blood serum concentration for the group is calculated for the baseline year, and each subsequent year based on the ratio between emissions and blood serum. For PFOA, PFOS, PFNA, and PFHxS, the trends from the collated Task 2 time-series are applied, but it is assumed that the difference between the aggregated blood serum level in any given year and the sum of PFOA, PFOS, PFNA and PFHxS is offset by the remaining PFAA members (i.e., if blood serum concentrations decline for these four, other PFAAs increase by an equal amount to offset the decline). Blood serum concentrations for other named substances of the PFAAs have not been calculated individually.

Table 2-6 provides the trend expressed as annual change in blood serum concentration for the four named PFAS.

Table 2-6 Blood serum concentration trends for PFOA, PFOS, PFNA and PFHxS from the Task 2 report.

PFAS	Percentage change from year to year
PFOA	-3.94%
PFOS	-7.74%
PFNA	-0.49%
PFHxS	-4.70%

Blood serum – decay

As this study aims to estimate the impacts of various scenarios of future developments of PFAS emissions and environmental concentrations until 2050, it is important to assess the persistence of PFAS in blood serum. Indeed, given the long-lived nature of PFAS, even after new exposure ceases it could be expected to take some time for the body to recover and blood serum concentrations to fall.

In practice, this is extremely challenging as different individual PFAS are metabolised and excreted at different rates, which further vary depending on age, gender, and underlying health. Rosato et al. (2024) provide a review study for different PFAS, which calculates half-life in blood serum of 1.5-5.1 years for PFOA, 3.5 to 5.7 years for PFOS, and 2.8 to 8.5 years for PFHxS. As a conservative value, a half-life of 5 years is used for the sum of 20 PFAAs, which implies a year-on-year decline of 10% once new exposure ceases. This is not intended to provide a detailed and exact estimate for decline in blood serum concentrations but should provide a more realistic estimate than simply assuming that blood serum concentrations decline immediately as emissions decline.

The information box below provides a worked example to better illustrate how these calculations have been applied.

Information box – worked example for blood serum decay

The estimates illustrate two competing forces, firstly new exposure in a given year which pushes blood serum concentrations up, and secondly existing blood serum concentrations which are declining. In scenarios where the environmental concentrations only increase (as emissions increase), the rate of new exposure exceeds the rate of decay, so blood serum concentration only ever increases.

In cases where environmental concentrations are declining, cohorts are exposed to new quantities via drinking water and food which add to blood serum concentration, but the existing blood serum concentration will decline, and provided the rate of environmental concentrations are declining, the rate of decay should win out and mean overall blood serum concentrations decline.

The table below aims to illustrate that within the calculations. The top row shows the declining drinking water and food concentrations & exposure, and the second-row blood serum concentration based on new exposure. To determine the decay cycle, we assume that new exposure offsets any decay within the existing blood to the same amount, so for example if new exposure adds 10 µg/l then for 10µg/l already in the blood there is no decay as it has been replenished. If there is a difference between existing levels and new exposure, that difference will decay, based on an estimated half-life of 5 years, which means a 10% reduction year on year until that amount hits zero.

If drinking water and food concentrations continue to fall (as seen in year 3), this creates an additional difference which is not replenished and begins to decay, but the decay process only begins from year 3. Hence the difference between year 2 and 3 sees a 10% decline, but the difference between year 1 and 2, has declined a further 10% by year 3 (hence why the value is multiplied by 80%). This process repeats until emissions hit zero, at which point all the year-to-year differences continue to decline at 10% per annum each.

The bottom row of the table shows how these values are aggregated back up to provide what would be the actual blood serum level in any given year based on new exposure + declining existing blood serum.

Year	Year 1 (2026)	Year 2 (2027)	Year 3 (2028)	Year 4 (2029)	Year 5 (2030)
Drinking water (adults) annual intake as (ng/l)	17,000	13,100	9,000	4,700	600
Food (adults) annual intake as ng	5,550,400	4,300,300	2,958,500	1,525,000	46,400
Blood serum concentration (Based on new exposure)	60	46	32	16	0.5
Difference Yr1 to Yr2	14	= 14*90% = 12.6	= 14*80% = 11.2	=14*70% = 9.8	=14*60% = 8.4
Difference Yr2 to Yr3	12		= 12*90% = 10.8	= 12*80% = 9.6	=12*70% = 8.4
Difference Yr3 to Yr4	16			=16*90% = 14.4	=16*80% = 12.8
Difference Yr4 to Yr5	15.5				=15.5*90% = 13.9
Blood serum conc. Sum total	60* (from year 1)	=46 + 12.6 = 58.6	=32+11.2+10.8 = 54	=16 + 9.8 + 9.6 + 14.4 = 49.8	=0.5 + 8.4 + 8.4 + 12.8 + 13.9 = 44

2.2.4. Developing ratios

The information provided thus far in this section allows to allocate the EEA population into cohort groups and to estimate environmental concentrations and blood serum concentrations associated to these cohorts. To project the situation out to 2050, additional information is needed. This draws upon the emission projections from the universal PFAS restriction proposal as one key piece of information to help determine what future trends may look like.

To establish future estimates for all relevant environmental compartments, we have aimed to triangulate the data we have for the baseline year (2024), to provide a series of metrics that can be used against the future projected emissions, as follows: Relate real-world environmental monitoring data (e.g., surface water concentrations) to PFAAs emission in 2024 (from uPFAS restriction dossier published in spring 2023). This provides us with a ratio that associates to every additional tonne of PFAS emitted an increase in surface water concentration expressed as ng/l for the sum of PFAAs.

The same approach is applied to groundwater, drinking water, soil, and food. Appendix B to Annex C1 provides the full set of ratios developed for both the sum of PFAAs, and TFA as a separate illustrative case.

A further comment about developing and using ratios

The current study presents a complex problem to predict the future environmental concentrations and future blood serum concentrations under specific 'what if' scenarios with no real environmental concentration data or blood serum data for future years to meet that challenge. Environmentally there is a link between emissions, witnessed environmental concentrations and blood serum concentrations. Developing ratios between these three points based on data for a given previous year (2024) helps develop an opinion about how changes to one of those three points affects the others. This allows us to use future emission projections to mathematically calculate environmental concentrations and blood serum levels with some confidence.

In terms of trends over time for previous and (therefore) future years, the existing data is incomplete. While there is data as a time-series for e.g., blood serum for a small number of PFAS, particularly PFOS and PFOA. The study looks at PFAAs and precursors as a group, with far less data for other substances within the PFAA group. For some substances, sufficient data exists to draw an average (e.g., between 2019-2024), but not sufficient numbers of samples over a longer timeframe to develop trends, which could then be used as the basis for future projections. Hence, the decision to develop ratios based on a single year using consolidated data as averaged values.

To determine the ratio between direct exposure via drinking water and food to blood serum (as a second set of ratios), it is necessary to determine annual intake of PFAS for both adults and children.

The EFSA dietary reference values have been used to determine that adults consume 2 litres of water per day, and older children 1.6 litres of water per day. Additionally, the EFSA 2022 food consumption survey has been used to determine the consumption rates for e.g., red meat, fish, vegetables, fruit, and dairy per country for adults and children (the full table is provided in Appendix B to Annex C1). The consumption rates of different food groups

(e.g., red meat) vary country by country and between adults and children. To support the calculations within the current study, the mean average for the EEA has been determined for adults and children separately. It should also be recognised that drinking water and food consumption data represents data gathered over a narrow time frame (a single year in the case of the food survey). The authors have assumed that these rates of consumption remain the same year on year for the entire timeframe (up to 2050). In reality, it is likely that dietary habits will change in the next two decades for a variety of reasons. However, to maintain a consistent approach that allows assessment of the main variables (e.g., change in surface water and groundwater concentrations) this simplification is deemed appropriate.

Based on the monitored data for environment compartments, a total annual intake of PFAS has been determined for water, food, and water and food combined. A worked example of how this method is applied is provided in the information box (on the next page). We have then divided the blood serum concentrations by the intake to determine, for each additional ng of PFAS consumed, a relation to blood serum concentrations increase in $\mu\text{g/l}$.

Information box – worked example for adults in background cohort

Drinking water concentration for the background cohort as the sum of 20 PFAS is 22 ng/l. Adults consume 2 litres of water per day (based on the EFSA guideline).

22 ng/l x 2 litres per day x 365 days per year = 16,060 ng intake per adult, per year.

For food, the EFSA risk assessment determines the concentrations for the sum of 20 PFAAs, while the EFSA food survey determines consumption rates per country and as an EEA average. With both sets of data provided below:

Food type	PFAA concentration (ng/g)	Daily food intake (g)
Red meat	1.6	157
Fish	184.9	71
Vegetables	1.4	178
Fruit	2.3	175
Dairy	1.2	246

For each food type the daily consumption calculations work as follows:

Red meat 157g x 1.6ng/g = 251ng

Fish 71g x 184.9ng/g = 13,127ng

Vegetables 178g x 1.4ng/g = 249ng

Fruit 175g x 2.3ng/g = 402.5ng

Dairy 246g x 1.2ng/g = 295.5ng

The total of all food types yields:

251ng + 13,127ng + 249ng + 402.5ng + 295.5ng = 14,325 ng / day.

Multiplied by 365 this yields an annual total of 5,228,625ng, per adult.

Then the combined intake of drinking water and food is 16,060ng + 5,228,625 ng = 5,244,685 ng (or equivalent to 5,244 µg.) This value is then used to determine the ratio between annual intake of PFAS via water and food vs blood serum concentrations.

2.2.5. Developing emission projections

Data from the universal PFAS restriction dossier (published in 2023) and the restriction on use of PFAS in firefighting foams (published in 2022) has been used to determine the future trends in use and emission for manufacture of PFAS and 15 sectors of use. Appendix B to Annex C1 provides the full details of these emission estimates.

The Annex B to the universal PFAS restriction dossier provides a full breakdown of emission estimates as a high, medium, low, or for some sectors high/low for the PFAS groups PFAAs (and precursors including side-chain polymers), fluorinated gases, and fluoropolymers in the baseline year. The emission projections in Annex E to the universal PFAS restriction dossier only provide a single value for total PFAS emissions by sector, without a breakdown

by PFAS group. The proportionate relationship of PFAAs (and precursors including side-chain polymers) to total emissions from Annex B has been used to estimate the share of the projected emissions from Annex E that is attributable to PFAAs and precursors. (i.e., the emissions of fluorinated gases and fluoropolymers are excluded). The research undertaken during Task 1 of the current study found a distinct lack of information on environmental presence and effects of fluoropolymers and fluorinated gases. These groups are therefore only considered in terms of non-polymeric PFAS used as processing aids for production of fluoropolymers (which is included and captured within the PFAAs total, as discussed further below), as well as the contribution of fluorinated gases to environmental concentrations of TFA (see section 3.6 and Appendix D to Annex C1).

The universal PFAS restriction dossier provides estimates as five-year segments (e.g., 2020, 2025, 2030, etc). A linear extrapolation has been used to fill in the gaps between segments, including the baseline year, 2024. This illustrates that, in the restriction's business-as-usual scenario, emissions are predicted to increase from 11,640 tonnes in 2020 to 29,364 tonnes in 2050: an increase of two and half times the original year over the course of a 30-year time span.

During the discussions with the Commission, it was also agreed to review the contribution that manufacture of fluoropolymers make to these emissions. The universal PFAS restriction dossier (under section A.2.1. of Annex A of the restriction dossier) states that, based on consultation with industry, 50-60% of fluoropolymer is made without the use of non-polymeric PFAS as a processing aid.

Further discussion and comment on estimated emissions for the fraction of production that does use non-polymeric PFAS is not provided but could be expected to be included in the emission estimates for PFAAs (and precursors) in the "manufacturing" sector of the restriction dossier, which are estimated at 86 tonnes per annum.

For comparison, the REACH restriction dossier for PFOA (2014) provides emission estimates emissions of 0.35 – 20 tonnes per annum of PFOA as a processing aid for fluoropolymer production. Given the wider shift away from use of non-polymeric PFAS as processing aids in fluoropolymer production since 2014, the current emissions could be expected to be on the lower end of this scale.

Therefore, for the calculations it is assumed that between 0.35 and 20 tonnes of PFAAs are emitted as part of fluoropolymer production, but that these emissions are already captured in the estimates as part of the manufacturing of PFAS sector (which includes fluoropolymer manufacturing).

2.3. Development of Scenarios

This section provides a brief overview of the approach that has been used to develop the scenarios outlined in the introduction. Note that the purpose of these scenarios is to test 'what if' cases, the practical considerations for how compliance is achieved is out of scope for this study. The methodological steps applied were as follows:

- **Scenario 1 (business as usual emissions without policy intervention):** Environmental concentrations for the years 2020 – 2050 (with 2024 as the baseline year) were calculated using the emission estimates from the universal PFAS restriction dossier multiplied by the ratios in Appendix B to Annex C1 to calculate surface water, groundwater, drinking water, soil, and food concentrations. The

second set of ratios in Appendix B to Annex C1 were then applied to the environmental concentrations and intake of PFAS via food and water to estimate future blood serum concentrations.

Changes to the area and population of cohorts and the number of contaminated sites are also projected. **The universal PFAS restriction dossier estimates that in the business-as-usual scenario emissions will increase by two and a half times the baseline between 2020 and 2050.** Eurostat data for growth rates in the manufacturing sector between 2003 and 2023 (excluding 2020 and Covid-19 impacts) provides data for the number of new companies. Additionally, the annual growth rates in annual turnover for the EU27's manufacturing sector helps represent the rate of economic activity changes. Based on this data and the increasing emissions assumed to be linked to increasing activity means the authors estimate that 75% of the increased emissions come from pre-existing sites through on-site expansion and increase in production. 25% of the increased emissions come from new sites. This data has been used to help determine how the scale of the contamination changes over the timeseries based on the emission trends.

- **Scenario 2 (Drinking Water Directive).** The DWD sets thresholds for PFAS at 100 ng/l for the sum of 20 substances is used in the main model calculations. Additionally, the 500 ng/l for Total PFAS threshold is used for TFA specifically because that TFA is not included within the sum of 20. **Scenario 2 follows the same approach as scenario 1, but for drinking water assumes that concentrations are capped at a maximum of 100 ng/l.** This hypothetical scenario does not explore how this limit is achieved, and therefore all other aspects from scenario 1 are kept the same (in particular rates of emissions and environmental concentrations other than drinking water). Furthermore, it is assumed that TFA is capped at the Total PFAS threshold of 500 ng/l, again keeping all other aspects constant. This hypothetical scenario will also explore the effects of the DWD thresholds in terms of intake of PFAS via drinking water and food to determine the overall impact on blood serum concentration.
- **Scenario 3 (Environmental Quality Standards Directive/GWD).** The **quality standard (QS) proposed for surface water and groundwater is 4.4 ng/l PFOA-equivalent. It is assumed that full compliance is achieved from the year 2030¹⁸** onwards. Based on achieving compliance with the QS for surface water and groundwater, the scenario 3 further considers what impact that compliance will have for drinking water and human exposure. This is based on the ratios outlined earlier in this section¹⁹. Note that Scenario 3 follows the same approach and calculations as scenario 1, with the main alteration being that surface and

¹⁸ Clarification note: The proposals for adoption of new priority substances and QS have passed the Trialogue step, with transposition into national law required by 2027 (when monitoring would start) and full compliance with QS by 2039. Because there is a delay in seeing the effects of QS compliance on drinking water and blood serum concentrations, with the scenario implemented in 2039, it is likely that the full effects of the EQS (surface water) and QS (groundwater) would not be clear by the 2050 upper end of the study timeframe. Therefore, an earlier year, 2030 (just after when monitoring would commence) has been selected to illustrate the before and after situation for EQS. The scenario as presented in this study provides a hypothetical 'what if' case, not a regulatory impact assessment.

¹⁹ Clarification note: the 'what if' scenarios are aimed at assessing a specific aspect in isolation to determine the outcome of only those aspects alone. In reality, it can be recognised that to achieve QS compliance would require regulatory intervention, additional abatement at source and end-of-pipe, and possible remediation actions. These aspects have been identified as being out of scope given they distract from the main aim of scenario 3, which is to determine the effects for human health from applying the proposed EQS standards.

groundwater concentrations are altered to meet the QS threshold from 2030 onwards.

- Scenario 4 (total stop of production and uses of PFAS).** The scenario assumes that **effective from 2030 there will be total stop on production and use of PFAS**. In terms of this full stop, further consideration needs to be given to in-use stockpiles of consumer items. While the scenario aims to explore a full stop to emissions (as a result of production and use ceasing), some use will continue until end of life as it is realistically not feasible to re-call these items from circulation. Therefore, there are two categories of sectors, one where production/use and associated emissions can cease immediately from 2030, and one where new production and use ceases, but emissions continue for in-use stockpiles. Additionally, the methodology also assumes a declining set of emissions in the years immediately before 2030. Indeed, it is unlikely that production would continue at full scale all the way up to December 31st, 2029. For industrial manufacture and use, expert judgement has been used to assume a 25% decline in emissions in 2027, a 50% decline in 2028, and a 75% decline in 2029 against the emissions predicted in scenario 1. For those uses with consumer aspects, a similar approach has been adopted assuming a 10% decline in 2027, 25% decline in 2028, 35% decline in 2029, and 50% decline in 2030. For all industrial uses, emissions cease effective 2030, assuming no further use and emission²⁰.

For consumer uses, it is assumed that in-use stockpiles continue to emit. (e.g., treated textiles continue to emit even after treatment and first use). A literature review was completed to determine a reasonable service life per sector, and then a linear decline emission based on that service life until emissions reach zero.

Similarly to scenarios 2 and 3, a significant reduction in emissions leads to reductions in environmental concentrations, blood serum concentrations, and the number of people in the elevated cohort. The number of sites manufacturing/using PFAS and of current workers in the occupational cohort fall to zero. This scenario further includes a new category for occupational exposure termed former workers. These are personal who were working at facilities using or producing PFAS, which ceased to do so as of 2030. These workers were identified based on the difference between 2029 and 2030. They are retained within the occupational cohort and join retired workers at the same rate as used for the other scenarios.

Table 2-7 Overview of sectors and categories for estimation of emissions in Scenario 4 – based on the universal PFAS restriction and restriction for PFAS in firefighting foams.

Industrial uses where all emissions cease from 2030
Manufacture of PFAS
Metal plating*
Electronics and semiconductors*
Energy*
Petroleum and mining
Firefighting foam
Transport*
Consumer uses with in-use stockpiles and estimated service life (years)

²⁰ Some emissions would continue – e.g., contaminated sites will continue to release emissions even after all use ceases. However, for the purposes of the scenario it is assumed all industrial emissions cease effective 2030.

TULAC	10
Food contact materials	3
Consumer mixtures	5
Cosmetics	<1
Ski Wax	<1
Medical devices	15
Construction products	10
Lubricants	5
Fluorinated gases	3

*For these sectors the use of PFAS is primarily as processing aids, solvents, and surfactants in the manufacture of components. The high majority of the emission occurs during manufacture. It is assumed that there will be no remaining PFAS that enters the in-use stockpile.

2.4. Assumptions and consideration of weaknesses

2.4.1. Assumptions

Section 2 presents the methodology that has been implemented to develop data on current and future levels of PFAS pollution in the EEA for Scenarios 1 to 4. As part of this approach, it has been necessary to utilise a series of assumptions to help frame the scope boundary and make the calculations possible. Table 2-8 provides a brief overview of key assumptions.

Table 2-8 Overview of key assumptions

Assumption	Why it was necessary	How it affects the calculations
Emissions are calculated as PFAAs and PFAA precursors, not individual PFAS	The number of substances involved, and potential sources are complex. In the emission projections from the universal PFAS restriction dossier, PFAAs and PFAA precursors are grouped together. We have been unable to disaggregate them.	It means emissions are simply treated as PFAAs, and assumed it includes the substances under the DWD and EQSD.
Quantity of TFA emitted is based on conversion rates of fluorinated gases and fluorinated pesticides	The data available looks at environmental concentrations of TFA, including concentrations in e.g., rainwater. But the emission element is largely unquantified. Development of emissions was necessary to be consistent with the overall approach.	Estimates are made for the quantity of TFA generated against quantified emissions of fluorinated gases, and fluorinated pesticide used. If the conversion rate to TFA alters (i.e., the amount of TFA made), it affects the size of the elevated cohort (by area), and the future emissions which are linked to F-gases.
Changes in emissions of named substances is not included	The universal PFAS restriction dossier includes emission projections for manufacture and use across 15 sectors (based on the version from March 2023 – we note additional sectors are added in the latest version, as well as changes in emissions values) ²¹ . The individual sector emissions increase or decrease independently of one another, with the aggregated total PFAAs and PFAA precursors used in the calculations. Specific PFAS substances used will vary by application and sector, so the specific proportion of a given substance within the PFAA total can change over time. These changes are not considered.	The outputs for the emissions are simply presented as PFAAs and PFAA precursors. The environmental concentrations are also based on PFAAs and PFAA precursors but are linked to a named set of substances, with monitoring data for a proportion of the DWD and EQS substances. This means in practice that the PFAAs and precursors group covered by the universal PFAS restriction emission estimates cover a bigger group of substances than the QS for surface water and groundwater. The calculations assume a proportional relationship (1:1) between emissions and environmental concentrations, but this may overlook the fact that changes in emissions relate to substances not covered by the surface and groundwater grouping. The blood serum concentrations span named substances, primarily the four HBM4EU substances (PFOA, PFOS, PFNA, and PFHxS). However, in total blood serum data for 12 PFAS were available from the Task 1 report. Therefore, there was a need for extrapolation to cover missing DWD and EQSD PFAAs.

²¹ The work for Task 3 was completed between late March 2025 and mid-September 2025; with the main model design and calculations completed by the end of August. The latest version of the REACH restriction Background Document was published in late August 2025. To maintain scheduling and within the resourcing available, the model could not be updated with the new emission data which is aggregated in a different way and includes new sectors. Based on a quick review of the August 2025 updated publication of the Background Document, total PFAS emissions (which includes polymers as a single headline value) increases by four-fold between 2020 and 2050, an increase from 20,000 tonnes per annum to 80,000 tonnes per annum in 2050. On the other hand, the 2023 publication of the Background Document (on which this study is based) indicated that, for PFAAs and PFAA precursors the emissions increase from 11,600 tonnes per annum in 2020 to 29,400 tonnes per annum in 2050 (an increase of 2.5 times on the year 2020). As a direct comparison, if the 'total' emission is used (including polymers) from the 2023 publication, emissions increase from 35,000 tonnes per annum in 2020 to 102,000 tonnes per annum in 2050 (a three-fold increase). It therefore seems that absolute values are lower in the updated Background Document but increase over time is larger. All in all, it is estimated that these differences remain within the range of uncertainty of the overall results of the study.

Populations are treated as a snapshot in time.

It has not been possible to track immigration/emigration, people moving house, changing jobs, etc and potential PFAS exposure for individuals at a given point in time.

The calculations provide proportions of adults and children at given time points, but not necessarily the same individuals.

2.4.2. Considerations of weaknesses

As a general comment, it should be recognised that the subject matter in this report is extremely complex, not only because of the high number of chemical substances involved, but also because of the wide range of uses, possible emission points, environmental pathways and exposure, metabolism of different substances, and projections spanning 26 years into the future.

There are a number of key weaknesses which should be clearly stated when assessing and using the data from this report. The sensitivity analysis (see Section 4) highlights that the most sensitive impact on the results is the **number of sites making and using PFAS**. The data from the Forever Pollution Project has been used as the most recent and up to date information available. However, presumptive sites have been used in the calculations which could lead to an overestimate for the elevated cohort. Also note that the degree of overlap between different sites, as well as the radius and scale of emissions are likely to vary by country and by site.

Another significant weakness is the fact that the **environmental concentrations and blood serum concentrations** have been based on the limited available data identified in Task 1 and 2. While this data provides a good body of evidence, it is critical to recognise the limitations. The environmental monitoring data is significantly more abundant than blood serum (thousands / tens of thousands of samples), but some PFAA substances are either not covered at all, or in a very limited way, while others such as PFOS and PFOA have very detailed datasets. For blood serum, there are relatively small sets of samples (hundreds of samples) have been used to calculate blood serum concentrations for over 460 million EEA citizens. Given the complexity of the issues outlined in this report, the data should only be used as a measure for magnitude of concentrations and concentration trends. The blood serum concentration of specific individuals could vary for a wide variety of reasons.

The future environmental concentrations and blood serum concentrations have been calculated based on the ratios between emissions, environment and blood serum in the baseline year (2024). This approach was adopted as a way of linking what has been seen in the environment and human biomonitoring to projected future emissions. A weakness here is that in reality environmental conditions and rates of exposure can change for a variety of reasons. For example, the specific mixture of individual PFAS substances, climatic conditions, changes in human behaviour, the mechanism of the emission etc. therefore, the future projected situation is indicative of what we see in the real-world for the baseline year.

One of the key aspects in this regard relates to environmental half-life. PFAS are highly persistent and therefore unlikely to decay/degrade. However, they can be metabolised and excreted from the body (human half-lives, estimated as an average of 5 years), and they can move between environmental compartments (e.g., surface water concentrations declining as PFAS is washed out to sea.) To support the human health calculations for Task 4, efforts have been made to look at declining blood serum concentrations using a simplified set of

calculations with large uncertainty. For environmental concentrations, the concentration is assumed to be linked directly to the emission in a given year without further calculation. This was because the specific localised geography will have an impact on environmental half-life. The results section includes further narrative beyond the tables of results for cases where persistence and half-life should be included in the conclusions.

Finally, it should be noted that the analysis presented in this report bears the unavoidable limitations induced by the forever evolving science and policy context:

Indeed, the analysis presented here does not consider the fact that the restrictions under REACH for PFHxA, its salts and related substances as well as the restriction on all PFAS used in fire-fighting foams have been adopted in the course of development of this study (which uses June 2024 as the regulatory position for the baseline scenario). These two restrictions are therefore not included into the scenario 1, which therefore present to some extent some over-estimates of the future emissions under the Scenario 1, with the caveat that we assume these restrictions did not lead to substitution of other PFAS as a replacement for PFHxA and its salts.

Furthermore, the analysis presented here is based on projected emissions taken from the universal PFAS restriction Background Document published in 2023. However, an updated version of this document was published in August 2025 and the updated data therein could not be incorporated into this study, due to time constraints. Absolute values of projected PFAS emissions are lower in the updated Background Document but increase more over time compared to the figures used in this study.

The combination of these two limitations (emissions without latest restrictions and data from 2023 version of the universal PFAS restriction proposal Background Document) could therefore to some extent mitigate each other and are considered anyhow within the acceptable range of uncertainty of the study.

3. Results

3.1. Introduction

This section provides the results of the assessment of pollution levels across the four scenarios, based on the methodology outlined in the previous section. For each scenario, the following results are discussed: the scale of environmental exposure in terms of the number of potential PFAS contaminated sites, geographic scale of the contamination, environmental concentrations in surface water, groundwater, drinking water, and PFAS intake via food, as well as human health exposure levels (blood serum concentrations). Following the discussion for scenarios 1 to 4 for PFAAs and precursors, a separate section is provided for TFA as a PFAS of emerging concern, and then a concluding section to discuss overarching reflections across scenarios.

3.2. Scenario 1 – Business as usual for emissions without intervention

3.2.1. Introduction

Scenario 1 presents the business-as-usual case, as of June 2024 (hence with no implementation of the proposed universal PFAS restriction).

3.2.2. Environmental exposure

The environmental exposure is provided as two separate sets of results. Firstly, in terms of land contamination based on the number of sites making or using PFAS, and secondly in terms of environmental concentrations (surface water, groundwater, drinking water, etc.).

Table 3-1 (below) shows the results for the projected numbers of sites and the area of contaminated land. It is estimated by the universal PFAS restriction dossier, **in the business-as-usual scenario (without further policy intervention), emissions will increase by two and a half times between 2020 and 2050**. This increase in emissions is driven by increased production and use of PFAS, which would likely lead to a significant increase in the number of sites. This in turn means that the scale of the contamination will increase substantially. In scenario 1 (unconstrained emissions without policy intervention, based on current real-world data, the calculations estimate 8.4% of the EEA (in terms of land area) has levels of PFAS in soil above “background” concentrations in 2024. If emissions were to increase in line with predicted emissions (for BAU) until 2050, this extends the geographic scale of contamination to around 10.4% of the EEA (as a worst-case scenario) having concentrations that exceed “background” levels, including 1.9% of the area being highly contaminated sites (e.g., akin to the situation in Dordrecht, Netherlands and Veneto region, Italy).

The sensitivity analysis (see Section 4) will assess how these results change when using the high/low emission estimates from the universal PFAS restriction dossier. However, the primary results for the scenario 1 predict a significant increase in environmental exposure.

Table 3-1 Overview of outputs for Scenario 1 (Environmental impacts - area) in the European Economic Area.

	2020	2024	2030	2040	2050
Number of PFAS manufacturing sites	17	17	18	19	21
Number of highly certain PFAS industrial using sites (starting from “known” contaminated sites in FPP)	185	190	197	212	235
Number of less certain PFAS using sites (starting from “presumptive” contaminated sites in FPP)	10,983	11,264	11,686	12,586	13,949
<i>Airports *</i>	792	812	842	907	1,006
<i>Firefighting training sites *</i>	1,040	1,067	1,107	1,192	1,321
<i>Industrial sites</i>	5,117	5,248	5,445	5,864	6,499
<i>Military sites *</i>	446	457	474	511	566
<i>Waste management sites</i>	3,588	3,680	3,818	4,112	4,557
Area corresponding to the Elevated cohort (km ²)	346,735	355,601	368,931	397,327	440,355
In Percentage of the total area of EEA	8.2%	8.4%	8.7%	9.4%	10.4%
Area corresponding to the Elevated-high cohort (km ²)	69,522	71,300	73,973	79,666	88,294
In Percentage of the total area of EEA	1.5%	1.5%	1.6%	1.7%	1.9%

*The ‘what if’ scenarios presented in this study are based on the legislative state of play as of June 2024. In reality, under the EU restriction on PFAS in firefighting foams, emissions from sites marked with an asterisk could be expected to cease by 2035. Note that the restriction on PFAS used in fire-fighting foams has not been included into the scenario 1 used in this study, which was developed before the finalisation of that restriction.

Table 3-2 provides the results for the calculation of environmental concentrations. As with the other tables for scenario 1, the predicted large increase in emissions between 2020 and 2050 has a substantial impact on environmental concentrations for all compartments. The key things to note from Table 3-2 are as follows. For all cohorts, the drinking water concentrations increase sharply. The data for drinking water and food suggests that food is the dominant pathway for PFAS intake, already in the baseline year. The data in Table 3-2 provides the results for food with and without the inclusion of fish, due to the wide range of PFAS concentrations observed in fish²². However, even when contributions from fish are removed entirely, the annual intake of PFAS from consumption of food and water illustrates that water makes up the smaller part of the overall intake of PFAS. For surface water and groundwater, the projections predict a broad increase in concentrations by two and a half times the baseline year, aligned with the similar increase in emissions.

²² The monitoring data from the EFSA, 2020 risk assessment), shows that some specific species of fish have particularly elevated PFAS concentrations (e.g., for PFOS the concentration in carp, 14 µg/kg, is equivalent to double herring, sardines, anchovy, salmon and trout, mackerel, tuna, cod and whiting and halibut combined).

Table 3-2 Overview of outputs for Scenario 1 (Environmental impacts - concentration) in the European Economic Area.

	2020	2024	2030	2040	2050
PFAS concentration in Drinking water (ng/l)					
<i>Background cohort</i>	20	22	26	36	50
<i>Elevated-low sub-cohort</i>	55	61	73	99	139
<i>Elevated – high sub-cohort</i>	90	100	120	163	227
PFAS concentration in Surface water (ng/l)					
<i>Background cohort</i>	181	201	241	326	456
<i>Elevated-low sub-cohort</i>	543	603	724	981	1,370
<i>Elevated-high sub-cohort</i>	906	1,006	1,207	1,636	2,285
PFAS concentration in Groundwater (ng/l)					
<i>Background cohort</i>	89	99	119	161	225
<i>Elevated-low sub-cohort</i>	268	298	357	484	676
<i>Elevated-high sub-cohort</i>	447	496	595	807	1,127
Annual intake of PFAS from Drinking water in µg / per person (Background cohort)					
<i>Adult annual intake</i>	14.5	16.1	19.3	26.1	36.5
<i>Children annual intake</i>	11.6	12.8	15.4	20.9	29.2
Annual intake of PFAS from Drinking water in µg / per person (Elevated-low sub-cohort)					
<i>Adult annual intake</i>	40	45	53	72	101
<i>Children annual intake</i>	32	36	43	58	81
Annual intake of PFAS from Drinking water in µg / per person (Elevated-high sub-cohort)					
<i>Adult annual intake</i>	65.7	73.0	87.6	118.7	165.8
<i>Children annual intake</i>	52.6	58.4	70.1	95.0	132.6
Annual intake of PFAS from Food in µg / per person (including fish)					
<i>Adult annual intake</i>	5,200	5,800	6,980	9,450	13,200
<i>Children annual intake</i>	3,000	3,300	4,000	5,400	7,600
Annual intake of PFAS from Food in µg / per person (Excluding fish)					
<i>Adult annual intake</i>	384.4	427.0	512.3	694.1	969.7
<i>Children annual intake</i>	330.0	367.2	440.7	597.2	834.2

3.2.3. Human exposure

Table 3-3 provides the results of the calculations for human exposure to PFAAs and precursors (including emissions from fluoropolymer manufacturing) in the EEA. It is estimated that around 61.7 million people (equivalent to 14% of the EEA population) is within the wider elevated cohort in 2024. For the highest concentrations and exposure, the elevated-high cohort, this covers 12.4 million people (equivalent to 2.7% of the EEA population). For comparison, the Goldenman et al. (2019) study estimated that 12.5 million people in the EEA would be exposed to particularly high concentrations of PFAS. A further 49.4 million in the elevated-low cohort are subject to above “background” levels of exposure. The majority of the remaining EEA population (393 million, equivalent to 86% of the population) sit within the “background” cohort, and 420,000 (0.01% of the EEA population) within the occupational cohort (including current and retired workers).

It is estimated that there would be 14.2 million people in elevated-high and a further 56.7 million in elevated-low cohorts by 2050. The total elevated cohort would hence reach 70.9 million, equivalent to 17% of the total EEA population, by 2050. Similarly, the significant

increase in emissions is expected to lead to increases in drinking water and food concentrations. This in turn means that the estimated blood serum concentrations also more than double from 15.6 µg/l for adults in the “background” cohort in 2024 to 35.4 µg/l for adults in 2050.

The number of workers in the occupational cohort is estimated to increase from 420,000 in 2024 to 520,00 in 2050. This is despite the overall population of the EEA being predicted to decline from 455 million in 2024 to 421 million in 2050.

Table 3-3 Overview of outputs for Scenario 1 (human health) in the European Economic Area

	2020	2024	2030	2040	2050
Background cohort					
Population (Total) (millions)	399.4	393.1	383.6	367.5	349.6
Share of total population of all cohorts (%)	87%	86%	86%	85%	83%
Population (Adults) (millions)	340.4	335.5	328.0	315.0	300.1
Population (Children) (millions)	59.0	57.6	55.7	52.5	49.5
Blood serum concentration - adults (µg/l)	14.0	15.6	18.7	25.4	35.4
Blood serum concentration - Children (≤14 yrs) (µg/l)	9.3	10.4	12.4	16.8	23.5
Elevated – High sub-cohort					
Population (Total) (millions)	12.2	12.4	12.6	13.2	14.2
Share of total population of all cohorts (%)	3%	3%	3%	3%	3%
Population (Adults) (millions)	10.4	10.6	10.9	11.6	12.7
Population (Children) (millions)	1.9	1.8	1.8	1.7	1.6
Blood serum concentration - adults (µg/l)	50.8	56.4	67.7	91.7	128.1
Blood serum concentration - Children (≤14 yrs) (µg/l)	33.7	37.5	44.9	60.9	85.1
Elevated – Low sub-cohort					
Population (Total) (millions)	48.7	49.4	50.4	52.7	56.7
Share of total population of all cohorts (%)	11%	11%	11%	12%	13%
Population (Adults) (millions)	41.3	42.1	43.4	46.1	50.5
Population (Children) (millions)	7.4	7.3	7.0	6.6	6.2
Blood serum concentration - adults (µg/l)	32.4	36.0	43.2	58.5	81.8
Blood serum concentration - Children (≤14 yrs) (µg/l)	21.5	23.9	28.7	38.9	54.3
Occupational cohort					
Population (Total) (millions)	0.41	0.42	0.44	0.47	0.52
Share of total population of all cohorts (%)	0.1%	0.1%	0.1%	0.1%	0.1%
Current workers	0.35	0.36	0.37	0.40	0.44
Retired workers	0.06	0.07	0.07	0.07	0.08
Blood serum concentration - current worker (µg/l)	50.8	56.4	67.7	91.7	128.1
Blood serum concentration - retired worker (µg/l)	50.8	56.4	67.7	91.7	128.1

3.2.4. Summary

The business-as-usual scenario illustrates the effects of the projected increase in emissions (two and a half times increase from 2020 to 2050 according to the universal PFAS restriction dossier). The number of sites producing and using PFAS is assumed to increase, extending the geographic scale of contamination. In 2024, 86% of the population are in the “background” cohort and 14% are in the elevated cohort (2.7% in elevated-high, and 10.8% in elevated-low), equivalent to 12.2 million people in the elevated-high cohort. By 2050, the elevated cohort makes up around 17% of the population, with 14 million people in the elevated-high cohort. Concentrations in drinking water, surface water and groundwater all increase at a similar rate as the emissions. Intake of PFAS via food and water also increases sharply, with food making up the more substantial fraction of human exposure.

3.3. Scenario 2 – Drinking Water Directive (DWD) thresholds

3.3.1. Introduction

Scenario 2 provides results on the basis that drinking water concentrations do not exceed 100 ng/l for the sum of 20 PFAS, and 500 ng/l for total PFAS, as set in the Drinking Water Directive (DWD). The scenario assumes that other variables are unchanged from the scenario 1 (business as usual emissions without policy intervention), such as increased PFAS emissions and exposure through other pathways than drinking water.

3.3.2. Environmental exposure

For the environmental exposure in this scenario, it is assumed that the DWD thresholds will be achieved while all other aspects remain unchanged from scenario 1. This means the number of sites, geographic scale of contamination, surface water concentrations and groundwater concentrations will mirror scenario 1 (see Table 3-1).

Results for scenario 2 (Table 3-4) show that, for adults, the annual PFAS intake from drinking water in the elevated cohort (both high and low sub-cohorts) is capped at 73 µg/per person/per annum, and for children at 58.4 µg/per person/per annum. For comparison, in scenario 1, the annual intake via drinking water reaches 184.2 µg/per person/per year for adults (as of 2050), and 147.3 µg/per person/per year for children. Under scenario 2, fulfilling the drinking water directive limit effectively cuts exposure by 60% annually by 2050 for adults and children via drinking water. Note that, despite this avoided increase of PFAS concentrations in drinking water, blood serum concentrations show a limited reduction due to increased concentrations in food in the assumed absence of intervention on this aspect (see Table 3-4).

Table 3-4 Overview of outputs for Scenario 2 (Environmental impacts - concentrations) in the European Economic Area

	2020	2024	2030	2040	2050
PFAS concentration in Drinking water (ng/l)					
<i>Background cohort</i>	20	22	26	36	50
<i>Elevated-low sub-cohort</i>	55	61	73	100	100
<i>Elevated-high sub-cohort</i>	100 ²³	100	100	100	100
Annual intake of PFAS from Drinking water in µg / per person (Background cohort)					
<i>Adult annual intake</i>	14.5	16.1	19.3	26.1	36.5
<i>Children annual intake</i>	11.6	12.8	15.4	20.9	29.2
Annual intake of PFAS from Drinking water in µg / per person (Elevated-low Sub-cohort)					
<i>Adult annual intake</i>	40.1	44.5	53.4	73.0	73.0
<i>Children annual intake</i>	32.1	35.6	42.7	58.4	58.4
Annual intake of PFAS from Drinking water in µg / per person (Elevated-high Sub-cohort)					
<i>Adult annual intake</i>	73.0	73.0	73.0	73.0	73.0
<i>Children annual intake</i>	58.4	58.4	58.4	58.4	58.4

3.3.3. Human exposure

The major difference between scenarios 1 and 2 is that, in scenario 2, drinking water concentrations are limited to a maximum of 100 ng/l (for the sum of 20 PFAS) and 500 ng/l (Total PFAS). Table 3-5 illustrates that, because drinking water accounts only for a relatively small share of human exposure, the overall impact on blood serum concentrations is minimal. For the “background” cohort, drinking water concentrations never reach 100 ng/l in scenario 1, even by 2050, so the results for the “background” cohort do not change in scenario 2. For the elevated-high sub-cohort, the drinking water concentration reaches the 100 ng/l limit already in the baseline year and continues to increase in scenario 1, whereas in scenario 2, the concentration is capped from 2024 onwards. For the elevated-low sub-cohort, the drinking water concentrations reach 100ng/l between 2030 and 2040 and continue to increase in scenario 1, whereas in scenario 2, from 2040 onwards the concentration is capped at 100ng/l. These limits imposed in scenario 2 result in a reduction in terms of PFAS intake and blood serum concentrations (equivalent to 1.0 µg/l in adults; and 0.9 µg/l in children by 2050 for elevated-high, and 0.5µg/l for adults and children in elevated-low) compared to scenario 1, but because food makes up the dominant pathway for exposure, the reduction in exposure in drinking water is offset by increases in food concentrations. This is based on the assumption that all remaining variables are kept unchanged, for instance that irrigation, rainfall, and existing concentrations in soil and groundwater are all unaffected by the imposed concentration limit for drinking water. The population of each cohort in scenario 2 is also the same as in scenario 1.

²³ Note that the ambient environmental concentration for elevated-high in surface water begins at 100 ng/l, i.e., it is already on the legal limit. Under scenario 1 it increases in future years, but for scenario 2 it remains capped at the current concentration.

Table 3-5 Overview of outputs for Scenario 2 (human health) in the European Economic Area

	2020	2024	2030	2040	2050
Background cohort					
Blood serum concentration - adults (µg/l)	14.0	15.6	18.7	25.4	35.4
Blood serum concentration - Children (≤14 yrs) (µg/l)	9.3	10.4	12.4	16.8	23.5
Elevated-High sub-cohort					
Blood serum concentration - adults (µg/l)	50.9	56.4	67.5	91.2	127.1
Blood serum concentration - Children (≤14 yrs) (µg/l)	33.8	37.5	44.8	60.5	84.2
Elevated-low sub-cohort					
Blood serum concentration - adults (µg/l)	32.5	36.0	43.2	58.3	81.3
Blood serum concentration - Children (≤14 yrs) (µg/l)	21.6	23.9	28.7	38.6	53.8
Occupational cohort					
Blood serum concentration - current worker (µg/l)	50.9	56.4	67.5	91.2	127.1
Blood serum concentration - retired worker (µg/l)	50.9	56.4	67.5	91.2	127.1

3.3.4. Summary

The implementation of drinking water thresholds limits the increase in PFAS exposure via that pathway. However, because this scenario assumes that drinking water thresholds are met, with all other variables remaining the same as in scenario 1, the outputs of scenario 2 largely mirror scenario 1, with the effects of the drinking water threshold not felt by the “background” cohort (concentrations never exceed the threshold in scenario 1). Moreover, because food is a key pathway, avoided PFAS exposure via drinking water in the elevated-low and elevated-high sub-cohorts are counteracted by increasing concentrations in food, assuming no other form of intervention is applied to reduce concentrations of PFAS in food.

3.4. Scenario 3 – Environmental Quality Standards

3.4.1. Introduction

This scenario provides the outcome of applying the Quality Standards (QS) for surface water and groundwater in the Commission’s 2022 proposal²⁴ to amend the Environmental Quality Standards Directive (EQSD) and Groundwater Directive²⁵. The QS are expressed as PFOA equivalents, on the basis of toxicity using a relative potency factor (RPF) for the named PFAAs and PFAA-precursors. The proposed QS of 4.4 ng/l PFOA-equivalent (for the sum of 24 PFAS) has been applied. It is assumed that other variables are unchanged from the scenario 1 (business as usual emissions without policy intervention), such as PFAS emissions and exposure through other pathways than surface water and groundwater. Note that in reality, it is likely that emission reductions would also be necessary to achieve

²⁴ [Proposal amending Water Directives - Environment - European Commission](#)

²⁵ Directive 2008/105/EC as amended by Directive 2013/39/EU and Directive 2006/118/EC, respectively.

compliance with the QS. The impacts of emission reduction are further explored in Scenario 4.

As a further note, the model assumes the new QS takes effect with full compliance from 2030 onwards (see Section 2.3). In reality, the result of the co-decision process concluded on the full compliance to be achieved by 2039. Because there is a delay in seeing effects on drinking water and blood serum following implementation of the EQS, it means using 2039 as the date of compliance would likely mean the full impacts of this scenario is not materialised before the end of this studies assessment period (2050). 2030 has therefore been used as a hypothetical compliance date to illustrate situations before and after compliance and the full effects of this scenario.

3.4.2. Environmental Exposure

For the environmental exposure in this scenario, it is assumed that the number of sites and geographic scale of contamination will mirror scenario 1 (see Table 3-1).

Table 3-6 provides the results of the environmental concentrations in scenario 3. This illustrates that concentrations in surface water and groundwater in the elevated-high sub-cohort are capped at the 4.4 ng/l PFOA-equivalent level (presented as the sum of the real concentrations). Drinking water concentrations and annual intake of PFAS via drinking water also decline sharply as a result. For comparison, note that the drinking water concentrations achieved in scenario 3 are much lower than the drinking water threshold in scenario 2.

Table 3-6 Overview of outputs for Scenario 3 (Environmental impacts - concentrations) in the European Economic Area

	2020	2024	2030	2040	2050
PFAS concentration in Drinking water (ng/l)					
<i>Background cohort</i>	20	22	0.8	0.8	0.8
<i>Elevated-low Sub-cohort</i>	55	61	0.8	0.8	0.8
<i>Elevated-high Sub-cohort</i>	90	100	0.7	0.7	0.7
PFAS concentration in Surface water (ng/l)					
<i>Background cohort</i>	181	201	4	4	4
<i>Elevated-low Sub-cohort</i>	543	603	4	4	4
<i>Elevated-high Sub-cohort</i>	906	1,006	4	4	4
PFAS concentration in Groundwater (ng/l)					
<i>Background cohort</i>	89	99	4	4	4
<i>Elevated-low Sub-cohort</i>	268	298	4	4	4
<i>Elevated-High Sub-cohort</i>	447	496	4	4	4
Annual intake of PFAS from Drinking water in µg / per person (Background cohort)					
<i>Adult annual intake</i>	14.5	16.1	0.59	0.59	0.59
<i>Children annual intake</i>	11.6	12.8	0.47	0.47	0.47
Annual intake of PFAS from Drinking water in µg / per person (Elevated-low Sub-cohort)					
<i>Adult annual intake</i>	40	45	0.6	0.6	0.6
<i>Children annual intake</i>	32	36	0.4	0.4	0.4
Annual intake of PFAS from Drinking water in µg / per person (Elevated-high Sub-cohort)					
<i>Adult annual intake</i>	66	73	0.5	0.5	0.5
<i>Children annual intake</i>	53	58	0.4	0.4	0.4
Annual intake of PFAS from Food in µg / per person (including fish)					
<i>Adult annual intake</i>	5,200	5,800	103.8	103.8	103.8

<i>Children annual intake</i>	3,000	3,300	59.6	59.6	59.6
Annual intake of PFAS from Food in µg / per person (Excluding fish)					
<i>Adult annual intake</i>	384.3	427.0	19.0	19.0	19.0
<i>Children annual intake</i>	330.0	367.2	16.3	16.3	16.3

3.4.3. Human exposure

Table 3-7 provides the scenario 3 outputs. Blood serum concentrations fall by a similar level (>95%) compared to environmental concentrations over the 30-year window. As discussed in Section 2, it is assumed that PFAS blood serum concentrations in blood fall with a half-life of 5 years, which means a 100% reduction after 10 years. Therefore, the benefits of capping groundwater and surface water concentrations from 2030 onwards (and the resulting decreases in PFAS intake via drinking water and food) would be fully realised by 2040²⁶.

The population of each cohort in scenario 2 is the same as in scenario 1 (see Table 3-1).

Table 3-7 Overview of outputs for Scenario 3 (human health) in the European Economic Area

	2020	2024	2030	2040	2050
Background cohort					
Blood serum concentration - adults (µg/l)	14.0	15.6	12.6	0.7	0.7
Blood serum concentration - Children (≤14 yrs) (µg/l)	9.3	10.4	9.5	0.5	0.5
Elevated – High sub-cohort					
Blood serum concentration - adults (µg/l)	50.8	56.4	45.4	0.5	0.5
Blood serum concentration - Children (≤14 yrs) (µg/l)	33.7	37.5	30.1	0.3	0.3
Elevated – Low sub-cohort					
Blood serum concentration - adults (µg/l)	32.4	36.0	29.0	0.6	0.6
Blood serum concentration - Children (≤14 yrs) (µg/l)	21.5	23.9	19.8	0.4	0.4
Occupational cohort					
Blood serum concentration - current worker (µg/l)	50.8	56.4	45.4	0.5	0.5
Blood serum concentration - retired worker (µg/l)	50.8	56.4	45.4	0.5	0.5

3.4.4. Summary

Surface water and groundwater QS of 4.4 ng/l PFOA-equivalent are assumed to apply from 2030 and to yield reductions of a similar order of magnitude (>95%) in both environmental and blood serum concentrations, the latter reaching 0.5µg/l in the elevated-high adult group by 2040.

²⁶ Clarifying note: The legal process for amendment of the surface water and groundwater quality standards has reached trialogue agreement at the time of writing. One development to highlight here is further amendments to the proposals for groundwater which will dynamically link the QS to the Drinking Water Directive requirements.

3.5. Scenario 4 – Total stop of production and uses of PFAS

3.5.1. Introduction

The final scenario explores the outcome of assuming a full stop on production and use of PFAS (assumed to commence from 2030). This has one caveat outlined in the methodology section, as goods for consumer uses already in use in 2030 are assumed to remain in use (and continue to emit) until they reach their end of service life.

3.5.2. Environmental Exposure

Table 3-8 illustrates the effect of stopping PFAS manufacture and industrial use. Scenario 4 assumes that all PFAS manufacturing and industrial use ceases in 2030, but that emissions from the remaining in-use stockpiles (of treated articles and mixtures) continue until they reach the end of their working life for the sectors identified in Section 2.3 (emissions from waste are also considered). As emissions fall, the scale of new contamination steadily declines in line with the emission reduction. However, as discussed in Section 2, due to the persistence of PFAS in soil, it is assumed that the extent of the contaminated area is fixed at the peak year of emissions (expected to be reached in 2026), with no decline or contraction in the area of the elevated cohort following declining emissions (i.e., the emissions cease but the sites remain contaminated). This is illustrated in the lower part of the table, which shows that while emissions are largely reduced, the scale of the contaminated area remains unchanged.

Table 3-8 Overview of outputs for Scenario 4 (Environmental impacts - area) in the European Economic Area

	2020	2024	2030	2040	2050
Number of PFAS manufacturing sites	17	17	0	0	0
Number of highly certain PFAS industrial using sites (starting from “known” contaminated sites in FPP)	185	190	0	0	0
Number of less certain PFAS using sites (starting from “presumptive” contaminated sites in FPP)	10,983	11,264	1,613	0	0
<i>Airports</i>	792	812	0	0	0
<i>Firefighting training sites</i>	1,040	1,067	0	0	0
<i>Industrial sites</i>	5,117	5,248	0	0	0
<i>Military sites</i>	446	457	0	0	0
<i>Waste management sites</i>	3,588	3,680	1,613	0	0
Area corresponding to the Elevated cohort (km ²)	346,735	355,601	359,600	359,600	359,600
In Percentage of the total area of EEA	8.2%	8.4%	8.5%	8.5%	8.5%
Area corresponding to the Elevated-high cohort (km ²)	69,522	71,300	72,102	72,102	72,102
In Percentage of the total area of EEA	1.5%	1.5%	1.5%	1.5%	1.5%

Table 3-9 provides the scenario 4 environmental concentrations. This shows the steady decline in concentrations in water, reaching zero by 2050. This reflects likely translocation of PFAS into other compartments and biota, with the ultimate final compartment likely

being marine. Note that, while the data here presented PFAAs and PFAA precursors as a family, the phys-chem properties of individual PFAS, particularly mobility, vary from substance to substance.

Table 3-9 Overview of outputs for Scenario 4 (Environmental impacts - concentrations) in the European Economic Area

	2020	2024	2030	2040	2050
PFAS concentration in Drinking water (ng/l)					
<i>Background cohort</i>	20	22	10	0.1	0
<i>Elevated-low Sub-cohort</i>	55	61	27	0.3	0
<i>Elevated-high Sub-cohort</i>	90	100	44	0.5	0
PFAS concentration in Surface water (ng/l)					
<i>Background cohort</i>	181	201	88	1	0
<i>Elevated-low Sub-cohort</i>	543	603	265	3	0
<i>Elevated-high Sub-cohort</i>	906	1,006	441	5	0
PFAS concentration in Groundwater (ng/l)					
<i>Background cohort</i>	89	99	43	0	0
<i>Elevated-low Sub-cohort</i>	268	298	130	1	0
<i>Elevated-high Sub-cohort</i>	447	496	218	2	0
Annual intake of PFAS from Drinking water in µg / per person (Background cohort)					
<i>Adult annual intake</i>	14.5	16.1	7.0	0.08	0.0
<i>Children annual intake</i>	11.6	12.8	5.6	0.06	0.0
Annual intake of PFAS from Drinking water in µg / per person (Elevated-low sub-cohort)					
<i>Adult annual intake</i>	40.1	44.5	19.5	0.2	0.0
<i>Children annual intake</i>	32.1	35.6	15.6	0.2	0.0
Annual intake of PFAS from Drinking water in µg / per person (Elevated-high sub-cohort)					
<i>Adult annual intake</i>	65.7	73.0	32.0	0.3	0.0
<i>Children annual intake</i>	52.6	58.4	25.6	0.3	0.0
Annual intake of PFAS from Food in µg / per person (including fish)					
<i>Adult annual intake</i>	5,200	5,800	2,550	27.7	0
<i>Children annual intake</i>	3,000	3,300	1,460	15.9	0
Annual intake of PFAS from Food in µg / per person (Excluding fish)					
<i>Adult annual intake</i>	384.4	427.0	187.9	2.0	0
<i>Children annual intake</i>	330.0	367.2	161.0	1.8	0

3.5.3. Human exposure

Table 3-10 provides the results of the scenario 4 calculations. Scenario 4 projects PFAS emissions to fall dramatically until reaching zero in 2045.

As a result, scenario 4 projects a steady decline in blood serum concentrations over the 30-year period. This takes into account a lag in the declining of blood serum concentrations over time to reflect a notional half-life in blood, and full elimination from the body 10 years after new exposure ceases. This means that blood serum concentrations reach zero in the latter part of the 2040s following the last remaining in-use articles entering waste phase before the end of the 2030s. It is the only one of the four scenarios to predict a complete elimination of PFAS in blood serum.

Table 3-10 Overview of outputs for Scenario 4 (human health) in the European Economic Area

	2020	2024	2030	2040	2050
Background cohort					
Population (Total) (millions)	399.4	393.1	385.4	374.2	363.1
Share of total population of all cohorts (%)	87%	86%	86%	86%	86%
Population (Adults) (millions)	340.8	335.5	328.9	319.3	309.8
Population (Children) (millions)	58.6	57.7	56.5	54.9	53.3
Blood serum concentration - adults (µg/l)	14.0	15.6	14.3	3.0	0.0
Blood serum concentration - Children (≤14 yrs) (µg/l)	9.3	10.4	9.5	2.0	0.0
Elevated-high sub-cohort					
Population (Total) (millions)	12.2	12.4	12.3	12.0	11.6
Share of total population of all cohorts (%)	3%	3%	3%	3%	3%
Population (Adults) (millions)	10.4	10.6	10.5	10.2	9.9
Population (Children) (millions)	1.8	1.8	1.8	1.8	1.7
Blood serum concentration - adults (µg/l)	50.8	56.4	51.6	10.7	0.0
Blood serum concentration - Children (≤14 yrs) (µg/l)	33.7	37.5	34.2	7.1	0.0
Elevated-low sub-cohort					
Population (Total) (millions)	48.7	49.4	49.2	47.7	46.3
Share of total population of all cohorts (%)	11%	11%	11%	11%	11%
Population (Adults) (millions)	41.5	42.1	41.9	40.7	39.5
Population (Children) (millions)	7.2	7.3	7.2	7.0	6.8
Blood serum concentration - adults (µg/l)	32.4	36.0	32.9	6.8	0.0
Blood serum concentration - Children (≤14 yrs) (µg/l)	21.5	23.9	21.9	4.5	0.0
Occupational cohort					
Population (Total) (millions)	0.41	0.41	0.26	0.08	0.06
Share of total population of all cohorts (%)	0.1%	0.1%	0.1%	0.02%	0.01%
Current workers (millions)	0.35	0.36	0.16	0.0001	0.0
Former workers (millions)	0.0	0.0	0.07	0.06	0.05
Retired workers (millions)	0.06	0.05	0.03	0.02	0.01
Blood serum concentration - current worker (µg/l)	50.8	56.4	51.6	10.7	0.0
Blood serum concentration - retired worker (µg/l)	50.8	56.4	51.6	10.7	0.0

3.5.4. Summary

The final scenario, which demonstrates the effects of a hypothetical stop of PFAS manufacturing and use in the EEA, shows a strong and steady decline in emissions, which is reflected in falling environmental concentrations and subsequently blood serum concentrations. The calculations predict (with some caveats discussed above) that all emissions and blood serum concentrations would reach zero by 2045. Note that as with the other scenarios, these are intended to present “what if” hypothetical cases to demonstrate what could be the outcome of specific measures in isolation. Consideration for wider

aspects to achieve a full stop on emissions and economic and society consequences of that are out of scope for the current task. Note that the scenario 4 (as scenario 3) assumes a 2030 implementation year to demonstrate the before and after situation. In reality achieving a full-stop by the year 2030 would be extremely ambitious.

3.6. Trifluoroacetic acid (TFA) (case study)

3.6.1. Introduction

Trifluoroacetic acid (TFA) is an ultra-short chain (C2) perfluoroalkyl acid that has been gaining increasing attention and concern within scientific and regulatory circles. Part of this concern stems from the fact that, while TFA has a much lower toxicity than PFOA and PFOS (Dekant, et al, 2023), it is also highly mobile and environmental concentrations are in an order of a magnitude higher than other PFAAs combined (Arp et al, 2024). It is important to recognise that since TFA is ultra-short chain, it is likely to be the terminal end product from any degradation of other PFAS. For example, the photolytic degradation of fluorinated gases emitted to air from air conditioning sources. Additionally, its high persistence and mobility pose specific challenges to remediation and treatment, which can be less effective against TFA compared to other PFAS.

Since TFA is a substance of emerging concern, the available monitoring data in the environment and blood serum is less complete than the other PFAAs. This means attempting a full set of calculations may not be appropriate at this time. However, given the environmental and human health concerns, a case study has been developed and is presented here alongside the rest of the PFAAs to provide an illustration of what the environmental situation looks like, and as scenario 1 case (i.e., business as usual emissions without policy intervention) what future environmental concentrations could look like as part of the 'what if' scenarios.

The methodological approach to determining environmental concentrations in the baseline year (2024) is provided in Appendix D to Annex C1. The scientific literature (detailed in Appendix D) highlights that a number of potential emission sources exist. The two primary sources relate firstly to the use of fluorinated gases, where atmospheric processes (such as photolysis) breakdown longer chain PFAS into TFA, which then falls back to Earth within precipitation or other forms of deposition (e.g., contaminated dust particles). These processes spread TFA over wide distances across political boundaries. The emissions and emission projections for F-gases from the universal PFAS restriction have been used as the basis of determining current and future rates of emissions. Environmental monitoring for "background" (cohort) concentrations utilises the same ratio approach as the main method to determine current and future environmental concentrations in the "background" cohort based on F-gases.

The second major source is the use of fluorine based organic pesticides, with the monitoring data highlighting elevated concentrations in rural areas associated with agricultural practices. Data on tonnages of fluorinated pesticide used in France and Germany have been used to help derive usage and emission rates against the monitored data to determine suitable ratios to then determine rates for future years. Full details are in Appendix D to Annex C1.

One further clarification needs to be raised for the scenario 2 on drinking water specifically. The DWD lists two named thresholds, one spanning the sum of 20 PFAAs with a maximum allowable concentration of 100 ng/l; and a second threshold based on total PFAS with a maximum allowable concentration of 500 ng/l. TFA is not named in the sum of 20 PFAS but would be included in the total PFAS listing. Currently, Member States have the option to use any one or both of these thresholds in national legislation. Given the challenges posed in defining “total PFAS” and completing monitoring, based on feedback from the Commission all Member States are likely to use the sum of 20 PFAS only. Because the case studies here present “what if” scenarios of what could be achieved under specific conditions, the scenario 2 makes the assumption that all Member States would apply both the 20 PFAS threshold and the total PFAS threshold.

As a counter-factual, it should also be noted that, under drinking water legislation, PFAS could be determined as a relevant metabolite of some fluorinated pesticides. Under the DWD, pesticides and relevant metabolites have a threshold of 100 ng/l. This would capture TFA as a possible relevant metabolite. Further consideration to this aspect is not included within the case study.

3.6.2. Results

Tables 3-11, provides the results of the calculations for scenario 1. The results indicate for the baseline year of 2024, around 93% of the European Economic Area is within the “background” cohort, with 7% in the elevated cohort. The emissions for fluorinated gases are estimated to broadly double between 2020 and 2050 (according to the universal PFAS restriction dossier). This is reflected in the environmental concentrations for scenario 1.

In the elevated cohort, the environmental concentrations are projected to decline over time. The calculations for the elevated cohort are based on population trends as a proxy for food demand. Arguably this is an indirect link, and it should be noted that this approach was used in lieu of better data. However, looking at pesticide usage trends, the European Commission’s dashboard²⁷ with projected trends to 2030, indicates a downward trend²⁸, noting that trends in pesticide use can be dynamic and changeable over longer time periods (e.g., regulation of neonicotinoids leading to greater uptake of fluorinated pesticides) following the EU’s commitment towards reduction in use of pesticides, particularly the most harmful ones.

The EEA population is predicted to decline from 460 million in 2020 (EEA) to 421 million in 2050, a fall of 8.5%, and therefore the use of fluorinated pesticides is estimated to fall as well. However, academic literature (Arp et al, 2024) highlights that over the last 20 years, concentrations of TFA in agricultural settings have steadily increased. This trend mirrors agriculture production which has also increased over the last 20 years²⁹, along with pesticide usage. Another source highlights a sharp rise in TFA concentrations in European wines between 2020 and 2024.³⁰ Since the adoption of the Farm-to-fork strategy in 2020,

²⁷ [EU: Trends - Food Safety - European Commission](#)

²⁸ Note that the dashboard was not used to help map the projected trends for two reasons. Firstly, only fluorinated pesticides are relevant, which cannot be easily disaggregated from the dashboard. Secondly, the projections only go out to 2030, and there are concerns around the more dynamic nature of pesticides with new substances coming to market as existing ones are sometimes removed / not renewed.

²⁹ <https://ourworldindata.org/agricultural-production>

³⁰ PAN Europe (2025) The Rapid Rise of TFA Contamination Across the EU. https://www.pan-europe.info/sites/pan-europe.info/files/public/resources/reports/Message%20from%20the%20bottle_TFA%20in%20wine%20_23042025.pdf

the usage of pesticides generally and for the most harmful one has begun to decline and is expected to continue declining. Regulatory decisions on pesticide authorisations may influence TFA emissions, e.g. the non-renewal of flufenacet (a pesticide which releases TFA) earlier in 2025.³¹ This poses a question of ‘lag time’ and how quickly the environmental concentrations in agricultural areas will start to fall. The declining trend in concentrations for the elevated cohort shown in Table 3-11 should be treated with some caution due to the uncertainties regarding pesticide use, which is affected by various factors, including population trends, consumption patterns, regulatory decisions, climate, and other economic factors. Trends in other sources of TFA emissions will also influence the exposure of the elevated cohort.

Note that under the drinking water directive there are thresholds limits for the sum of 20 PFAAs (100 ng/l) and PFAS Total (500 ng/l), with the latter covering all PFAS. This latter grouping would also include TFA as one of its members. Monitoring data for surface water and groundwater (as sources of drinking water) are reported to routinely exceed this concentration (e.g., Arp et al, 2024 – quotes monitoring studies where surface and groundwater were found to be around 1,000 ng/l as the median; The JRC (2022) available monitoring data for TFA in groundwater quote concentrations range between 100 ng/l and 5,000 ng/l; The FPP project has only limited data on TFA, with one study for drinking water with concentrations that ranged from 84 to 2,100 ng/l (median of 435 ng/l)).

The estimates in Table 3-11 indicate that even in the “background” cohort the concentrations of TFA exceed the current drinking water directive level from 2020 onwards.

³¹ Commission Implementing Regulation (EU) 2025/910 of 20 May 2025 concerning the non-renewal of the approval of the active substance flufenacet. https://eur-lex.europa.eu/eli/reg_impl/2025/910/oj/eng

Table 3-11 Overview of outputs for TFA for scenario 1

	2020	2024	2030	2040	2050
Environmental					
<i>Elevated area thousands of km²</i>	318	318	318	318	318
<i>Area of the EEA as a percentage</i>	6.8%	6.8%	6.8%	6.8%	6.8%
<i>Background area thousands of km²</i>	4,334	4,334	4,334	4,334	4,334
<i>Area of the EEA as a percentage</i>	93.2%	93.2%	93.2%	93.2%	93.2%
Background zone					
<i>Surface water concentration (µg/l)</i>	4.70	5.09	5.73	6.98	8.51
<i>Groundwater concentration (µg/l)</i>	0.30	0.33	0.37	0.45	0.54
<i>Drinking water concentration (µg/l)</i>	0.70	0.76	0.85	1.04	1.27
Elevated zone					
<i>Surface water concentration (µg/l)</i>	23.90	23.62	23.19	22.51	21.84
<i>Groundwater concentration (µg/l)</i>	3.20	3.17	3.11	3.02	2.93
<i>Drinking water concentration (µg/l)</i>	3.90	3.85	3.78	3.67	3.56

In terms of the 'what if' scenarios, we can make the following general comments:

- Scenario 2 (DWD). Assuming that TFA falls within the definition of Total PFAS would cap the drinking water concentrations at 500 ng/l effective from 2024 onwards for both "background" and elevated cohorts. This assumes full compliance and enforcement of the directive, but limits the increases seen in Table 3.11 based on increasing emissions under Scenario 1.
- Scenario 3 (EQSD). As of the 25 September 2025³² the European Parliament and Council agreed a plan for implementation of proposed changes to the EQSD which would include PFAS. As part of these negotiations TFA has been added to the list of PFAS substances, but the proposed threshold is not yet clear. It is likely that this proposed EQS for TFA would be significantly lower than the estimated surface and groundwater concentrations in Table 3-11. This would also have a marked impact on the drinking water concentrations. It is not possible yet to estimate the scale of the reduction, noting that TFA was not included as part of the original proposals for 4.4 ng/l.
- Scenario 4 (full stop). This scenario would see emissions of PFAS cease in 2030. As indicated in Section 2.3, there are specific sectors and cases where in-use stockpiles could be expected to continue after any new use is banned. This was on the basis that product recalls would either be very costly, have severe negative impacts for society, or both. In the case of the primary sources of TFA, it could be argued that management of pesticide stocks could be handled in a manner that prevented the need for ongoing use and emissions would cease in 2030. For fluorinated gases, it could be argued that industrial applications (such as foam blowing) would cease, but that air conditioning systems (both mobile and static) would likely meet the definition for a problematic recall, with emissions ongoing for 3-5 years³³ after 2030.

³² [Water pollution: Council and Parliament reach provisional deal to update priority substances in surface and ground waters - Consilium](#)

³³ Based on expert judgement – in terms of containment mobile air con (cars, trucks etc) will be the most likely to leak and emit, with recharge of systems every 2-5 years. Industrial / professional a/c including supermarket refrigeration and chiller cabinets, can

3.6.3. Summary

TFA is a PFAS of emerging concern, with literature indicating that, over the last 20 years, its environmental concentrations have increased steadily. Table 3.11 (scenario 1 business as usual emissions without policy intervention) illustrates that under scenario 1 based on the increasing emissions for fluorinated gases, “background” TFA concentrations would continue to increase in the coming years. Trends in concentrations in the elevated cohort due to pesticides is more uncertain (given the use of population trends as a proxy), but note that trends in use and emissions of pesticides are dynamic, and heavily influenced by regulatory measures (e.g., whether fluorinated pesticides see their active ingredient renewed or not, bans on certain types of pesticides such as neonicotinoids increasing the use of fluorinated pesticides, regrettable substitution – swapping one fluorinated pesticide for another).

The calculated outputs suggest a decline in environmental concentrations in coming years, with “background” concentrations matching and then exceeding those in the elevated areas. In scenario 4, the full stop on production and use means a significant reduction in emissions as of 2030, which would translate into reductions in environmental concentrations. For the “background” cohort, there are some continued emissions from use in products still in use (e.g. air conditioning), which are computed to cease after 2033. For the elevated cohort, use of pesticides means a direct end to emissions under scenario 4. The environmental concentrations under scenario 4 also fall to zero (i.e., no new emissions). However, in terms of half-life, it could be expected that in reality groundwater concentrations remaining broadly similar to 2024 levels, given a potential half-life of hundreds of years. For surface water, while TFA is highly persistent, it is also highly soluble and does not readily bind to sediment³⁴. For flowing waters, the most likely outcome is that TFA will be washed out into the marine environment as the ultimate sink.

3.7. Comparison of results across scenarios

This section provides some overarching reflections based on comparison of the outputs across the scenarios, focusing on three key issues:

- How the area of contamination and the population of the elevated cohort compares across scenarios
- How predicted concentrations of PFAS in the environment and in blood serum compare across scenarios
- How the population and breakdown of the occupational cohort compare across scenarios

3.7.1. Changing area of contamination and cohort size

The data presented in the universal PFAS restriction dossier projects the emissions to increase two and a half times between 2020 and 2050, which has a substantial bearing on the results overall. Firstly, the growing emissions are associated with a significant rise in

be more prone to leakage, but would be subject to inspections under F-gas regulations. Office / public building A/C systems tend to be more stable and less likely to leak but would also be subject to the same checks and maintenance. Assume 3 – 5 years for continued emissions based on mobile air conditioning units in the automotive sector.

³⁴ [Trifluoroacetic acid / CF₃COOH / CID 6422 - PubChem](#)

contaminated areas and the number of people living near them, secondly, emissions data is also used as the primary driver to determine concentrations in drinking water, surface water, groundwater, and food (based on a set of derived ratios in the baseline year of 2024 for this study), and consequently blood serum concentrations.

In scenarios 1 (business-as-usual emissions without further policy intervention), 2 (drinking water directive fulfilment) and 3 (EQS), this results in growing areas of contamination and a growing share of the population the elevated cohort: by 2050, 16.8% of the population falls into the elevated cohort (with 3.4% in the elevated-high sub-cohort), compared to 13.6% in the baseline year 2024 (with 2.7% in the elevated-high sub-cohort). This also reflects the assumptions that in scenario 2, only drinking water concentrations are reduced, and in scenario 3, only surface water, groundwater, drinking water and food concentrations are reduced, while all other variables (e.g., size of cohorts, rate of emissions, geographic scale of contamination, and concentrations in soil) remain unchanged.

In contrast, scenario 4 (stop of production and use) focuses on reducing emissions, which halts the contamination trend: by 2030, 13.8% of the population is in the elevated cohort (with 2.8% in the elevated-high sub-cohort), and this is assumed to remain constant as emissions further decline after 2030, due to the persistence of PFAS.

Figure 3-2 Changes to cohort size between background and elevated concentration cohorts.

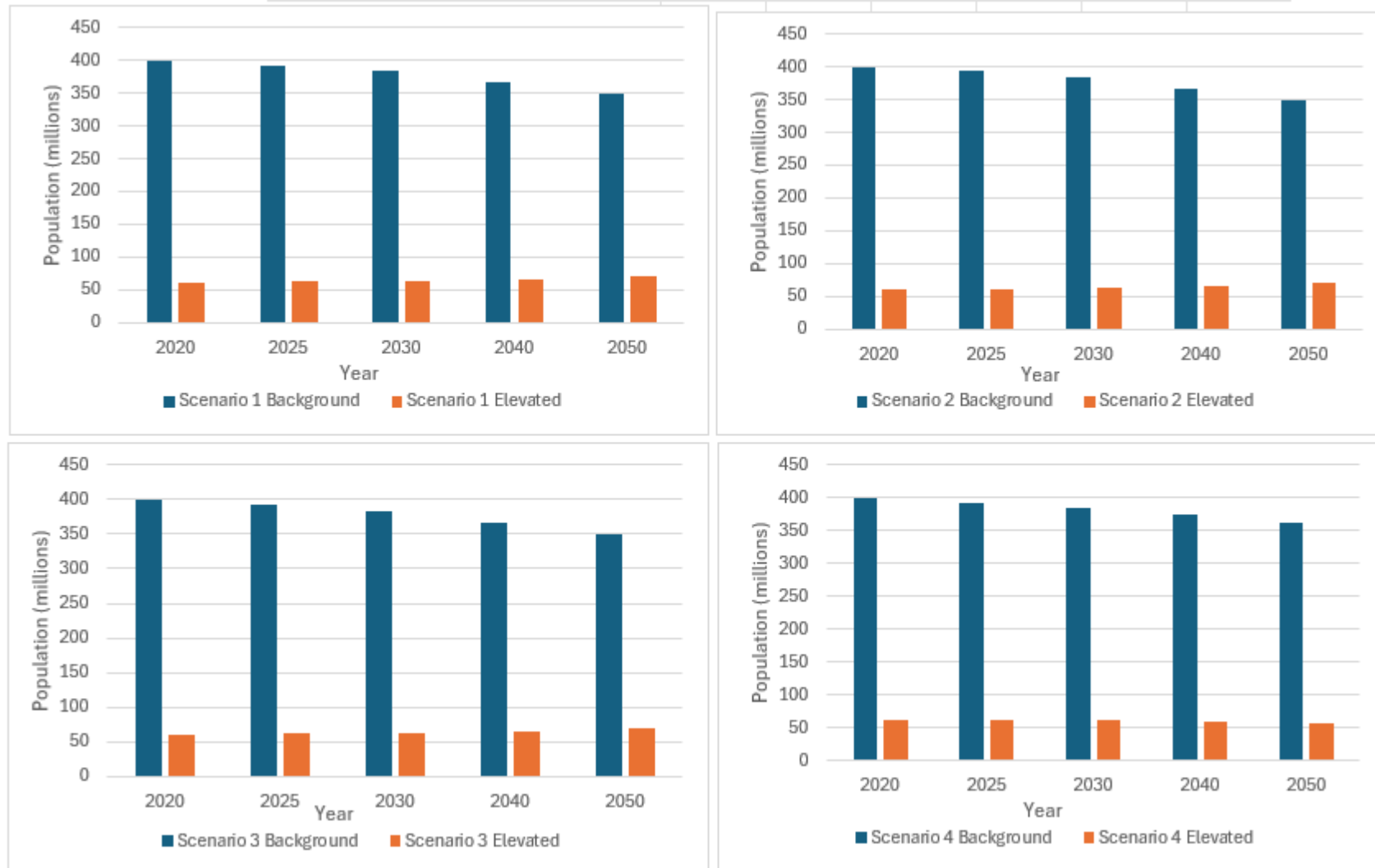
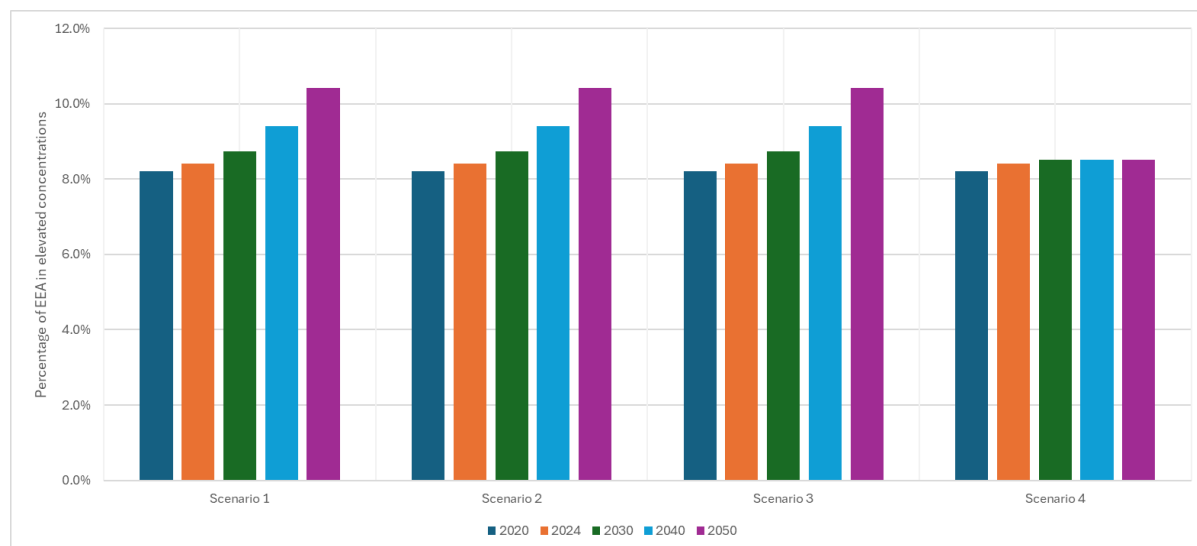


Figure 3-3 further illustrates this phenomenon in terms of the proportion of land contaminated to elevated concentrations (i.e. the area of the elevated cohort). It illustrates that, based on the FPP data, in the baseline year (2024), 8.4% of the EEA area is close to a contamination site from manufacture or use of PFAS, with elevated environmental concentrations. Under scenarios 1, 2 and 3, this increases to 10.4% by 2050. In scenario 4, a stop in production and use of PFAS halts this trend, and the area of the elevated cohort remains stable at 8.5% of the EEA area from 2030.

Figure 3-3 Changes in geographic area of the elevated cohort for scenarios 1 - 4.



3.7.2. Environmental and blood serum concentrations

In terms of environmental concentrations, a similar pattern emerges for drinking water, surface water, groundwater and food. The results for drinking water are provided in Figure 3-4, with the graphs for the other compartments included in Appendix F to Annex C1 for the sake of brevity.

Figure 3-4 illustrates the “background”, elevated-low and elevated-high cohorts for each of the four scenarios side by side. This demonstrates that for scenario 1 (business-as-usual) where emissions are left unchecked for all three cohorts, the drinking water concentrations increase steadily between 2020 and 2050. The scenario 2 graphs show the effect of the Drinking Water Directive, where concentrations are capped at 100 ng/l. Note that for surface water, ground water and food, concentrations in scenario 2 are assumed to mirror scenario 1 and are not affected by compliance with the Drinking Water Directive. Scenarios 3 and 4 illustrate the effects of the EQS thresholds and stop of manufacture and use of PFAS, effective from 2030 onwards, which either immediately cut drinking water concentrations, or show a slow but steady decline to 2040, with elimination between 2040 and 2050.

Figure 3-5 provides the results of the blood serum concentrations for adults. The chart for children follows the same pattern, and again for the sake of brevity is included in Appendix F to Annex C1.

Figure 3-4 Comparison of drinking water concentrations across scenarios 1 - 4

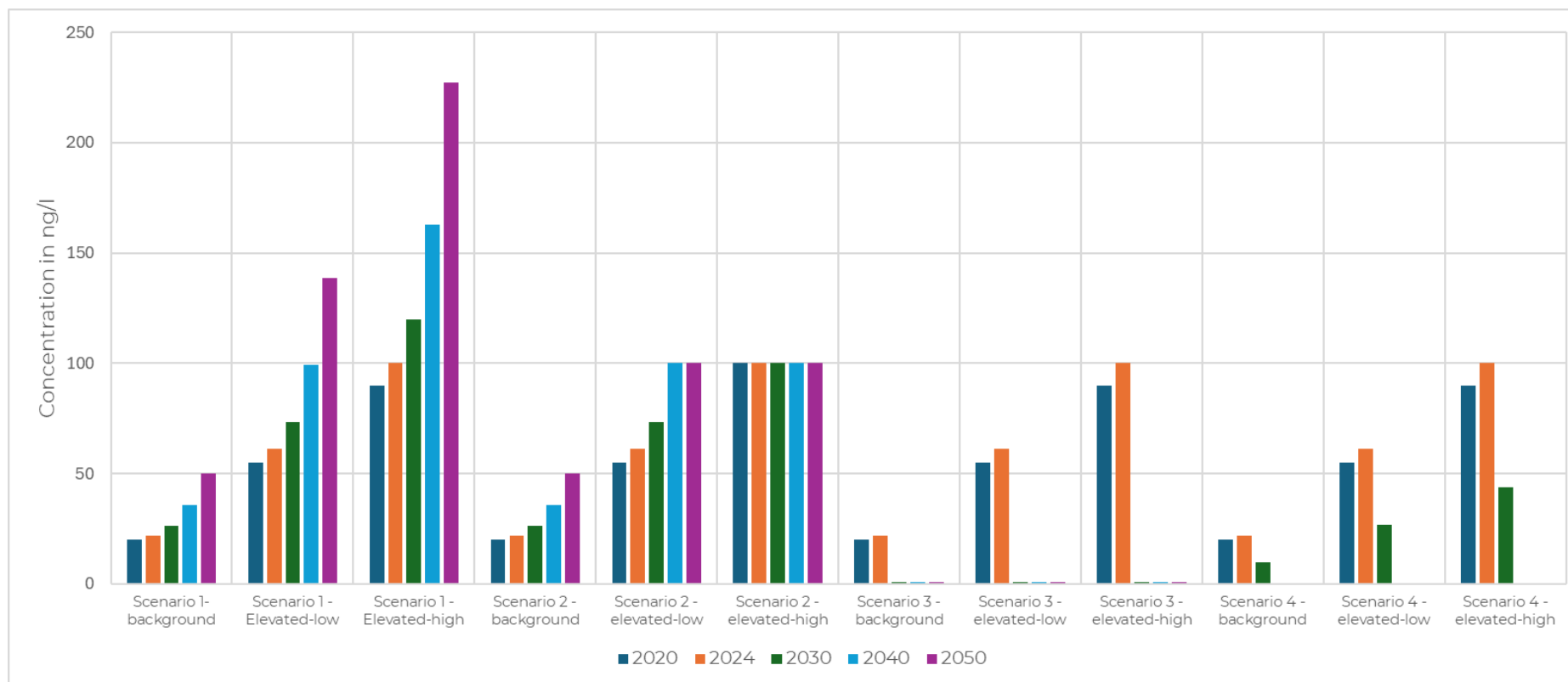
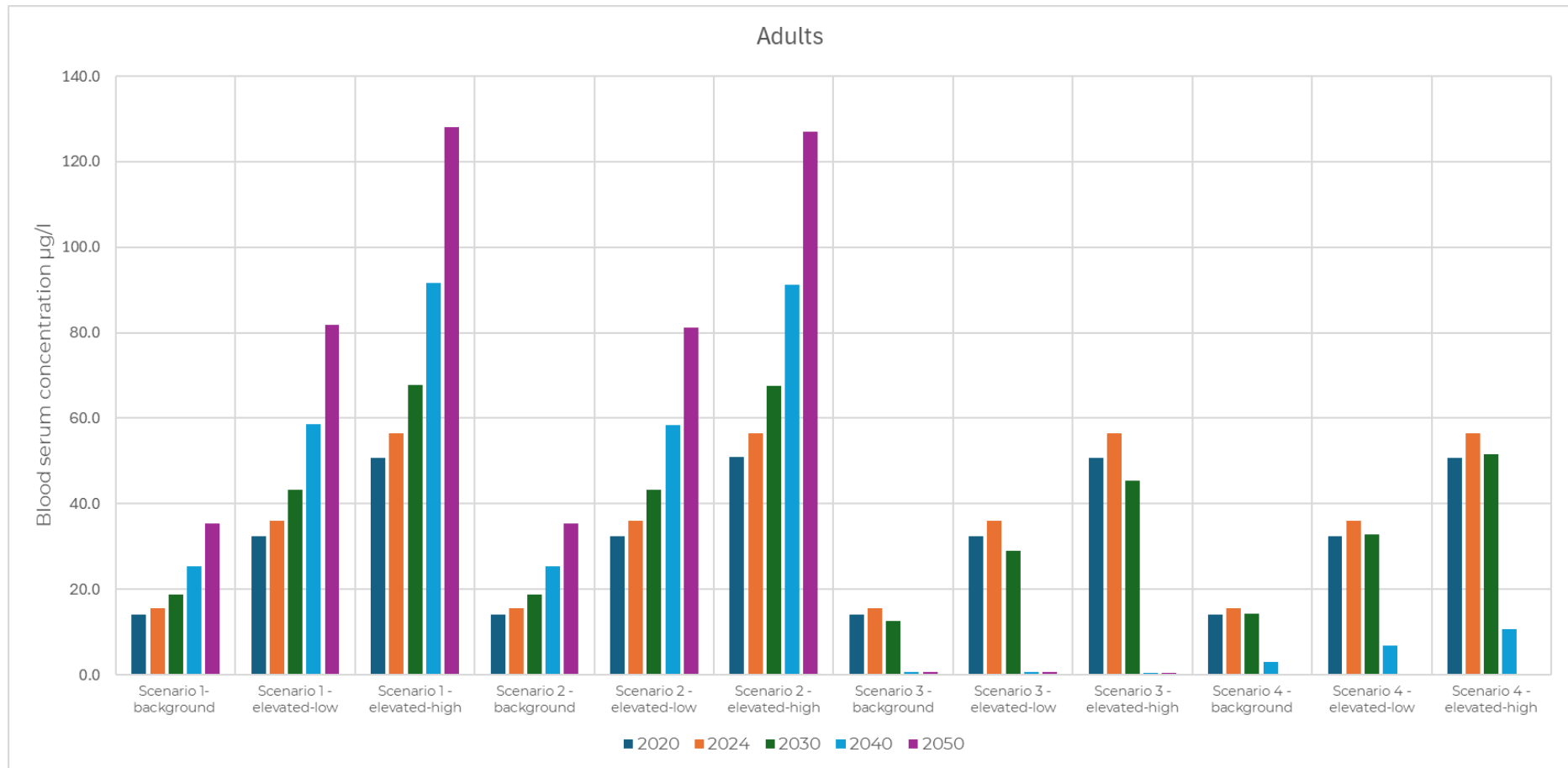


Figure 3-5 Comparison of blood serum concentrations across scenarios 1 – 4 (for adults)



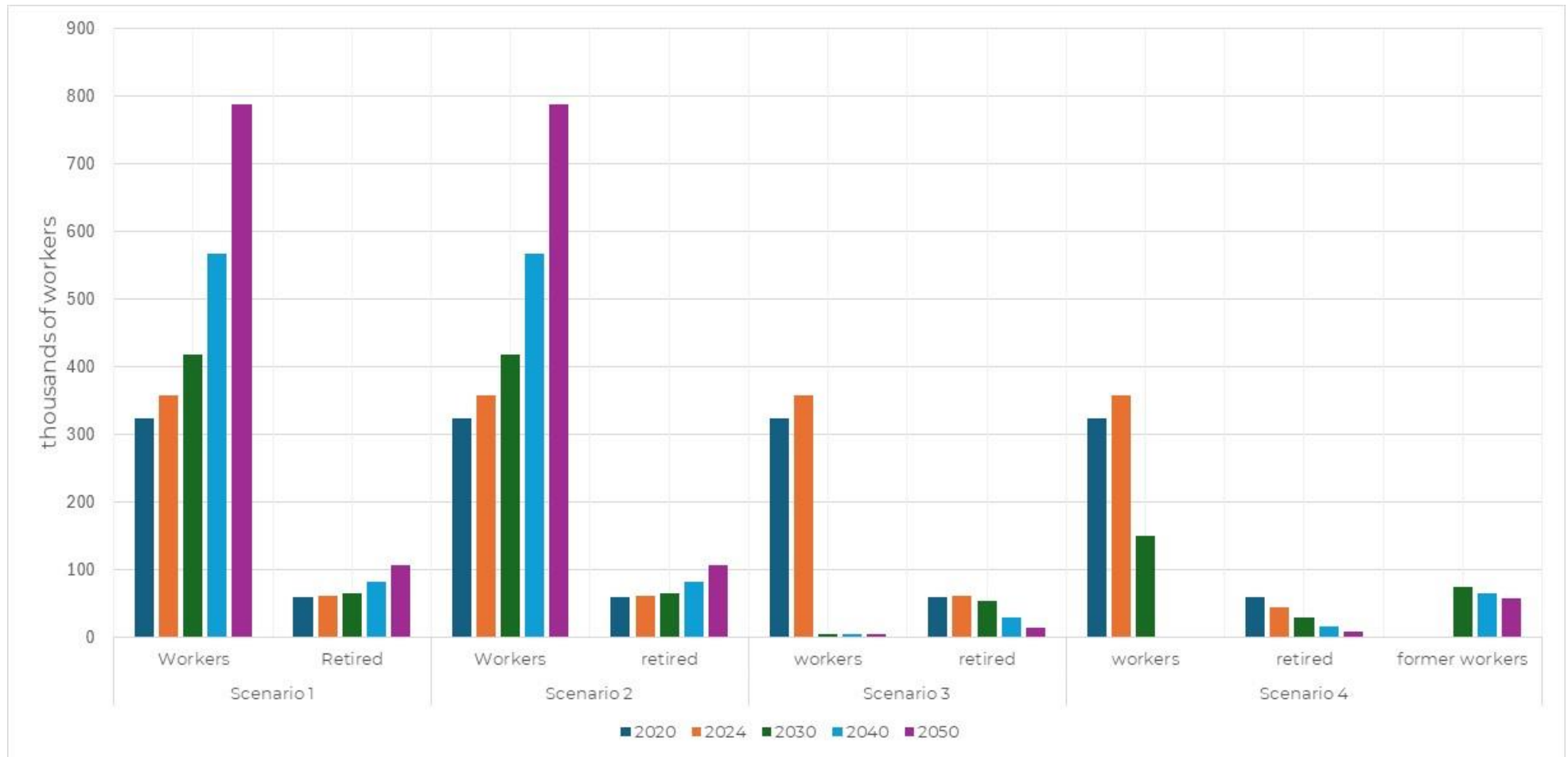
The Figure 3-5 illustrates a similar trend, with the concentrations under scenarios 1 and 2, increasing steadily all the way to 2050. While the cap on drinking water concentrations under scenario 2 does have an effect on blood serum levels, it is heavily offset by increasing concentrations in food, showing a minimal decline overall. Scenarios 3 and 4 illustrate the reduction in exposure leading to declining blood serum concentrations and in the case of scenario 4 elimination.

3.7.3. Occupational cohort (size and mixture)

Figure 3-6 provides the results for the four scenarios side by side in terms of the number of current, retired, and former workers (scenario 4 only). For scenarios 1 (business-as-usual emissions without further policy intervention), 2 (DWD thresholds) and 3 (EQS thresholds), the predicted sharp increase in emissions between 2020 and 2050 also reflects increasing production and use of PFAS, and therefore a demand for an increasingly large workforce in facilities making or using PFAS. The figure below illustrates that the workforce of 358,000 in the baseline year increases to 439,000 by 2050. The number of retired workers also grows as the general size of the workforce increases.

Scenario 4 shows a steady decline in the workforce in facilities making or using PFAS, on the basis that manufacturing and industrial use cease by 2030, but possible professional and consumer use of existing stockpiles continues until end of life. This scenario also includes calculations for former workers that were involved in the use and exposure of PFAS but have not yet retired.

Figure 3-6 Overview of the population of workers in facilities making or using PFAS under scenarios 1 – 4



4. Sensitivity analysis

4.1. Introduction

The development of the methodology puts in place a sound approach to draw together recent datasets and an adaptation of the general overall approach utilised by Goldenman et al. (2019). As the development of this approach required a combination of published data and expert judgement, and because the results include projections out to 2050 for hypothetical scenarios, it is important to recognise that the results cannot be taken as exact numbers. Therefore, an assessment of the confidence of the results is key to determining how reliable the data is for next steps under Task 4.

As part of the method development phase, due consideration was given to the aspects of the approach which could most influence the outputs. These areas have been targeted for further assessment as part of the sensitivity analysis.

This sensitivity analysis spans the following aspects:

- The emission projection estimates from the universal PFAS restriction dossier and the restriction dossier on the use of PFAS in firefighting foams, assessing sensitivity for low and high emissions estimates when available.
- The data from the FPP, in particular the effects linked to inclusion of presumptive sites in the calculations. Therefore, a sensitivity analysis is provided to use only known production and use sites, based on the same radii (31 km²) per site.
- The data on PFAS concentration in water is available not only for average values but also for min and max values, and those are also tested to see their impacts on the results (cf steps 4 and 5 of Appendix A to Annex C1).
- The data on PFAS concentrations in blood serum is available not only for the mid-values used in the main calculations but also for minimum and max values, and those are also tested to see their impacts on the results.
- The exposure under Scenario 3 is based on the mixture of surface water and ground water used to service drinking water. This assumes 65% ground and 35% surface, other sources suggest closer to 50% each. This latter set of values are tested to see the effect on blood serum concentrations.
- Scenario 4: It was assumed that consumer products already in circulation would continue to be used until the end of their service life, which has been determined based on available data. The service life could be varied (increased/decreased) to determine how significantly it affects phase-out and reduction of environmental concentrations.

4.2. Approach

The methodology detailed in Section 2 was used as the basis to create an architecture in MS Excel to carry out the calculations, including a summary sheet which has been used as the basis for the tables in Section 3. This workbook has been through a rigorous technical review and checks for errors before finalisation. This workbook was then used as the basis for the template for the sensitivity analysis.

Copies of the completed workbook were made for each sensitivity test. The relevant input values in each cloned version of the main MS Excel workbook were then altered to perform the sensitivity test. For example, the sheet holding the emission and emission projection estimates from the universal PFAS restriction holds the middle or derived mid-value estimate from the restriction dossier. In the test for the 'low emissions' workbook, the values were replaced by the low emission estimates from the universal PFAS restriction dossier.

The summaries from each sensitivity workbook were pasted into a sheet called 'sensitivity' in the main workbook and used to complete comparison analysis between the main outputs reported in Section 3, and review of the calculations to determine why specific outputs change.

This analysis is reported below.

4.3. Outcome

4.3.1. Sensitivity on the level of the emission projections

The universal PFAS restriction dossier provides emission projections to 2050 for the central set of estimates under Annex E of the restriction dossier. In Annex B, it further provides estimates in the baseline year as low, medium and high in the majority of sectors. For some sectors (e.g., manufacture of PFAS), only a high and low estimate is provided for the year 2020, and we have used the mid-value for the central estimate. To complete the sensitivity analysis, the values for the low and high estimates were used to create a version of the study outputs against a 'low emission' and 'high emission' version. These revised emission estimates were then used to drive all other outputs. All three datasets (low, medium and high emission estimates) see an increase of around 2.5 times between the baseline year (2024) and 2050, with an increase slightly higher for the low emission estimates (at $\times 2.75^{35}$, from 5,400tonnes per annum (tpa) in 2020 to 14,850tpa in 2050). The emissions for the scenarios 1 and 2 go from 11,600tpa in 2020 to 29,400tpa in 2050, and the high release estimates go from 15,300tpa in 2020 to 38,000tpa in 2050.

As indicated within the infobox in section 2.2.4, the ratios are developed based on known data for estimated emissions, environmental concentrations and blood serum concentrations for a previous year, in this case 2024. The ratios developed help explain the relationship between these three points and how altering one will affect the other two. However, developing that initial understanding is key. In this case if we vary the emission estimates for 2024 to the low, medium, or high emission sets (from the universal PFAS restriction) but retain the same environmental and blood serum concentrations, the ratio itself will adjust to take into account the difference, while maintaining the same outcomes for the environmental concentrations. For the future years with the high and low emission estimates the adjusted ratios will take into account baseline year environmental and blood

³⁵ Note that, within the REACH restriction dossier, for some sectors the same emission estimate is used for the low, medium, and high emission estimates. These have been used verbatim in the sensitivity analysis, but where the same values are used for low, medium, and high (e.g., consumer mixtures, ski-wax, petroleum and mining, and fire-fighting foams), it means the contribution of these 'fixed' estimates to the overall emission becomes more important if they remain the same but other sectors have their emissions reduced. That affects the proportionate change year on year, particularly if the sectors with the same tonnage for low/medium/high grow more strongly in future years, which is why the emissions increase by $\times 2.75$ from 2020-2050; while medium and high estimates increase by $\times 2.5$.

serum concentrations and adjust in turn, meaning the same or very similar outputs to the medium emission estimates.

Where this is the case, the emission trend then becomes the most important factor as a different emission trend will supersede any adjustment to the ratio and provide a new outcome (which mathematically is correct – i.e., if the trend changes so should the outputs).

This means that where the low emission estimate set grows more aggressively (i.e., it increases by x2.75 between 2020 and 2050, compared to x2.5 for the medium and high emission estimates), it will result in higher environmental concentrations, which in turn will then mean higher blood serum concentrations.

Note that the number of sites and scale of contamination (i.e., size of populations within different cohorts) also makes use of the ratio between known emissions in the baseline year and number of sites in the same year. This means the same adjusting ratio / trend effect is also true for this aspect of the calculations.

Table 4-1 provides the main results of **scenario 1** with the values presented as a range based on the high and low emission estimates from the universal PFAS restriction dossier, with the value used in the core analysis provided outside of the brackets.

The biggest divergence between the results using the low, middle, and high emission projection values comes at the end of the time-series, with the values for all metrics (drinking water, surface water, etc.) in 2040 and 2050, reflecting the sharper increase in projected emissions under the low, medium, and high emission estimates (particularly for the low emission set).

In terms of geographic coverage for contaminated sites, this means that, by 2050, the low, medium and high emission sets all agreed that the scale of the contamination increases from 8% of the EEA (by area) to 10.5% of the EEA by 2050. The methodology section comments that for the increasing emissions we assume (based on Eurostat data) that 75% of the additional emissions are from the same sites, and 25% are new sites. This smaller fraction which contributes to new sites is the main driver for expansion of the contamination. Where it makes up a smaller proportion of the additional emissions, it means variation in emissions and emission trend between the low, medium, and high emission sets is less pronounced. This likely explains the strong agreement in all three versions of the model.

The change in emissions also has consequences for the environmental concentrations (drinking water, surface water, groundwater, food) and subsequently blood serum concentrations. In the case of water (drinking, surface, and ground), there is little variation between the core analysis and sensitivity analysis in the estimates up to 2030, with the range in concentration estimates varying by +/- 5ng/l at most. For the years 2040 and 2050, the range increases, with the biggest range found for the “elevated high” sub-cohort estimates. For drinking water, the estimated concentration ranges by 24 ng/l between the lowest and highest estimates, for surface water by 250 ng/l, and groundwater by 80 ng/l. The concentrations in drinking water, surface water and for groundwater by +/- 10%, depending on which set of estimates are used, with closer alignment for the middle and high emission sets (i.e., a proportionate increase of x2.5 vs an increase of x2.75 for the low emission estimate set).

The same is also true of the blood serum concentrations, and the scale of contamination (radius).

Therefore, within this study, the main effect of varying the emissions is two-fold: Firstly, it has an impact on the projected number of polluting sites, with consequences on the extent of the contaminated areas, and therefore the size of the elevated cohorts and geographic scale of contamination. Secondly, it impacts the environmental concentrations and, by proxy, blood serum concentrations.

This is, however, primarily driven by differences in the emission trends for the low, medium, and high emission estimates, rather than the quantity of emission. It reflects the bigger emission growth (x2.75) for the low emission set has a different outcome compared to medium and high (x2.5). In some respects, this analysis provides a positive note. The emission estimates and projections are estimates. The authors of the universal PFAS restriction highlighted the challenge and complexity in compiling such emission estimates, which are given as a range from low to high. The environmental concentrations and blood serum concentrations are based on analytical results. Again, the issue is complex, but it means provided the environmental concentration and blood serum data is robust for the baseline year (2024), variation in the possible emission estimates still largely result in the same outcomes, provided there's good confidence in the emission trend.

Table 4-1 Emission projection sensitivities - Overview of range (low-high estimates) for scenario 1

	2020	2024	range	2030	range	2040	range	2050	range
Background cohort									
Population (total millions)	400.0	393.1	(393-393)	383.6	(383.9-383.9)	367.5	(367.5-367.9)	349.6	(347.3 - 349.9)
Blood serum concentration – adults – (µg/l)	14.0	15.6	(15.6-15.6)	18.7	(18.2-18.7)	25.4	(24.9-25.4)	35.4	(35.1-38.6)
Blood serum concentration – children – (µg/l)	9.3	10.4	(10.4-10.4)	12.4	(12.1-12.4)	16.8	(16.5-16.8)	23.5	(23.3-25.6)
Elevated-high sub-cohort									
Population (Total) millions	12.2	12.4	(12.4-12.4)	12.6	(12.6-12.6)	13.2	(13.1-13.2)	14.2	(14.2-14.7)
Blood serum concentration – adults – (µg/l)	50.8	56.4	(56.4-56.4)	67.7	(65.7-67.7)	91.7	(90.0-91.7)	128.1	(127.1-139.6)
Blood serum concentration – children – (µg/l)	33.7	37.5	(37.5-37.5)	44.9	(43.7-44.9)	60.9	(59.8-60.9)	85.1	(84.4-92.7)
Elevated-low sub-cohort									
Population (Total) millions	48.7	49.4	(49.4-49.4)	50.4	(50.2-50.4)	52.7	(52.4-52.7)	56.7	(56.5-58.6)
Blood serum concentration – adults – (µg/l)	32.4	36.0	(36.0-36.0)	43.2	(42.0-43.2)	58.5	(57.5-58.5)	81.8	(81.1-89.1)
Blood serum concentration – children – (µg/l)	21.5	23.9	(23.9-23.9)	28.7	(27.9-28.7)	38.9	(38.2-38.9)	54.3	(53.9-59.2)
Occupational cohort									
Population (Total) millions	0.41	0.42	(0.42-0.42)	0.44	(0.44-0.44)	0.47	(0.47-0.47)	0.51	(0.51-0.52)
Current workers	0.35	0.36	(0.36-0.36)	0.37	(0.37-0.37)	0.40	(0.39-0.40)	0.44	(0.44-0.45)

Retired workers	0.06	0.06	(0.06-0.06)	0.07	(0.07-0.07)	0.07	(0.07-0.08)	0.07	(0.07-0.07)
Blood serum concentration – current and retired workers (µg/l)	50.8	56.4	(56.4-56.4)	67.7	(65.7-67.7)	91.7	(90.0-91.7)	128.1	(127.1-139.6)

	2020	2024	range	2030	range	2040	range	2050	range
Number of PFAS manufacturing sites	17	17	(17-17)	18	(18-18)	19	(19-19)	21	(21-21)
Number of PFAS using sites (based on “known” sites under FPP)	185	190	(190-190)	197	(196-197)	212	(211-212)	235	(235-241)
Number of PFAS possible PFAS using sites (in thousands, based on “presumptive” sites in FPP)	10.9	11.2	(11.2-11.2)	11.7	(11.7-11.7)	12.6	(12.5-12.6)	13.9	(13.9-14.4)
Elevated cohort area (‘000’s km²)	346	356	(356-356)	369	(369-369)	397	(395-397)	440	(438-454)
Percentage of the Total area of EEA	8.2%	8.4%	(8.4-8.4%)	8.7%	(8.7-8.7%)	9.4%	(9.4-9.4%)	10.4%	(10.4-10.8%)

	2020	2024	range	2030	range	2040	range	2050	range
Drinking water (ng/l)									
Concentration for the Background cohort	20	22	(22-22)	26	(26-26)	36	(35-36)	50	(50-55)
Concentration for the Elevated-low Sub-cohort	55	61	(61-61)	73	(71-73)	99	(97-99)	139	(137-152)
Elevated-high Sub-cohort	90	100	(100-100)	120	(117-120)	163	(160-163)	227	(225-249)
Surface Water (ng/l)									
Background cohort	181	201	(201-201)	241	(235-241)	326	(320-327)	456	(452-500)
Elevated-low Sub-cohort	543	603	(663-670)	724	(777-804)	981	(1,065-1,090)	1,370	(1,502-1,650)
Elevated-high Sub-cohort	906	1,006	(1,006-1,006)	1,207	(1,179-1,207)	1,636	(1,606-1,636)	2,285	(2,266-2,503)
Groundwater (ng/l)									
Background cohort	89	99	(99-99)	119	(116-119)	161	(158-161)	225	(223-246)
Elevated-low Sub-cohort	268	298	(298-298)	357	(349-357)	484	(475-484)	676	(670-740)
Elevated-high Sub-cohort	447	496	(496-496)	595	(581-595)	807	(792-807)	1,127	(1,118-1,234)
Drinking water µg / per person / per annum (Background cohort)									
Adult annual intake	14.5	16.1	(16.1-16.1)	19.3	(18.8-19.3)	26.1	(25.6-26.1)	36.5	(31.9-36.5)
Children annual intake	11.6	12.8	(12.8-12.8)	15.4	(15.0-15.4)	20.9	(20.5-20.9)	29.2	(29.2-31.9)
Drinking water µg / per person / per annum (Elevated-low cohort)									
Adult annual intake	40.1	44.5	(44.5-44.5)	53.5	(52.2-53.5)	72.4	(71.0-72.4)	101.2	(98.2-109.0)
Children annual intake	32.1	35.6	(35.6-35.6)	42.7	(41.7-42.7)	57.8	(56.8-57.9)	80.9	(80.4-88.6)
Drinking water µg / per person / per annum (Elevated-high cohort)									
Adult annual intake	65.7	73.0	(73.0-73.0)	87.6	(85.5-87.6)	118.6	(116.5-118.8)	165.8	(164.4-181.6)
Children annual intake	52.6	58.4	(58.4-58.4)	70.0	(68.4-70.0)	94.6	(93.2-95.0)	132.6	(131.5-145.3)
Food µg / per person / per annum									

Adult annual intake	4,700	5,240	(5,240- 5,240)	6,280	(6,100- 6,280)	8,510	(8,350- 8,510)	11,890	(11,800- 12,960)
Children annual intake	2,700	3,000	(3,000- 3,000)	3,600	(3,500- 3,600)	4,900	(4,800- 4,900)	6,800	(6,800- 7,450)

4.3.2. Sensitivity on the number of sites stemming from the Forever Pollution Project data

The FPP identifies (using their terminology) what are described as manufacturers, known users and presumptive users of PFAS on a country-by-country basis. This data has been used within the current study to help determine the scale of the population and geographic contamination for the wider elevated cohort.

In terms of the analysis there are some potential concerns that the category of 'presumptive users', may be more exploratory, rather than on identified sites. To test the impact on the study outputs the calculations within the sensitivity analysis have been based only on the known manufacturers and users. To keep consistency with the main model, the radius of each site is retained at 31 km².

This change will most significantly affect the number of contaminated sites, and therefore the geographic scale of the contamination. That consequently will also affect the populations living in those areas and therefore the size of the cohorts for "background", and the two elevated cohorts (high and low), as well as the number of workers.

Table 4-2 and Table 4-3 provides the results of the sensitivity test in terms of how altering the number of sites affects the population of the different cohorts, this is presented as both changes in percentage terms (Table 4-2) and as total population (Table 4-2).

The results demonstrate that by using only known producers and users the scale of the contamination is significantly smaller than when presumptive sites are also included. The "background" cohort in the main study varies between 83 and 87% of the EEA (spanning around 350 to 400 million people – depending on which time segment is used). Utilising only the known sites increases the size of the "background" cohort to between 96 – 97% of the total EEA population (405 – 447 million people – again depending on time segment). The worker cohort is also significantly altered; the main study estimates around 400,000 workers (including both current and retired staff), while if only known sites are used this falls to 16,000 workers.

Table 4-2 and 4-3 present the elevated cohort as a single value for both the high and low sub-cohorts. In the main study, it is estimated around 12 million people living in the elevated-high (most contaminated) cohort in 2024. The amended approach reduces this number to 2.7 million. Compared to other references, particularly Goldenman, 2019, this would be a significant underestimate, with the Goldenman, 2019, calculations broadly agreeing with the estimates in the main study.

The primary conclusion from this sensitivity analysis is that using only known sites likely underestimates the scale of the issue by wide distance. However, equally including the presumptive sites also likely means including false positives, and an overestimate for the scale of the issue. One caveat in this regard is that the sites identified by the FPP project are dominated by sites in North-west and central Europe. The countries further east and south-east have far fewer known/presumptive sites. It is unclear whether this is a genuine artefact or whether the available data is weaker in these areas, meaning that there is to an extent underestimations in the FPP data at EEA scale, even if there are overestimates for the number of sites in specific named countries.

Table 4-2 FPP sensitivities – Scenario 1 - proportion of population in different cohorts (percentage of total population) – Elevated cohort includes both elevated-high and elevated-low

Case	Cohort	2020	2024	2030	2040	2050
Main	Background	86.7%	86.3%	85.8%	84.7%	83.0%
Main	Elevated	13.2%	13.6%	14.1%	15.2%	16.8%
Main	Workers	0.1%	0.1%	0.1%	0.1%	0.2%
Amended	Background	97.1%	97.0%	96.9%	96.7%	96.3%
Amended	Elevated	2.9%	3.0%	3.1%	3.3%	3.7%
Amended	Workers	<0.01%	<0.01%	<0.01%	<0.01%	<0.01%

Table 4-3 FPP sensitivities – Scenario 1 - proportion of population in different cohorts (population – in millions) – Elevated cohort includes both elevated-high and elevated-low

Case	Cohort	2020	2024	2030	2040	2050
Main	Background	399.4	393.2	383.6	367.5	349.6
Main	Elevated	60.9	61.7	63.1	65.9	70.9
Main	Workers	0.4	0.4	0.4	0.5	0.5
Amended	Background	447.0	441.3	432.9	419.0	405.0
Amended	Elevated	13.3	13.5	13.8	14.4	15.5
Amended	Workers	0.02	0.02	0.02	0.02	0.02

4.3.3. Varying the drinking water mixture (ground/surface water contribution)

Drinking water is sourced from a combination of groundwater and drinking water, with different PFAS concentrations in those environmental compartments. The study identified two key references, one from the European Environment Agency (2022) which quotes 65% from groundwater and 35% from surface water. A second reference from EurEau (2021) quotes a value of 50% from groundwater and 50% from surface water.

The EEA (2022) value has been used within the main study to help determine the impacts of the EQSD on drinking water supplies, with the EurEau (2021) value used to test the sensitivity. For the sake of brevity, Table 4-4 provides the impacts for one cohort ("background") within scenario 3. The other cohorts present a similar result. Table 4-4 illustrates that by altering the mixture of ground and surface water used to service drinking water, the drinking water concentrations after EQS is applied are marginally different. The reason for this change relates to the two ratios that have been developed. The environmental concentrations in surface water and groundwater are different (for all cohorts). For the baseline year this means that the same emission compared to concentration in surface water and groundwater produces different ratios, and likewise the concentration between surface water and drinking water; and groundwater and drinking water also produce different ratios, despite the drinking water concentration in the baseline year remaining unchanged. In future years if the concentration in surface water and groundwater is altered to match the EQS, those differing ratios will result in different drinking water concentrations. Where surface water concentrations are higher than groundwater. The reduction in concentration to 4.4 ng/l (to meet EQS) sees a bigger change in the surface water concentration compared to groundwater, and therefore lower drinking water concentrations based on the ratio. If the mixture is altered from 65:35% ground : surface to 50:50% ground : surface, that lower surface water concentration (than groundwater) has a bigger impact on the drinking water concentration in the outputs, hence why the values in brackets are lower than the main study.

In practical terms this is likely an artefact of how the ratios work than a real-world material difference. However, the resulting annual intake of PFAS via drinking water is only amended slightly (10% difference, equivalent to 60ng per annum per person for adults, and 40ng per annum per person for children).

Table 4-4 Results of amending the drinking water source – based on scenario 3 for the background cohort. Numbers in brackets are the amended ground/surface mixture used to service drinking water.

	2020	2024	2024	2030	2030	2040	2040	2050	2050
Drinking water µg / per person / per annum (Background cohort)									
Adult annual intake	14.4	16.1	(16.1)	0.59	(0.53)	0.59	(0.53)	0.59	(0.53)
Children annual intake	11.6	12.8	(12.8)	0.47	(0.43)	0.47	(0.43)	0.47	(0.43)

4.3.4. Scenario 4 – Sensitivity analysis on the length of the service life of consumer goods remaining in use

For scenario 4 the study assumes that production and uses of PFAS cease in the EEA. However, for in-use treated articles or in-use stocks within equipment (e.g., air-con systems), use is assumed to continue for some time as no market recall can be envisaged. The calculations include service life estimates for sectors where relevant, and where emissions during service life could still impact the environment or human health. Given the broad scale of each use sector and potential complexity for individual articles within sub-sectors or specific uses, there is a need to consider the effects of using a single broad service life for all uses.

To test this scenario the service life of the key sectors has been varied by 50% in either direction (i.e., 50% shorter or longer) based on expert judgement as per the details in Table 4-5.

Table 4-6 presents the results of this analysis. As the only metric that was altered is service life, the size of the cohorts and environmental concentrations in the early part of the time-series remains unchanged. The major difference is the point at which emissions reach zero and the impacts for environmental concentrations and blood serum. Under the reduced service life version of the calculations, emissions reach zero between 2040 and 2050. In the extended service life set of calculations, the remaining sectors (primarily medical devices) continue until shortly after 2050. This means that the emissions fail to reach zero within the timescale of the study.

Beyond this, the concentrations around 2040 and 2050 differ from the results of the main calculations, but the difference is less marked than some of the other assessments in the sensitivity analysis.

Table 4-5 Identified sectors and service life³⁶.

Sector	Service life (main calculation) in years	Variance
Textiles, upholstery, leather, apparel and carpets (TULAC)	10	5-15
Consumer mixtures	3	1.5-4.5
Medical devices	15	7.5-22.5
Construction products (mixtures)	10	5-15
Lubricants	5	2.5-7.5
Fluorinated gases (air-con)	3	1.5-4.5

Table 4-6 Overview of range for scenario 4 – varied service life.*

	2020	2024	2030	2040	2050
Background cohort					
Population (Total) (millions)	399	393	385	374	363
Blood serum concentration - adults (µg/l)	14.0	15.6	14.3	3.0	0.0
Blood serum concentration - Children (≤14 yrs) (µg/l)	9.3	10.4	9.5	2.0	0.0
<i>Blood serum concentration - adults (µg/l)</i>	<i>14.0</i>	<i>15.6</i>	<i>14.3</i>	<i>1.3-4.2</i>	<i>0.0-0.1</i>
<i>Blood serum concentration - Children (≤14 yrs) (µg/l)</i>	<i>9.3</i>	<i>10.4</i>	<i>9.5</i>	<i>0.9-2.8</i>	<i>0.0-0.0</i>
Elevated-high Sub-cohort					
Population (Total) (millions)	12.2	12.4	12.3	11.9	11.6
Blood serum concentration - adults (µg/l)	50.8	56.4	51.6	10.7	0.0
Blood serum concentration - Children (≤14 yrs) (µg/l)	33.7	37.5	34.2	7.1	0.0
<i>Blood serum concentration - adults (µg/l)</i>	<i>50.8</i>	<i>56.4</i>	<i>51.6</i>	<i>4.8-15.1</i>	<i>0.0-0.2</i>
<i>Blood serum concentration - Children (≤14 yrs) (µg/l)</i>	<i>33.7</i>	<i>37.5</i>	<i>34.2</i>	<i>3.2-10</i>	<i>0.0-0.2</i>
Elevated-low Sub-cohort					
Population (Total) (millions)	48.7	49.4	49.2	47.7	46.3
Blood serum concentration - adults (µg/l)	32.4	36.0	32.9	6.8	0.0
Blood serum concentration - Children (≤14 yrs) (µg/l)	21.5	23.9	21.9	4.5	0.0
<i>Blood serum concentration - adults (µg/l)</i>	<i>32.4</i>	<i>36.0</i>	<i>32.9</i>	<i>3.1-9.6</i>	<i>0.0-0.1</i>
<i>Blood serum concentration - Children (≤14 yrs) (µg/l)</i>	<i>21.5</i>	<i>23.9</i>	<i>21.9</i>	<i>2.0-6.4</i>	<i>0.0-0.1</i>

*results of sensitivity test in blue italics.

³⁶ Expert judgement has been used to select which sectors should continue service life (and emissions). This selection has been based on two key principles. Firstly, if the sector relates to treated articles, where significant numbers of articles (potentially hundreds of thousands) are in use, particularly within consumer settings. A product recall would be very costly and logistically challenging. Secondly, for applications where immediate removal of mixtures or treated articles are within sectors that would have a significant societal impact it is assumed they would be allowed to continue. For example, 'lubricants' within the table refers to uses in seal articles for e.g., aerospace, rail transport, infrastructure etc.

4.3.5. Environmental concentrations set to minimum and maximum

The calculations in the main study make use of monitored data (with some further extrapolation) to calculate the environmental concentrations within different compartments (surface water, groundwater, etc) and for different cohorts (“background”, elevated, etc). The values selected for use in the main study use mid-values from the range of concentrations witnessed. To test this sensitivity the calculations have been run again using both the minimum environmental concentrations and maximum concentrations from reported data.

Table 4-7 provides the results of these calculations with the minimum and maximum environmental concentrations presented in blue font and brackets. Note that as with the high and low emission sensitivity test the ratio between emissions, environmental concentrations and blood serum concentrations in the baseline year define the relationship between these three points and the effects for all future years. As with the emission sensitivity test, if the environmental concentrations are altered (as a minimum and maximum), but the estimated emissions and blood serum concentrations in the baseline year remain the same, the ratio itself adjusts to compensate for the changing environmental concentrations. This means that because the emissions and emission trend remain unchanged, the consequence for blood serum concentrations means that the same results are achieved for each time segment and cohort irrespective of whether the minimum, medium, or maximum environmental concentration is used. This is a mathematical artefact of how the ratios work.

Table 4-7 demonstrates the potentially wide range in concentrations witnessed from monitoring studies in the EEA. This wide range is most strongly illustrated in the elevated-high cohort where the effects of variation environmental concentrations mean that by the year 2050, the possible drinking water concentration is between 170 and 1,100 ng/l for the sum of PFAS, for surface water and groundwater the range is even greater, with concentrations between 500 and 11,400 ng/l for surface water and 333 and 5,700 ng/l for groundwater.

In terms of impacts for the study, the scenario 2 on implementation of drinking water thresholds not exceeding 100 ng/l would witness the biggest possible impacts. In the “background” cohort irrespective of whether minimum, medium or maximum concentration is used, the values never reach the 100 ng/l during the course of the study timeframe. For elevated-low and elevated-high, there are noticeable differences, for elevated-low using the minimum concentrations means it too never reaches 100 ng/l before 2050, while in the main study it does. For elevated-high using the minimum concentration means it does not reach 100 ng/l until later in the time-series (compared to the main study). Using the maximum concentrations means that for both cohorts the 100 ng/l is exceeded immediately even in 2020 by quite some distance.

The data in Table 4-7 primarily reflects the broad ranges in concentrations identified, including outliers at the minimum and maximum end of the range. It also reflects the highly localised conditions and settings that affect those concentrations. This is challenging when addressed at an EEA scale as part of this kind of overview.

Table 4-7 Overview of impacts for using minimum and maximum environmental concentrations based on scenario 1*. Values in blue brackets indicated the minimum and maximum values based on amended environmental concentrations for the baseline year (2024)

	2020	2020	2024	2024	2030	2030	2040	2040	2050	2050
Background cohort										
Surface water	181	(16-270)	201	(18-300)	241	(22-360)	326	(29-488)	456	(41-681)
Groundwater	89	(11-135)	99	(12-150)	119	(14-180)	161	(20-244)	225	(27-341)
Drinking water	20	(9-30)	22	(10-33)	26	(12-40)	36	(16-54)	50	(23-75)
Elevated-high cohort										
Surface water	906	(198-4,500)	1,006	(220-5,000)	1,207	(264-6,000)	1,636	(358-8,100)	2,285	(500-11,400)
Groundwater	447	(132-2,300)	496	(147-2,500)	595	(176-3,000)	807	(238-4,000)	1,127	(333-5,700)
Drinking water	90	(68-450)	100	(75-500)	120	(90-600)	163	(122-810)	227	(170-1,100)
Elevated-low cohort										
Surface water	543	(107-2,400)	603	(119-2,700)	724	(143-3,200)	981	(193-4,300)	1,370	(270-6,000)
Groundwater	268	(71-1,200)	298	(79-1,300)	357	(95-1,600)	484	(129-2,100)	676	(180-3,000)
Drinking water	55	(38-240)	61	(43-270)	73	(51-320)	99	(69-430)	139	(97-600)
Food – all cohorts										
Food (adults)	4,700	(1,500-6,700)	5,200	(1,700-7,500)	6,300	(2,000-8,900)	8,500	(2,700-12,100)	11,900	(3,800-16,900)
Food (children)	2,700	(800-3,900)	3,000	(900-4,400)	3,600	(1,100-5,200)	4,900	(1,500-7,000)	6,800	(2,000-9,900)

*units as follows: surface water, groundwater, drinking water = ng/l; food = annual intake as µg.

4.3.6. Blood serum concentrations set to minimum and maximum

As with environmental concentrations the data gathered and collated for blood serum represents a range of values from the monitored blood serum. The main study makes use of the mid-values of these ranges for the different cohorts with some extrapolation to gap fill missing data. To test the effect of this range, the final sensitivity test in this section uses the minimum and maximum concentrations from the data to assess how the calculations change.

Table 4-8 provides the results of these changes for the study cohorts. Note that for occupational workers where the decision was taken to align the mid-value blood serum concentration with the highest category (elevated-high), the results for this cohort mirror the elevated-high cohort and are excluded from the table for the sake of brevity.

As with environmental concentrations the data in Table 4-8 illustrates the wide range in blood serum concentrations, which is more noticeable for some cohorts than others. In particular the elevated-high cohort illustrates blood serum concentrations spanning hundreds of $\mu\text{g/l}$. for the 2050 year in adults, this range is between 24 and 2,386 $\mu\text{g/l}$ (i.e., more than 1 order of magnitude). Other cohorts, specifically the “background” cohort illustrates a more modest range, albeit still in the 10s of $\mu\text{g/l}$ (2050 for adults ranges between 8.4 and 156 $\mu\text{g/l}$).

Also note that the range for children in the “background” cohort is wider than for adults in the same cohort, with the upper limit of the child blood serum concentrations exceeding the upper limit for adults.

The specific underlying factors that determine blood serum concentration are complex, spanning biological, environmental, and exposure factors, which are likely to be heavily influenced by the specific settings of exposure, geography, and genetic factors.

The point of this sensitivity test is to illustrate how the concentration ranges may impact the results. But note that the very wide range in concentrations reflects the highly variable nature of the situation, with the lowest and highest concentrations more likely to be outliers based on a normalised distribution.

Table 4-8 Overview of impacts for using minimum and maximum blood serum concentrations based on scenario 1*. Values in blue brackets indicated the minimum and maximum values based on amended blood serum concentrations for the baseline year (2024)

	2020	2024	2030	2040	2050
Background cohort					
Population (Total) (millions)	399	393	385	374	363
Blood serum concentration - adults (µg/l)	14.0	15.6	18.7	25.4	35.4
Blood serum concentration - Children (≤14 yrs) (µg/l)	9.3	10.4	12.4	16.8	23.5
Blood serum concentration - adults (µg/l)	(3.3-61.9)	(3.7-68.8)	(4.5-82.5)	(6.0-111.8)	(8.4-156.2)
Blood serum concentration - Children (≤14 yrs) (µg/l)	(0.9-89.6)	(1.0-99.5)	(1.2-119.4)	(1.6-161.8)	(2.3-226.0)
Elevated-high Sub-cohort					
Population (Total) (millions)	12.2	12.4	12.6	13.2	14.2
Blood serum concentration - adults (µg/l)	50.8	56.4	67.7	91.7	128.1
Blood serum concentration - Children (≤14 yrs) (µg/l)	33.7	37.5	44.9	60.9	85.1
Blood serum concentration - adults (µg/l)	(9.5-946.0)	(10.6-1,050.7)	(12.7-1,260.9)	(17.2-1,708.4)	(24.0-2,386.5)
Blood serum concentration - Children (≤14 yrs) (µg/l)	(2.6-1,369.1)	(2.8-1,520.7)	(3.4-1,824.7)	(4.6-2,472.4)	(6.5-3,453.8)
Elevated-low Sub-cohort					
Population (Total) (millions)	48.7	49.4	50.4	52.7	56.7
Blood serum concentration - adults (µg/l)	32.4	36.0	43.2	58.5	81.8
Blood serum concentration - Children (≤14 yrs) (µg/l)	21.5	23.9	28.7	38.9	54.3
Blood serum concentration - adults (µg/l)	(6.4-504.0)	(7.1-559.8)	(8.5-671.7)	(11.6-910.1)	(16.2-1,271.3)
Blood serum concentration - Children (≤14 yrs) (µg/l)	(1.7-729.3)	(1.9-810.1)	(2.3-972.1)	(3.1-1,317.1)	(4.4-1,839.9)

4.3.7. Summary

This sensitivity analysis has aimed to identify the inputs and assumptions of the calculations that are most uncertain or have the highest impact on the results. For each aspect, an analysis has been undertaken to vary the data in a sensible and logical way to determine the scale of the impact upon the results. Table 4-9 provides a summary of this analysis, and pinpoints specifically which aspects are the most sensitive.

The most sensitive aspects are two-fold: firstly, from a monitoring perspective the data for environmental concentrations and blood serum data show wide ranges, reflecting a range of issues (the fact we are covering a mixture of substances where each substance can vary independently, localised emission and exposure settings that vary, biological differences in the cohorts that provided blood serum, and analytical factors in testing). In reality applying

the minimum or maximum concentrations at EEA scale is probably not defensible, given the very wide geographic area and sizeable population (hundreds of millions). The mid-values have been adopted with some expert judgement and statistically assuming a normalised distribution, would see the majority of concentrations cluster in the middle range. This is further corroborated by evidence in specific cases (e.g., drinking water).

Secondly, the specific number and location of sites making and using PFAS has a significant impact for the size of the cohorts. This affects the number of people in the “background” or elevated cohorts, and therefore the rate of exposure. It also affects the geographic scale of contamination. The analysis shows that using only known manufacturers and users will likely significantly underestimate the scale of the issue when compared to the estimates from Goldenman et al. (2019). On the other hand, including the presumptive sites will likely include false positives meaning an overestimate for the proportion within the elevated cohort.

In this case the authors have used the Goldenman, 2019 study as a corroborating piece of evidence to determine that including all of the presumptive sites (even with potential false positives) is likely closer to the true situation than relying on known sites alone.

Table 4-9 Summary of sensitivity

Test	Impact (minor, medium, major)	Notes
Emissions (high/low)	Minor	The analysis illustrates that where ratios are defined in the baseline year, the emission trend is a stronger driver to output results than varying the quantity of emission. All three estimates (low, medium, and high) have similar emission trends between 2020 and 2050, meaning the impact on the results is less significant.
Known PFAS producers and users only	Major	Because the presumptive sites make up a significant proportion of the overall sites in the FPP data. It means that using only known sites, has a very significant impact on the scale of contamination and number of people within each cohort.
Scenario 3 – Amend the proportion of groundwater and surface water used to service drinking water.	Minor	The surface and groundwater compartments have different concentrations. These affect the ratios that are defined in the baseline year. When EQS is applied, these differing ratios mean a bigger decline for surface water. That means the more surface water included in the drinking water mix, the lower the drinking water concentration. In reality however the effect of 65:35% GW:SW or 50:50% GW:SW have limited impact on the outputs.
Scenario 4 – Reduce/extend service life	Medium	Extending or reducing service life (of consumer products that are already in circulation when the stop of PFAS manufacture/use starts) affects the blood serum and environmental concentrations in the latter part of the timeseries 2040-2050 and determines when emissions are eliminated.

		However, the effects are otherwise relatively limited.
Apply the minimum and maximum environmental concentrations.	Major	The monitoring data for environmental concentrations, particularly for elevated-high, shows very wide ranges in the concentrations. Depending on the minimum/maximum the outputs for environmental concentrations can be significantly impacted. However, also note that the ratios developed and applied in Scenario 1 show that provided the other two metrics (emissions and blood serum concentrations) are retained from the main study, the outputs for blood serum generally remain largely unchanged compared to the main study. There are a range of factors that affect environmental concentrations on a localized scale but applying the minimum or maximum at the EEA scale would be less scientifically defensible.
Apply the minimum and maximum blood serum concentrations.	Major	The blood serum concentrations also show a wide range of values, notably the range is broader for children in the “background” cohort than adults in the “background” cohort. Depending on whether minimum/maximum blood serum concentration was selected it would have very significant impacts for the outputs of Task 4. But as with environmental concentrations applying the minimum or maximum concentration value at EEA scale is likely less defensible.

5. Conclusions

The objective of Task 3 was to determine the current and future pollution levels associated with PFAS under four different scenarios, including a business-as-usual scenario (reflecting the emission projections based on the regulatory landscape as of June 2024, with the caveat that DWD thresholds appear under scenario 2), implementation of thresholds for drinking water, implementation of thresholds for EQS in surface water and groundwater, and a scenario where PFAS use and production was stopped. To help carry out this analysis, different approaches have been assessed and tested, with the ultimate conclusion to follow the work of Goldenman et al. (2019) as closely as possible with two major updates. This includes the use of the Forever Pollution Projects dataset of PFAS manufacturers and users in Europe, which was published in 2023 and updated in 2024, and the universal PFAS restriction data (dossier published in 2023), which includes detailed emission estimates and projections.

Following these calculations and development of outputs, Section 3 has provided the results of the analysis for each scenario. Based on this analysis, the following key conclusions can be drawn:

- The universal PFAS restriction dossier (version 2023) provides data³⁷ for a **business-as-usual scenario** where emissions will multiply by 2.5 to 2.75 times between 2020 and 2050. This large increase in emissions not only **means at least a two and a half times increase of environmental concentrations and human blood serum, but also** entails, according to our calculations, **an increase in the area corresponding to the elevated exposure cohort** (i.e. the area exposed to elevated concentrations of PFAS) from 8% of the area of the EEA in 2020 to 10.5% by 2050.
- **For the baseline year (2024), 86% of the EEA population is estimated to be in the “background” exposure cohort**, with 14% in the wider elevated cohort (3% in the elevated-high, and 11% in the elevated-low sub-cohort) and <1% in the occupational cohort. **Depending on the specific scenario, by 2030 between 80 and 99% of the population is in the “background” exposure cohort.** In scenarios 1 and 2, the increase in emissions by two and a half times the baseline year (2020 in the universal REACH restriction dossier) means that by 2050, 17% of the population is in the elevated cohort.
- **Assuming drinking water threshold (100 ng/l) is respected everywhere in the EEA, scenario 2 is estimated to lead to a minor reduction in blood serum concentrations (<2µg/l).** The majority of drinking water supplies are calculated as being well below the 100 ng/l in scenario 1, even by 2050. In the cases where water was predicted to exceed the limit (elevated-high sub-cohort from 2020, and elevated-low sub-cohort by 2040) in scenario 1, limiting the intake of PFAS via drinking water in scenario 2 resulted in only very limited reductions in blood serum

³⁷Data from the 2023 version of the Background Document of the universal restriction proposal is used in this study. Update made in August 2025 could not be incorporated into this study due to time constraints. It is however considered that the overall conclusions are not changed.

concentrations, because of the more significant intake of PFAS via other pathways such as food (along with dust and air, not included in the study).

- The scenarios presented are hypothetical “what if” cases to look at how different policy scenarios might affect environmental and human health (blood serum) concentrations. For scenario 3 and 4, it is assumed that the policy scenario is applied from 2030 onwards. In reality the EQS threshold compliance would be later (between 2039 and 2045), and the ‘full stop’ scenario cannot be expected to start applying in 2030 in reality. The 2030 date was selected to present clearly the effects before and after application of the policy measures in each of those scenarios.
- **The EQS threshold (4.4 ng/l PFOA-equivalent) considered in scenario 3** is very low compared to actual surface water and groundwater concentrations (in the tens to low hundreds of ng/l). Compliance with this threshold in surface water and groundwater **would be equivalent to the effect of a reduction of emissions by 99% compared to the year 2024**. This results in blood serum concentration declines of a similar order (95-99%) by 2050. For the “background” exposure cohort, adult blood serum concentrations decline from 14 µg/l in 2020 to 0.7 µg/l in 2050. For the elevated-high exposure cohort, the biggest declines are seen, falling from 51 µg/l in 2020 to 0.7 µg/l in 2050.
- **Scenario 4 (the stop of PFAS use and production) reflects a significant reduction in emissions from 2030** (64% reduction compared to 2024), with continued decline reaching zero by 2040. **This has strong benefits for human health and potential avoided impacts on the environment**. The results of scenario 4 show that blood serum concentrations fall by 100% by 2050 (i.e., for both “background” and elevated exposure cohorts (high and low), full elimination is achieved by 2050, assuming a full stop on use and emissions from 2030). The declining rate in blood serum concentrations takes between 15 and 20 years, depending on the initial concentration level.
- The **sensitivity analysis** has aimed to identify which aspects of the methodology most significantly alter the results and what that might mean for the main calculations. **The two areas of greatest impact relate to the environmental and blood serum concentrations utilised, along with the number of sites identified** (from the FPP data). For the former category, both the environmental concentrations and blood serum concentrations present wide ranges of what has been monitored. The main calculations utilise mid-values, on the basis that within a normalised distribution the lowest and highest values are unlikely to be reflective of the majority of cases. However, the wide range does reflect the complexity of the subject matter and quantifying estimates at an EEA level. For the second point, using only known producers and users reduces the scale of the cohorts markedly, but it also reflects a likely under estimation of the issue. The use of presumptive sites has a much closer corroboration to other studies, particularly Goldenman et al, 2019, but likely also includes a few false positives, while acknowledging that, on the other hand, some polluted sites might also have not been identified.
- The biggest limitations and uncertainties (see also Table 4-9) which may have a bearing on the Task 3 study results include:

- 1. The number of contaminated sites, which has a direct bearing on the size of the cohort populations. The sensitivity analysis addresses this uncertainty to an extent, illustrating the impact that “presumptive” sites have on the overall results. The study’s main calculations likely reflect a ‘best-estimate’ situation on the basis that false positives may be cancelled out by unidentified sites.
- 2. The wide range in concentrations seen for PFAS in different environmental compartments and biota (including humans). This includes the fact that the analysis has focussed on PFAS as a group, with individual substances having broader/narrower ranges. PFOS has a particularly wide range of values. Effort has been made to focus on the more recent timeframe (last 10 years) to limit changes seen in monitoring results over the longer term (i.e., significant reduction in use and emission of PFOS from the early 2000s). Effort has also been made to utilise large datasets (hundreds of samples) to mitigate the effect of outliers, but this means the results provide a high-level pan-European average situation, and concentrations at the local scale may vary widely.
- 3. Projections to the year 2050 represent a challenge in that the uncertainty within the results increases over time, with the estimates for 2050 being the most uncertain. This would be the case for any study that involves the use of projections, given the complexity of the environment, society, and other factors. The study has made use of data from the REACH universal PFAS restriction proposal to support these aspects on the basis that it is the most comprehensive data available.

6. References

Author	Year	Title
Anderson	2016	Occurrence of select perfluoroalkyl substances at U.S. Air Force aqueous film-forming foam release sites other than fire-training areas: Field-validation of critical fate and transport properties. Chemosphere, 150, 678–685. [PubMed: 26786021]
Aquapublica	2023	Survey data of Aquapublica members for monitoring data on PFAS
Arp et al	2024	The global threat from irreversible accumulation of trifluoroacetic acid (TFA), Environmental science and technology, vol 58
Behringer et al	2021	Persistente Abbauprodukte halogenerter Treib- und Kältemittel in der Umwelt: Art, Umweltkonzentrationen und Verbleib unter besonderer Berücksichtigung neuer halogenerter Ersatzstoffe mit kleinem Treibhauspotenzial, Abschlussbericht, UBA-Texte 36/2021 https://www.umweltbundesamt.de/publikationen/persistente-abbauprodukte-halogenerter-kaelte (Stand: 19.08.2021)
Bergstrom	2014	Transport of per- and polyfluoroalkyl substances in soil and groundwater in Uppsala, Sweden Swedish University of Agricultural Sciences.
Boutonnet et al	1999	environmental risk assessment of trifluoroacetic acid. Published in Human and Ecological Risk Assessment
Braunig	2017	Fate and redistribution of perfluoroalkyl acids through AFFF-impacted groundwater. Science of the Total Environment, 596-597, 360–368.
Brusseau et al	2021	PFAS concentrations in soil: Background levels versus contaminated sites, Science Total Environment
CNRS	2025	Forever Pollution Project central PFAS data hub.
Dekant et al	2023	mammalian toxicity of trifluoroacetate and assessment of human health risks due to environmental exposure', Archives of Toxicology, vol 97, pp 1069-1077.
Derksen et al	2021	PFAS in influent, effluent, and sewage sludge – results of a monitoring campaign at eight WWTPs, report 46E for STOWA
Duan et al	2020	Distribution of novel and legacy per/polyfluoroalkyl substances in serum and its associations with two glycemic biomarkers among Chinese adult men and women with normal blood glucose levels. Environmental International. Vol 134
ECHA	2023	Universal PFAS restriction - Annex XV dossier and accompanying annexes
EFSA	2020	Risk to human health related to the presence of perfluoroalkyl substances in food
EFSA	2022	Food consumption survey and database: https://www.efsa.europa.eu/en/data-report/food-consumption-data

European Commission	2024	Ageing report: Economic and budgetary projections for the EU Member States (2022 - 2070).
Eurostat	2022	Eurostat labour force survey report - https://ec.europa.eu/eurostat/web/microdata/european-union-labour-force-survey
Eurostat	2025	Agricultural land use data. https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Farms_and_farmland_in_the_European_Union_-_statistics
Eurostat	2025	Geographic data from NUTS3 data sets: https://ec.europa.eu/eurostat/web/regions/database
Filipovic	2015	Historical usage of aqueous film forming foam: A case study of the widespread distribution of perfluoroalkyl acids from a military airport to groundwater, lakes, soils and fish. Chemosphere, 129, 39–45. [PubMed: 25262531]
Forever Pollution Project	2023	Forever pollution: explore the map of Europe's PFAS contamination: https://www.lemonde.fr/en/les-decodeurs/article/2023/02/23/forever-pollution-explore-the-map-of-europe-s-pfas-contamination_6016905_8.html
Gluege et al	2020	An overview of the uses of per and polyfluoroalkyl substances, environmental science: processes and impacts issue 12
Goldenman et al	2019	The cost of inaction: A socioeconomic analysis of environmental and health impacts linked to exposure to PFAS. Available at: THE COST OF INACTION
Gottschall et al	2017	Brominated flame retardants and perfluoroalkyl acids in groundwater, tile drainage, soil, and crop grain following a high application of municipal biosolids to a field. Science of the Total Environment, 574, 1345–1359.
Groffen et al	2019	Do concentrations of perfluoroalkylated acids (PFAAs) in isopods reflect concentrations in soil and songbirds? A study using a distance gradient from a fluorochemical plant. Science of the Total Environment, 657, 111–123.
GWA	2017	PFAS 10 Facts - Groundwater Association
HBM4EU	2020	Data compiled on human biomonitoring of PFAS under EU monitoring programs: https://www.hbm4eu.eu/hbm4eu-substances/per-polyfluorinated-compounds/
Holstrom	2014	Nationell screening av perfluorerade föreningar (PFAA) i dricksvatten, Rapport No. 2014-20
Houtz	2013	Persistence of perfluoroalkyl acid precursors in AFFF-impacted groundwater and soil. Environmental Science & Technology, 47(15), 8187–8195.
HWG	2018	Immediate Response Action Plan Status Report 3, Barnstable Municipal Airport Hyannis, Massachusetts; RTN 4-26347, April 2018. (Horsley Witten Group, Inc.)
JRC	2022	Dossier prepared for nomination of PFAS as a priority substance, including support monitoring data as annexed spreadsheets.

JRC	2023	PFAS in European Groundwater: Evidence, risks and measures
Karman et al	2011	Environmental levels and distribution of structural isomers of perfluoroalkyl acids after aqueous fire-fighting foam (AFFF) contamination. Environmental Chemistry, 8(4), 372–380.
Kikiuchi et al	2018	Analysis of per- and polyfluoroalkyl substances (PFASs) in soil from Swedish background sites. Rapport till Naturvårdsverket Överenskommelse NV-2219-17-003 https://pdfs.semanticscholar.org/edf9/bdb40780c32cebfa431cbb9c09eee3575702.pdf
Liu et al	2017	Crop bioaccumulation and human exposure of perfluoroalkyl acids through multi-media transport from a mega fluorochemical industrial park, China. Environment International, 106, 37–47. [PubMed: 28558301]
Martinsen et al	2012	Polyfluorinated compounds at fire training facilities: Assessing Contaminated soil at 43 Norwegian airports. Presented at the Section for Waste Treatment and Contaminated Ground Common Forum Meeting, Bilbao, 23.10.12. https://www.emergingcontaminants.eu/application/files/8214/5217/1295/05_PresentationF_cpds_at_No_airports_Martinsen.pdf
McGuire et al	2014	Evidence of remediation-induced alteration of subsurface poly- and perfluoroalkyl substance distribution at a former firefighter training area. Environmental Science & Technology, 48(12), 6644–6652. [PubMed: 24866261]
MEDEP	2017	Stone Farm, Arundel Sample Collection - Data Report Summary; Report Date: June 15, 2017 https://kkw.org/wp-content/uploads/2018/02/DEP-Phase-2-study.pdf
NEA	2018	Environmental Pollutants in the Terrestrial and Urban Environment 2017, M-1076.
NH DES	2016	Investigation into the presence of Per- and Polyfluoroalkyl Substances (PFASs) in New Hampshire. https://www.des.nh.gov/organization/commissioner/pfoa.htm (New Hampshire Department of Environmental Services)
NORMAN	2023	Monitoring programme of activities for 2020 - 2022 in European Surface Waters
OVAM	2018	Study of the presence of PFAS in groundwater, soil, and sediment near risk activities in Flanders.
PAN	2023	Europe's toxic harvest : unmasking PFAS pesticides authorised in Europe
Rosato et al	2024	Estimation of per- and polyfluoroalkyl substances (PFAS) half-lives in human studies: a systematic review and meta-analysis, vol 242.
RIVM	2020	Sources of PFAS for Dutch surface water, report published by RIVM, Netherlands.

Salvatore et al	2022	Presumptive contamination: A new approach to PFAS contamination based on likely sources. Environmental Science & Technology letters
Scher et al	2018	Occurrence of perfluoroalkyl substances (PFAS) in garden produce at homes with a history of PFAS-contaminated drinking water. Chemosphere, 196, 548–555. [PubMed: 29329087]
Sepulvado et al	2011	Occurrence and fate of perfluorochemicals in soil following the land application of municipal biosolids. Environmental Science & Technology, 45(19), 8106–8112. [PubMed: 21446724]
SFT	2008	Screening of polyfluorinated organic compounds at four fire training facilities in Norway (TA-2444/2008). https://evalueringsportalen.no/evaluating/screening-of-polyfluorinated-organic-compounds-at-four-fire-training-facilities-in-norway/ta2444.pdf/@@inline
Skaar et al	2019	Elucidation of contamination sources for poly- and perfluoroalkyl substances (PFASs) on Svalbard (Norwegian Arctic). Environmental Science and Pollution Research, 26(8), 7356–7363. [PubMed: 29754295]
Styrnar et al	2012	Pilot scale application of a method for the analysis of perfluorinated compounds in surface soils. Chemosphere, 86(3), 252–257. [PubMed: 22130124]
Tauw	2017	Updated soil survey of Schiphol Trade Park Lot B in Hoofddorp. Report prepared for the SADC authority in Netherlands. Actualiserend bodemonderzoek Schiphol Trade Park Kavel B te Hoofddorp – report translated from Dutch.
UBA	2021	Reducing the input of chemicals into waters: trifluoroacetate (TFA) as a persistent and mobile substance with many sources.
UBA	2023	Literature review and assessment of available toxicological data for PFAS, report 129/2023
Wallington et al	2016	Atmospheric chemistry of CF ₃ Cf=CH ₂ : products and mechanisms of Cl atom and OH radical initiated oxidation. Environmental science and technology vol 50
Washington et al	2010	Concentrations, distribution, and persistence of perfluoroalkylates in sludge-applied soils near Decatur, Alabama, USA. Environmental Science & Technology, 44(22), 8390–8396. [PubMed: 20949951]
Wilhelm et al	2008	Assessment and management of the first German case of a contamination with perfluorinated compounds (PFC) in the Region Sauerland, North Rhine-Westphalia. Journal of Toxicology and Environmental Health, Part A, 71(11-12), 725–733. [PubMed: 18569570]

World Bank	2025	World population data and demographics: https://data.worldbank.org/indicator/SP.POP.TOTL
Xiao et al	2015	Perfluorooctane sulfonate (PFOS) and perfluorooctanoate (PFOA) in soils and groundwater of a U.S. metropolitan area: Migration and implications for human exposure. Water Research, 72, 64–74. [PubMed: 25455741]
Xie et al	2019	Distribution characteristics of trifluoroacetic acid in the environments surrounding fluorochemical production plants in Jinan, China, Environmental Science and Pollution Research, vol 27
Zheng et al	2023	Elevated levels of ultrashort and short-chain perfluoroalkyl acids in US homes and people. Environmental Science and Technology vol 57
Zhu et al	2019	Distribution and partitioning of perfluoroalkyl carboxylic acids in surface soil, plants, and earthworms at a contaminated site. Science of the Total Environment, 647, 954–961.

Appendices to Annex C1

A. Step-by-step approach used in this study

Table A-1 Step-by-step methodology

No.	Description	Data source	Sensitivity
current state			
1	Split population into three cohorts (occupational, elevated, background).	Follows the same approach as Goldenman et al. (2019).	N/A
2	Populate the 3 population cohorts (occupational, elevated, and background cohorts). <i>Occupational cohort:</i> Use approach from Goldenman et al. (2019) (number of workers per type of site) updated with the number of sites identified by FPP. This includes 17 PFAS production facilities, 378 known hot spots, and 11,291 presumptive sites based on use of PFAS. <i>Elevated cohort:</i> Goldenman et al. (2019) used Swedish data to determine that 3% of Sweden by population was in the elevated cohort and applied this "3%" as a flat rate to all countries. We use the number of contaminated sites in Sweden and derive a radius per site based on 3% of population and national average population density. Then, for the other countries, this calculated radius (31km²) is multiplied by the number of hotspots, which defines the area of each country that is in the elevated cohort <i>Background cohort</i> – everyone not in the elevated cohort.	Goldenman et al. (2019) and Forever Pollution Project (FPP).	As a sensitivity analysis we will derive the 'elevated' area in three other ways: 1. Exclude the presumptive sites from the calculations. 2. Apply the average population of the EEA in the elevated cohort (15%) to every country 3. Apply the average population of north-western Europe (France, Germany, Netherlands, Belgium, Luxembourg, and Denmark) in the elevated cohort (22.5%) to every country.

3	FPP (2023) shows that 2,300 hotspots with concentrations above 100 ng/l were identified. Apply these sites proportionately to the number of contaminated sites per country and the 31km ² radius to determine which ones are 'hotspots' and used to define the "elevated-high" sub-cohort. The remainder of elevated cohort is then deemed "elevated-low".	Forever Pollution Project (2023)	
4	Collect PFAS concentrations in: - surface water - ground water - drinking water - food - blood serum - soil	Surface water, drinking water: Forever Pollution Project (pan-European – data capped from 2014-2024 by the authors (i.e., 10 years), Aqua Publica survey(2021), JRC MEC data (spans all MS states and covers data from 2014 onwards), Task 1 literature review, SR12 data Soil: Literature review from Task 1. Food: Literature review from Task 1, EFSA (2020) risk assessment. Blood serum: NHANES, Goldenman et al. (2019).	where monitoring results provided data as a range, with a minimum and maximum, we will capture this data to test sensitivity, as detailed in step 5 (below).
5	Define exposure levels in different cohorts based on the following data sources: <u>Background cohort</u> Surface water – see Appendix C to Annex C1 Drinking water – see Appendix C to Annex C1	-Task 1 literature review results. -Brusseau et al. (2021) review paper. -Forever Pollution Project data. -JRC MEC data	The sensitivity for this step relates to the same issues as step 4 (above). To test the sensitivity of the monitoring data we will use the minimum and maximum concentrations from the monitoring data in step 4.

Food – EFSA 2020 PFAS risk assessment. Soil – Brusseau averaged data for background concentrations. See Appendix C to Annex C1. Blood Serum – NHANES data from Task 1 report. <u>Elevated cohort</u> Surface water – Forever Pollution Project monitoring at known & presumptive sites, literature review from Task 1 report. Drinking water – Forever Pollution Project for areas close to hotspots, literature review from Task 1 report. Food – No estimate. Assumes a standard background concentration for all cohorts. Soil – Brusseau et al. (2021) averaged data for elevated zones. Blood Serum – NHANES, Goldenman et al. (2019), and Task 1 literature review. <u>Occupational cohort</u> Surface water – Forever pollution project, PFAS production facilities. Drinking water – same as elevated. Food – No estimate. Assumes a standard background concentration for all cohorts. Soil – Brusseau et al. (2021) hotspots.	-Aqua Publica survey of drinking water companies - NHANES blood monitoring. - Goldenman et al. (2019).	

	Blood serum – NHANES, Goldenman 2019, and Task 1 literature review.		
6a	Defining ratios between blood serum concentrations and environmental concentrations: Establish a correlation based on trends in: - NHANEs data from 2000 to 2020 for PFOS, PFOA, PFHxS, and PFNA. - Environmental monitoring data – surface water, drinking water, food, and soil spanning the period 2014 – 2024.	NHANES Task 1 literature review	The primary issue here is that NHANEs is based on US populations. Data from the EEA (including Goldenman et al.) <u>which is less complete</u> was used to compare how the values vary between US and EEA data. A complete match was assumed as an extrapolation from the US to the EEA where data is incomplete.
6b	Defining ratios between blood serum concentrations and environmental concentrations: Establish the ratios For the baseline year, calculate the ratio between blood serum concentration and each of the environmental vectors (surface water, drinking water, food, and soil). Ratios will be used for the projections in later steps.	Calculations using the references from Task 5a.	
7a	Defining ratios between emissions and environmental concentrations: Identify emissions Using the data from the universal PFAS restriction dossier, collate the emissions from production of PFAS and 15 use sectors grouped as per fluoro alkyl	Universal PFAS restriction dossier PFAS in fire-fighting foams restriction dossier	The universal PFAS restriction dossier includes emission estimates as a low, medium, and high. We propose to use the medium for the main calculations.

	acids (PFAAs) and precursor compounds.		The low and high will be used to test the sensitivity in results.
7b	Defining ratios between emissions and environmental concentrations: Establish the ratios For the aggregated emissions of the PFAAs and precursors, calculate a ratio with each of the environmental vectors, surface water, groundwater, drinking water, food, and soil. Note that the data for background is more well defined for monitoring datasets compared to the elevated cohort. Ratios will be used for the projections in later steps.	Calculations using the references from Task 6a.	
8	Human exposure: Three cohorts ~ Occupational, elevated, background. Use Eurostat population density data for national average population density to determine population in the elevated zone per MS, aggregated to EU totals. For occupational exposure, use the number of sites from the FPP (see step 1) with the approach defined by Goldenman to re-evaluate the number of workers exposed (Goldenman estimates 300,000 – 1,200,000; based on preliminary calculations FPP would equate to 350,000).	Population density data (Eurostat) Calculations from preceding steps.	The sensitivity analysis from step 2 will also apply here to determine the potential number of sites and therefore number of workers.

	Background concentration - For national population subtract occupational workers and elevated exposure group. What is left over is background.		
9	For environmental exposure: Use the radius defined in step 2 plus number of sites from FPP (production facilities, known, and presumptive sites) to define the area (km²) of the elevated cohort by country and for the EEA as a whole. This provides outputs as number of sites, and area affected, along with concentration data from step 4.	Calculations based on previous steps.	The sensitivity analysis from step 2 will also apply here.
Polymers			
10	Define emissions – Review of emissions.	Universal PFAS restriction dossier Quantities of use and emissions of non-polymeric PFAS as processing aids in production of fluoropolymer are estimated and projected in the universal PFAS restriction proposal. Calculate the ratio of emissions from fluoropolymer production to total PFAS emissions for PFAA and precursors. This will be used as a proxy to determine what proportion of environmental concentrations came	The universal PFAS restriction provides estimates for emissions as low, medium, and high. We will use the medium dataset in the main calculations. However, we will use the low and high to test the sensitivity.

		from fluoropolymer production.	
TFA (as standalone case in Scenario 1 – business as usual emissions without policy intervention)			
11	Define environmental concentrations of TFA as two cohorts – background and elevated. Background: Monitoring data for surface water, groundwater and drinking water from the FPP, Task 1 report and supplemental literature review. Elevated: Monitoring data for surface water, groundwater and drinking water in agricultural areas from Task 1 report and supplemental review.	Task 1 literature. Supplemental literature outlined in Appendix C to Annex C1.	
12a	Define emissions: Background. For background concentrations, assume the primary emission pathway is via F-gases. Use universal PFAS restriction dossier provides quantities of use and emissions of fluorinated gases. Use data from literature (quoted in the Task 3 technical note) to determine conversion rates to TFA in the atmosphere. Calculate ratio between emissions and environmental concentrations in surface water, groundwater, and drinking water.	Universal PFAS restriction.	The data on conversion rates of f-gases to TFA vary depending on the specific f-gas and the type of release. We have data from literature that provides data as a range. We therefore will develop estimates a low, medium and high set of values as with the other PFAS in earlier steps.
12b	Define emissions: Elevated. For elevated concentrations, assume the primary	Eurostat data on arable land area Literature review.	The data on conversion rates of pesticides to TFA vary depending on the specific pesticide and the

	emission pathway is via agriculture. Use data from literature (quoted in the Task 3 technical note) to calculate quantities of fluorinated pesticide used and emitted. Use data from Eurostat to define arable land area, and pesticide usage rates for available countries (Germany and France) to define what proportion of that area has been treated by fluorinated pesticides. Apply that proportion to all countries to define % area of each country in the elevated concentration area. Define ratio between pesticide usage and elevated concentrations.		type of release. We have data from literature that provides data as a range. We therefore will develop estimates a low, medium and high set of values as with the other PFAS in earlier steps.
Projections – Scenario 1 - BAU			
13	Emission projections until 2050 from the universal PFAS restriction dossier for production of non-polymeric PFAS, 15 sectors of use, and non-polymeric PFAS used as a processing aid in the production of fluoropolymer.	Universal PFAS restriction dossier. PFAS in fire-fighting foams restriction dossier	The universal PFAS restriction also provides the emission projections as a low, medium, and high. We will use the medium dataset for the main calculations but will also use the low and high to provide a sensitivity analysis.
14	Calculate environmental concentrations in surface water, drinking water, food and soil: Apply the ratios from step 7b to calculate expected concentrations in hotspot, elevated, and background cohorts.	Calculations based on previous steps.	See earlier steps

15	Calculate blood serum concentrations: Using the predicted environmental concentrations from step 13, apply the ratios from step 6b to determine the blood serum concentrations in hotspot, elevated, and background cohorts.	Calculations based on previous steps.	See earlier steps
16	Managing the issue of new workers: The projections span the period from 2024 (baseline) to 2050. In that time, there will be births, deaths, immigration, and emigration that affects the size and demographics of the EU population. The population projections (from Task 2) will help define the number of people, and the breakdown between adults and children. These data will then be sorted into the three cohorts for different levels of exposure. The time segments (2024, 2030, 2040, and 2050) represent a snapshot of the population at that time. Due to births/deaths, immigration/emigration, people moving home, changing jobs etc., we cannot track specific individuals over the course of the 29-year timeframe. This means data relating to births, deaths, emigration and immigration will be	Eurostat – demographic and labour datasets	

considered out of scope for this study. One exception to this rule is retired workers. For occupational exposure over a long-time frame, workers will retire and change jobs. That does not mean blood serum concentration drops to zero, or health effects cannot occur afterwards. We therefore need to track these changes, which is managed as follows: We use the approach from step 1 to 7 to determine the number of workers and blood serum concentration in the baseline year. Year on year we use a natural attrition factor from Eurostat demographic and labour statistics datasets to calculate the number of workers that leave the profession through retirement on average per year and create a sub-cohort called former workers. The age of retirement is based on the EU average. Average life-expectancy for the EU is used to determine when individuals should be removed from the former worker sub-cohort (i.e., retire at 65, life expectancy is 81). The former worker sub-cohort will therefore be based on additions from attrition of current workers, minus former workers reaching life expectancy. The overall hotspot cohort for occupational exposure is		

	based on current and former workers across the timeseries.		
17	For environmental exposure: The emissions for each time segment in the projection (2024, 2030, 2040, and 2050) are combined with the ratios developed from earlier steps to calculate how the total emissions in a given year relate to the environmental concentrations in the same year. We will then use the ratio developed to calculate blood serum concentrations in each cohort based on estimated environmental concentrations.	Calculations based on previous steps.	See sensitivity analysis under step 2.
Projections - Scenario 2 - DWD			
18	Assume full compliance with the existing DWD standards of 100 ng/l for sum of 20 PFAS. If the drinking water concentrations exceed this value in scenario 1 (BAU), it will be capped at 100 ng/l in scenario 2 for elevated and background cohorts. Apply the ratio from step 6b to determine reduced blood serum concentrations for populations where BAU estimates drinking water exceeds 100 ng/l.	Calculations based on previous steps.	The assumption here is that all drinking water is capped to 99.9 ng/l (i.e., <100ng/l). In reality, some will already be below this threshold and will remain unaffected in the calculations.
Projections – Scenario 3 - EQSD			
19	Assume full compliance with the proposed EQSD standards for surface water and groundwater 4 ng/l of	Calculations based on previous steps.	The main calculations assume that compliance will be achieved through source control, so that emissions to all

	PFOA-equivalence for sum of 24 PFAS. Use the ratio from step 7b to calculate the impacts on drinking water and food from achieving EQS compliance in surface and groundwater. We note that achieving this compliance will likely require a very significant emissions reduction. However, the focus on this 'what if' scenario will be on the impacts from achieving compliance, not how compliance was achieved. Emissions projections from scenario 1 will be retained for ease of application but not included in consideration for scenario 3's outputs.		environmental compartments are reduced. The sensitivity analysis assesses the impact of sourcing water from surface / ground has on the drinking water concentrations. This assumes that all DW is a mixture of surface and ground water resources.
20	Determine the new blood serum concentrations by applying the ratio from 6b to the environmental concentrations.	Calculations based on previous steps.	N/A
Projections – Scenario 4 – Total stop of PFAS manufacture and use			
21	The environmental release category (ERC) factors used to calculate emissions in the universal PFAS restriction dossier include releases during manufacture, service life, and waste. This scenario assumes that all emissions associated with manufacture and industrial use of PFAS will cease immediately. To reflect a realistic phase out scenario where consumer products that are already in circulation cannot	Literature sources for average service life of articles within specific sectors where consumer use applies. Calculations based on previous steps.	As we will define a sector-wide service life based on multiple articles, we will develop a range based on min and max service life (e.g., 7 – 15 years), which will affect the rate of decline in emissions. The mid-value of this range will be used as the main calculations, but the low and high estimates will be used to define the range.

	practically be prevented from being used, all emissions from consumer use during service life and waste will continue but decline over time. Therefore, the relevant sectors (from the 15 identified from the universal PFAS restriction dossier) with consumer uses are used to calculate service life and waste emissions. A standardised service life for each sector as a whole is determined from review of literature on example articles in the sector, and a linear decline applied in terms of tonnes in use. Emissions are calculated based on this linear decline and aggregated for all relevant sectors as EEA total emissions.		
22	Based on the revised emissions from step 22, the ratios for the environmental compartments from step 7b are used to calculate surface water, drinking water, food, and soil concentrations for all three cohort levels (occupational, elevated, and background).	Calculations based on previous steps.	N/A
23	Based on the revised environmental concentrations from step 21, the ratio from step 6b will be used to calculate the blood serum concentrations for all three cohort levels (occupational, elevated, and background).	Calculations based on previous steps.	N/A

B. Input data for calculations

Table B.1 Forever Pollution Project data on number of sites of PFAS production and use

Country	PFAS production sites	Known sites	Industrial sites	Presumptive sites	Airport	Firefighting training site	Industrial sites	Military Sites	Waste management
Austria	0	5	5	278	8	0	119	5	146
Belgium	1	10	10	1,106	12	814	247	16	17
Bulgaria	0	0	0	140	23	0	62	8	47
Croatia	0	0	0	33	11	0	16	6	0
Cyprus	0	0	0	26	6	0	5	7	8
Czechia	0	4	4	225	15	0	103	6	101
Denmark	0	3	3	249	17	0	127	7	98
Estonia	0	0	0	39	7	0	15	9	8
Finland	0	2	2	288	33	0	229	9	17
France	5	27	27	1,506	154	5	854	39	454
Germany	6	67	67	2,333	97	0	837	116	1283
Greece	0	0	0	108	31	0	26	35	16
Hungary	0	2	2	219	11	0	139	5	64
Iceland	0	0	0	19	9	0	9	1	0
Ireland	0	2	2	50	11	0	24	6	9
Italy	2	38	38	1,189	78	1	727	34	349
Latvia	0	0	0	32	6	0	11	4	11
Liechtenstein	0	0	0	0	0	0	0	0	0
Lithuania	0	0	0	87	7	0	55	5	20
Luxembourg	0	0	0	25	1	0	14	0	10
Malta	0	0	0	13	3	0	5	2	3
Netherlands	1	15	15	442	17	0	178	15	232
Norway	0	1	1	492	46	247	107	17	75
Poland	1	2	2	550	32	0	238	27	253
Portugal	0	0	0	172	32	0	125	15	0

Romania	0	2	2	139	23	0	106	10	0
Slovakia	0	0	0	57	8	0	32	3	14
Slovenia	0	1	1	40	4	0	34	2	0
Spain	1	8	8	1,000	55	0	495	29	421
Sweden	0	1	1	407	55	0	309	19	24
Totals	17	190	190	11,264	812	1,067	5,248	457	3,680

Table B.2 universal PFAS restriction emissions projections for PFAAs (medium estimate) tonnes

Table Ref in Annex XV	Sector	2020	2025	2030	2035	2040	2045	2050
B.20	Manufacture of PFAS	86	98	115	132	155	181	217
E.10	TULAC	6137	6776	7481	8260	9120	9585	10074
E.37	Food Contact Materials	491	597	726	884	1075	1307	1550
E.58	Metal Plating	6	6	6	6	6	6	6
E.66	Consumer mixtures	1.2	1.2	1.2	1.2	1.2	1.2	1.2
E.69	Cosmetics	32	32	32	32	32	32	32
E.78	Ski Wax	0.95	0.62	0.41	0.39	0.37	0.37	0.37
E.107	Medical Devices	222	290	370	472	602	769	980
E.126	Electronics and semiconductor	512	820	1320	2127	3426	5517	8887
E.133	Energy	42	66.75	108	174	280.5	451.5	726.75
E.139	Construction Products	1696	2057	2757	3120	3529	3709	3898
E.150	Lubricants	1.1	1.4	1.8	2.0	2.3	2.4	2.5
E.156	Petroleum and mining	2028	2132	2240	2355	2475	2601	2734
B.41*	Firefighting foams	470	470	470	470	470	470	470
	TOTAL	11640	13251	15514	17903	21020	24453	29364

*Annex XV restriction dossier for PFAS in firefighting foams – not included in the universal PFAS restriction.

Table B-3 Ratios of emissions to environmental concentrations (sum of PFAAs)

Compartment	ratio	Units
Drinking water		
Background	0.0017	Tonnes emitted / ng/l
Elevated-low	0.0047	Tonnes emitted / ng/l
Elevated-high	0.0077	Tonnes emitted / ng/l
Surface water		
Background	0.0155	Tonnes emitted / ng/l
Elevated-low	0.0467	Tonnes emitted / ng/l
Elevated-high	0.0778	Tonnes emitted / ng/l
Groundwater		
Background	0.0077	Tonnes emitted / ng/l
Elevated-low	0.0230	Tonnes emitted / ng/l
Elevated-high	0.0384	Tonnes emitted / ng/l
Soil		
Background	0.0031	Tonnes emitted / µg/kg
Elevated-low	0.342	Tonnes emitted / µg/kg
Elevated-high	0.6811	Tonnes emitted / µg/kg

Table B-4 Ratios of environmental concentrations (sum of PFAAs) vs blood serum

Compartment	ratio	Units
Drinking water		
Background – Adults	0.0010	ng intake / µg/l
Background – Children	0.0012	ng intake / µg/l
Elevated-low – Adults	0.0009	ng intake / µg/l
Elevated-low - Children	0.0011	ng intake / µg/l
Elevated-high – Adults	0.0008	ng intake / µg/l
Elevated-high – Children	0.0010	ng intake / µg/l
Occupational – current worker	0.0005	ng intake / µg/l
Occupational – retired worker	0.0005	ng intake / µg/l
Food		
Adults	405	Tonnes of emission / annual intake as ng
Children	233	Tonnes of emission / annual intake as ng
Food and water (combined)		
Background – Adults	0.000,003	ng annual intake / µg/l
Background – Children	0.000,003	ng annual intake / µg/l
Elevated-low – Adults	0.000,007	ng annual intake / µg/l
Elevated-low - Children	0.000,008	ng annual intake / µg/l
Elevated-high – Adults	0.000,010	ng annual intake / µg/l
Elevated-high – Children	0.000,012	ng annual intake / µg/l
Occupational – current worker	0.000,010	ng annual intake / µg/l
Occupational – retired worker	0.000,010	ng annual intake / µg/l

Table B-5 EFSA (2022) food consumption survey (grams/day consumed)

Country	Children					Adults				
	Red meat	fish	vegetables	fruit	dairy	Red meat	fish	vegetables	fruit	dairy
Austria	85	49	69	103	305	135	62	190	189	236
Belgium	96	46	70	143	280	162	68	183	160	185
Bulgaria	70	42	156	105	250	157	71	178	175	246
Croatia	86	51	91	181	300	153	94	174	181	214
Cyprus	106	42	103	102	311	173	99	205	143	220
Czechia	106	44	81	179	296	188	80	119	147	181
Denmark	98	16	138	149	525	132	23	162	200	372
Estonia	87	31	127	222	443	139	58	170	264	297
Finland	84	21	70	86	605	136	68	185	172	412
France	100	38	132	136	337	155	60	239	166	255
Germany	77	25	98	148	283	117	65	106	199	206
Greece	52	38	44	90	378	127	108	194	167	216
Hungary	79	27	128	140	281	189	76	238	202	262
Iceland	86	39	102	142	352	157	71	178	175	246
Ireland	86	39	142	142	352	178	46	131	96	274
Italy	100	59	147	143	238	138	85	237	204	196
Latvia	84	39	102	190	173	190	80	205	178	154
Liechtenstein	86	39	102	142	352	157	71	178	175	246
Lithuania	86	39	102	142	352	136	71	178	175	246
Luxembourg	86	39	102	142	352	164	71	178	175	246
Malta	86	39	102	142	352	154	71	178	175	246
Netherlands	70	42	86	142	371	157	55	168	152	376
Norway	86	39	102	142	352	157	71	178	175	246
Poland	75	50	76	169	224	157	85	159	144	124
Portugal	113	53	152	141	495	157	85	183	184	261
Romania	86	39	102	142	352	157	81	155	161	117
Slovakia	86	39	102	142	352	157	71	178	175	246
Slovenia	59	33	102	142	352	182	77	153	191	166
Spain	116	52	95	149	486	150	59	195	212	361
Sweden	65	25	40	131	453	190	56	167	136	317
European Union	86	39	102	142	352	157	71	178	175	246

Note: text in red means no data - EU average applied

C. Environmental monitoring data

Table C-1 Consolidated monitoring data from the Forever Pollution Project

	Unit s	GW (Min)	GW (Max)	GW (median)	No. of sampl es	SW (Min)	SW (Max)	SW (median)	No. of sampl es
Perfluorosulfonic acids (PFSAs)									
PFBS	ng/l	0.3	16650	2.3	993	0.6	1000	7.0	181
PFPeS	ng/l	5	74	25.0	8	0.1	5.1	1.0	40
PFHxS	ng/l	0.16	3400	2.8	1005	1	120	1.0	262
PFHpS	ng/l	0.1	637	6.3	204	0.10	4.6	1.0	260
PFOS	ng/l	0.00005 4	104,000	3.7	1629	0.0002	39000	3.7	3911
PFNS	ng/l	5	7	-	2	-	-	-	0
PFDS	ng/l	18	18	-	1	0.1	0.8	0.1	38
PFUnDS	ng/l	-	-	-	0	-	-	-	0
PFDnDS	ng/l	-	-	-	0	0.1	0.8	0.1	38
PFTnDS	ng/l	-	-	-	0	-	-	-	0
Perfluorocarboxylic acids (PFCAs)									
PFBA	ng/l	0.63	5900	5.1	1535	0.1	490	4.1	407
PFPeA	ng/l	0.2	32000	10.5	1057	0.1	209	7.0	531
PFHxA	ng/l	0.1	25000	7.3	1234	0.1	60	5.0	322
PFPhA	ng/l	0.1	5300	3.9	1253	0.5	66	6.0	137
PFOA	ng/l	0.16	82400	7.6	2286	5	15	6.0	71
PFNA	ng/l	0.1	600	2.4	398	0.85	98	1.0	256

PFDA	ng/l	0.1	229	16.7	60	0.1	5	0.2	259
PFUnDA	ng/l	0.4	12	-	4	0.1	11	0.2	253
PFDoDA	ng/l	2.4	39	5.3	9	0.1	1.0	0.2	253
PFTTrDA	ng/l	27	60	-	3	0.1	1.0	0.2	508
Sum of 20 PFAS	ng/l			99	11681			44	7727

Other PFAS in scope (EQSD, GWD, and TFA)

TFA	ng/l	480	1100	970	5	370	3300	1000	31
GEN-X	ng/l	5	6965	69	121	7	30	19	3
ADONA	ng/l	0.5	0.63	0.5	7	-	-	-	0
10-2 FTOH	ng/l	600	600	-	1	0.6	24	2.1	15
8-2 FTOH	ng/l		-	-	0	0.5	27	2.5	15
6-2 FTOH	ng/l		-	-		0.3	3.7	0.6	15
C6O4	ng/l	45	8855	190	80	115	2600	355	11
PFHxDA	ng/l		-	-		0.2	23.17	0.2	192
PFOcDA	ng/l		-	-		0.04	25.19	1.44	8

Table C-2 Source data used for the consolidated monitoring data (Table C-1)

CNRS ref no.	Author	Year	Title	Details
12	Muir et al	2021	Spatial and temporal trends of PFAS in global ocean and coastal waters, Environmental science, and technology vol 55	Review paper. Most of the focus is on coastal and marine but does include monitoring in rivers and estimates for

						loadings at estuarine environments.
14	AGES		2022	POPMON monitoring program by Austrian Agency for Health and Food Safety	~ Environmental monitoring program, includes drinking water post-treatment.	
20		Danish Ministry of Environment	2018 - 2022	Groundwater and drinking water monitoring for Sjælland Region		Part of the monitoring program for Denmark split into regions. Older data is available but screened to 2018 or more recent.
21	Danish Ministry of Environment		2018 - 2022	Groundwater and drinking water monitoring for Midtjylland region	As above	
22		Danish Ministry of Environment	2018 - 2022	Groundwater and drinking water monitoring for Syddanmark region	As above	
23	Danish Ministry of Environment		2018 - 2022	Groundwater and drinking water monitoring for Nordjylland region	As above	
25		FEI		2018 - 2022	Finnish Environment Institute monitoring in surface water and fish	National monitoring program for PFAS. Older data is available but screened to 2018 or more recent.
34	LfU for Schleswig-Holstein		2019 - 2021	Regional environment agency groundwater monitoring	Part of the regional environment agency for Schleswig-Holstein, groundwater monitoring program.	

39	LfU for Bremen		2019 - 2022	Regional environment agency surface water monitoring	Part of the monitoring program under the WFD for Bremen and Hansestadt.
55	ARPA - Veneto	2021-2022		Groundwater monitoring in Miteni by the regional environment agency	This is a groundwater monitoring program in the Miteni area. Note that this is a known hotspot.
58	ARPA - Lombardia		2021	Surface water monitoring program by regional environment agency	Surface water program in Lombardia.
60	ARPA Lombardia	2021		Groundwater monitoring program by regional environment agency	Groundwater program in Lombardia
65	ARPA Umbria		2018 - 2021	Surface water monitoring program by regional environment agency	Surface water program in Umbria
66	ARPA Umbria	2018 - 2021		Groundwater monitoring program by regional environment agency	Groundwater program in Umbria
68	ARPA Valle d'Aosta		2018 - 2022	Surface water and groundwater monitoring program by regional environment agency	Surface and groundwater monitoring data for Valle d'Aosta
70	ARPA Piemont	2021		Groundwater monitoring program by regional environment agency	Groundwater program in Piemont
94	England Environment Agency		2020 - 2024	Surface and groundwater monitoring program for England	England Environment Agency monitoring programs.

109	Thomaidis	2020	Academic study on around the river Asopos.	Academic paper for surface and groundwater monitoring in Greece.
123	Vivaqua		2022-2023	Monitoring data from the Vivaqua water company based in Belgium. Study is based on reservoirs.
126	AGES	2022	Part of the POPMON program conducted by the Austrian authorities – surface water	See entry 14.
127	ARPA Valle d'Aosta		2018-2022	Groundwater monitoring by the regional environment agency Groundwater monitoring data for Valle d'Aosta
131	Radio France	2024	Academic study by journalists for PFAS in drinking water	Widescale tap water sampling by journalists in France.

Table C-3 data collated by the joint research centre (JRC) from Member State monitoring – referred to as the 'monitored environmental concentrations' (MEC) in the JRC EQS dossier for priority substances. (data below is the consolidated averages from 18 Member States per substance, per year)

ng/l	2014	2015	2016	2017	2018	2019	2020	2021
HFPO-DA (Gen X)	0.0	0.0	0.0	16.1	1.8	3.7	2.0	0.0
PFBA	211.8	6.9	15.0	11.1	12.0	16.9	26.8	0.0
PFBS	17.2	20.4	18.1	15.0	15.0	15.0	19.5	3.0
PFDA	1.0	5.0	5.0	5.0	15.0	15.0	0.7	0.8
PFDoDA (PFDoA)	0.6	5.0	5.0	5.0	5.0	5.0	0.1	12.2
PFDS	0.9	5.0	5.0	5.0	5.0	5.0	0.0	0.0
PFHpA	4.9	5.0	5.0	15.0	15.0	15.0	4.6	0.8
PFHpS	0.0	91.0	87.1	5.0	5.0	5.0	0.3	0.0
PFHxA	10.5	11.0	11.0	15.0	15.0	15.0	11.5	1.8
PFHxS	5.9	5.0	15.0	15.0	15.0	15.0	2.5	0.0
PFNA	2.4	5.0	5.0	5.0	5.0	5.0	1.0	0.3
PFOA	17.1	15.0	15.0	9.0	7.0	30.0	20.0	1.3
PFOS	10.0	17.0	11.0	10.0	10.0	10.0	10.0	1.9
PFPeA	0.2	5.0	6.8	6.5	10.0	11.0	10.6	0.3
PFPeS (PFPS)	0.0	0.0	0.0	1.1	1.0	0.9	0.9	0.0
PFTeDA (PFTDA)	1.6	0.0	0.1	0.0	0.0	0.0	0.0	0.0
PFUnA (PFUnDA)	1.0	5.0	5.0	5.0	5.0	5.0	0.0	4.1

Table C-4 Comparison of MEC data collated by the JRC and surface water monitoring data from FPP

PFAS	JRC – MEC data mean average (ng/l)	CNRS collated data – median average (ng/l)
Perfluorosulfonic acids (PFSAs)		
PFBS	16.1	7.0
PFPeS	1.0	1.0
PFHxS	11.9	1.0
PFHpS	3.8	1.0
PFOS	10.0	3.7
PFDS	3.8	0.1
Perfluorocarboxylic acids (PFCAs)		
PFBA	16.7	4.1
PFPeA	9.5	7.0
PFHxA	14.1	5.0
PFHpA	12.4	6.0
PFOA	16.5	6.0
PFNA	4.0	1.0
PFDA	8.9	0.2
PFuDA	3.8	0.2
PFDoDA	3.8	0.2
PFTTrDA	0.0	0.2

Other PFAS		
HFPO-DA (GenX)	5.9	19.0

Table C-5 Comparison of pre-treated and treated PFAS in drinking water based on Aqua publica member survey. Mean average concentrations.

PFAS	Mean average pre-treated concentration ng/l	Number of reporting operators	Mean average treated concentration ng/l	Number of reporting operators
Perfluorosulfonic acids				
PFBS	13.0	8	4.6	4
PFPeS	5.5	4	<LOD	4
PFHxS	21.8	6	1.8	2
PFHpS	1.2	3	<LOD	3
PFOS	15.9	13	0.9	1
Perfluorocarboxylic acids				
PFBA	15.6	10	6.4	6
PFPeA	19.7	10	4.8	5
PFHxA	35.3	8	0.5	1
PFOA	41.0	13	1.6	3
PFNA	6.0	4	0.4	1
Sum of the above	218		22.1	

Table C-6 Collated data from the CNRS datahub for drinking water concentrations (ng/l) 2018 or more recent

PFAS	Drinking water (min)	Drinking water (max)	Drinking water (median)	No. of samples
Perfluorosulfonic acids				
PFBS	0.5	744	2.2	24
PFPeS	1.2	3.1	1.3	5
PFHxS	0.8	1,400	4.4	8
PFHpS	16.0	109.0	-	2
PFOS	1.1	1.6	1.4	3
Perfluorocarboxylic acids-				
PFBA	0.9	320	3.6	33
PFPeA	0.9	1,000	6.2	30
PFHxA	0.4	785	2.4	35
PFPhA	0.3	270	1.1	29
PFOA	0.8	122	2.2	53
PFNA	0.4	3.9	2.2	6
PFDA	0.3	0.3	-	1
Other PFAS (EQSD, GWD, TFA)				
TFA	84	2,100	435	12
HFPO-DA (GENX)	0.1	0.7	0.3	4

Table C-7 Derksen (STOWA) (2021) monitoring data for four WWTPs (pink highlight denotes where influent/effluent differ)

PFAS	Dordrecht (known hot spot)		Aarle Pixtel (former hot spot)		Bath (mainly industrial flows)		Lelystad (mixed dom/ind flows)	
Capacity (as popn equivalent)	230,000		318,000		509,000		116,000	
	Influent concentration	Effluent concentration	Influent concentration	Effluent concentration	Influent concentration	Effluent concentration	Influent concentration	Effluent concentration
PFBS	45	45	10	10	45	45	0.5	10
PFPeS	10	10	0.25	0.25	10	10	0.25	10
PFHxS	45	45	10	10	45	45	10	10
PFHpS	0.25	0.25	0.25	0.25	10	10	0.25	10
PFOS	45	45	10	10	45	45	10	45
PFDS	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75
PFBA	45	45	1	10	450	45	1	10
PFPeA	45	45	1	45	45	45	1	45
PFHxA	450	45	10	45	45	45	10	45
PFHpA	45	45	10	45	10	45	10	45
PFOA	450	450	10	10	45	45	10	10
PFNA	10	45	0.5	0.5	0.5	0.5	0.5	0.5
PFDA	0.5	10	0.5	0.5	10	10	0.5	0.5
PFunDA	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
PFDoA	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
PFTTrDA	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
HFPO-DA (GenX)	450	450	0.1	0.1	10	10	0.1	0.1
ADONA	0.1	0.1	0.1	0.1	10	0.1	0.1	0.1

PFAS	Piershil (mainly domestic)		Asten (mainly domestic)		Hapert (mainly domestic)		Hatten (mixed domestic and industrial flows)	
Capacity (as popn equivalent)	7,000		74,000		56,000		60,000	
	Influent concentration	Effluent concentration	Influent concentration	Effluent concentration	Influent concentration	Effluent concentration	Influent concentration	Effluent concentration
PFBS	45	10	0.5	0.5	10	10	0.5	0.5
PFPeS	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
PFHxS	10	10	10	0.25	10	0.25	10	0.25
PFHpS	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
PFOS	45	10	10	0.5	10	0.5	10	0.5
PFDS	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75
PFBA	10	10	10	10	1	10	10	10
PFPeA	10	10	1	1	1	10	1	1

PFHxA	45	45	10	10	10	10	10	10
PFHpA	10	10	0.5	0.5	0.5	10	0.5	0.5
PFOA	45	45	10	10	10	10	10	10
PFNA	10	0.5	0.5	0.5	0.5	0.5	0.5	0.5
PFDA	0.5	0.5	10	0.5	0.5	0.5	0.5	0.5
PFunDA	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
PFDoA	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
PFTTrDA	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
HFPO-DA (GenX)	10	10	0.1	0.1	0.1	0.1	0.1	0.1
ADONA	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1

Table C-8 Collated data on background concentrations in soil – based on Brusseau et al, 2021

Original study	Country	Concentrations (µg/kg)	Max PFOA conc	Max PFOS conc	PFAS included
Skaar 2019	Norway	<0.05 – 7.1	0.01	7.1	14
Strynar 2012	multiple	<0.5 - 150	32	10	13
Xiao 2015	USA	6 - 135	28	126	2
NH DES 2016	USA	<0.5 - 71	33	59	12
Scher 2018	USA	1.3 - 30	7	3	12
Kikiuchi 2018	Sweden	<0.02 - 20	28	0.6	1.7
HWG 2018	USA	<0.2 – 5.1	6	0.5	3.1
NEA 2018	Norway	0.4 - 174	17	3.3	162
Zhu 2019	USA	0.5 - 35	17	4.9	9.7
Groffen 2019	Belgium	0.8 - 53	15	3.7	37
Overall	Maximum	-	-	123.6	162
Overall	Minimum	-	-	0.01	0.003
Overall	Median	-	-	2.7	2.7

Table C-9 Collated data on elevated concentrations in soil – based on Brusseau et al, 2021

Original study	Country	Type of site	Max PFOA concentration µg/kg	Max PFOS Concentration µg/kg
Zhu 2019	USA	Adjacent to PFAS manufacturing site	470	
Wilhelm 2008	Germany	Industrial waste site	910	5,500
Washington 2010	USA	PFAS impacted waste site	2,531	1,409
Sepulvado 2011	USA	Application site for municipal biosolids	38	483
Gottschall 2017	Canada	Application site for municipal biosolids	0.8	0.4
MEDEP 2017	USA	Paper mill residues and application of biosolids	23.6	878
Braunig 2017	Australia	Site contaminated after use of contaminated groundwater for irrigation	7	1,692
Liu 2017	China	Site contaminated after use of contaminated groundwater for irrigation	623	7
Overall		Median	38	680

Table C-10 Collated data on concentrations in soil at hot spots – based on Brusseau et al, 2021

Original study	Country	Type of site	Maximum PFOA concentration µg/kg	Maximum PFOS concentration µg/kg	Notes
SFT 2008	Norway	Fire training ground	141	8,924	4 sites in Norway
Karman 2011	Norway	Fire training ground	12	1,905	1 airport
Martinsen 2012	Norway	Fire training ground	-	17,400	4 airports in Norway
Houtz/ McGuire 2013/2014	USA	Fire training ground	11,484	36,534	1 US air base
Bergstrom, 2014	Sweden	Fire training ground	2	486	1 air base
Filipovic, 2015	Sweden	Fire training ground	219	8,520	1 air base
Anderson, 2016	USA	Fire training ground	58	9,700	10 military installations
Groffen, 2019	Belgium	PFAS production facility	114	7,800	1 site in Belgium
Skaar, 2019	Norway	Fire training ground	-	1,055	1 airport
Overall		Median	83	8,722	

Table C-11 Collated data on concentrations in soil at hot spots – based on Goldenman, et al 2019

Original study	Location	Concentrations µg/kg dry weight	PFAS included	Notes
OVAM, 2018	Flanders	<200 – 9,400	PFOS, 10:2 FTS, PFBA, PFHxS	Study at contaminated sites in Flanders. Fire training grounds
OVAM, 2018	Flanders	1,200 – 2,900	PFBA, PFOS, PFHxS	Study at contaminated sites in Flanders, former fire incident
RIVM, 2020	Netherlands	1.9 (PFOA), 1.4 (PFOS)	PFOA, PFOS	Sampling campaign across 100 sites in Netherlands. These are the average background concentrations.
National soil limits	Denmark	400 µg/kg /TS	PFOA and PFOS	Legal limits for soil protection.
Tauw (2017)	Netherlands	2.26 (PFOS) in topsoil; 2.70 (PFOA) in topsoil	PFOA and PFOS	Schiphol trade park. The site was formerly agricultural land, no known contamination but is in the vicinity of Schiphol airport.

D. Methodology for TFA case study

TFA calculations

Trifluoroacetic acid (TFA) is a PFAS of emerging concern due to its very high mobility in the environment and concentrations which are an order of magnitude greater than the sum of the PFAAs combined. It is an ultrashort chain PFAS (C2) which is primarily formed as a breakdown product of other PFAS. Primary sources include fluorinated gases which, when emitted into the atmosphere, are subject to photolysis creating TFA from longer chain PFAS substances. Other key sources include fluorinated pesticides and biocides, consumer mixtures, some types of pharmaceuticals, and wastewater treatment works (UBA, 2023). This study has therefore calculated the releases, environmental concentrations, and human health costs of TFA separately from the combined PFAAs. This is due to the fact that concentrations in the environment are very different to other PFAAs, and its environmental pathway is also different. Two cohorts have been assumed for TFA, “background” and elevated. This was on the basis that TFA is primarily formed through environmental processes and as a by-product of some industrial processes. “background” concentrations in the environment are primarily the result of precipitation from TFA formed or directly released to the atmosphere. Transboundary air movements mean a wider distribution of TFA and creation of this “background” concentration from spread of TFA released to air. Studies by UBA (2021, 2023) and Arp et al. (2024) further determined that elevated concentrations in soil and water are primarily located in agricultural areas in proximity to where fluorinated pesticides have been applied. Therefore, the elevated and “background” cohorts have been calculated as follows:

- Elevated cohort:** Studies on use of fluorinated pesticides were identified for Germany (UBA, 2021) and France (PAN, 2023). This estimates 521 tonnes per annum of fluorinated pesticide used in Germany, and 2,332 tonnes in France. Typical working concentrations for different pesticides as grams/hectare per active substance were identified in the literature³⁸ for 27 fluorinated pesticides³⁹, with a minimum of 5 g/ha for lambda-cyhalothrin to a maximum of 750 g/ha for fluazinam. This leads to an average usage rate of 250g/ha. This has been multiplied with the tonnage of fluorinated pesticides used to estimate the hectares of area treated (assuming the soil is treated once per annum). This yields 1.6 million hectares in Germany, and 7.5 million hectares in France. Data from the Eurostat agricultural land use database (2025) has been used to determine the total amount of arable and permanent crops (as hectares) for the year 2023 (latest available year). For Germany this amounts to 11.8 million hectares (i.e., the amount treated with fluorinated pesticides is 14%), and 18 million hectares in France (area treated with fluorinated pesticides equates to 42%). The mid-value of 28% has been used to estimate the area of treated land for the other EEA countries. We recognise that this represents an uncertain estimate given that the EEA data has been extrapolated from only two countries. The quantity and type of pesticide used likely varies country by country for a range of reasons. It should also be noted that depending on the number of cropping cycles and severity of pests in any given year, a second round

³⁸ Based on collated data from the US EPA, EFSA, Health Canada's PMRA, and Australian pesticides and veterinary medicines authority. Market data also included manufacturer product labels for guideline concentrations for selected crop types.

³⁹ Beflubutamid, cyflufenamide, Diflufenican, flazasulfuron, flonicamid, fluazifop-p, fluazinam, flufenacet, fluopicolide, Fluopyram, flupyrsulfuron, flurtamone, gamma-cyhalothrin, isoxaflutole, lambda-cyhalothrin, metaflumizone, oxathiapiprolin, penoxsulam, picoxystrobin, prosulfuron, pyroxsulam, tau-fluvalinate, tembotrione, trifloxystrobin, triflurosulfuron, triosulfuron.

of treatment might be used for the same field in one year. This could mean a potential underestimate in the TFA emissions. However, in the absence of better data, this represents a best estimate.

To project the use of pesticide in future years, it has been assumed that pesticide use increases/decreases at the same rate as the EEA population, which serves as a proxy for food demand. This may represent an over or underestimate for a range of reasons (import/export of food, changing land use, policy initiatives on use of pesticides e.g., farm-to-fork⁴⁰, and changing trends in which pesticides are used).

- **“background” cohort:** The “background” cohort is calculated based on the total land area minus the elevated cohort area. For the “background” cohort the primary source of TFA comes from emissions of fluorinated gases to atmosphere, and atmospheric processes which degrade the f-gases into TFA. The projections of future surface water, groundwater, and drinking water concentrations of TFA are therefore linked to the emission estimates and projections of fluorinated gases from the universal PFAS restriction dossier, using the same ratio approach that was explained for PFAAs (and precursors) in Section 2.2.4 (i.e., the ratio between environmental concentrations of TFA and emissions of fluorinated gases in the baseline year (2024) is applied to projected emissions of fluorinated gases to estimate future environmental concentrations of TFA, assuming that environmental concentrations of TFA increase/decrease at the same rate as emissions of fluorinated gases).

For both elevated and “background” cohorts, populations have been calculated using the same population density data used for the PFAA calculations and applying it to the area of each cohort. For both “background” and elevated cohorts, future population estimates have been calculated the same way as the PFAA calculations using the CAGR values from the Task 1 report.

Table D-1 (below) provides the results of the calculation for the two TFA cohorts. This illustrates that around 8% by population and 6% by geographic area are in the elevated cohort, the remainder is in the “background”. Note that the national average population density has been used for the TFA calculations as with the main study. While it can be argued that pesticides are applied in rural areas where rural population applies, the surface water and ground water used to service drinking water for both rural and urban populations also come from rural areas.

⁴⁰ [Farm to Fork Strategy - European Commission](#)

Table D-1 TFA cohorts (2024)*

Country	Background area (area km2)	Population in background cohort (millions of people)	Elevated area (area km2)	Population in elevated cohort (millions of people)
Austria	80,000	8.5	3,900	0.42
Belgium	28,200	10.6	2,500	0.94
Bulgaria	100,900	6.3	10,100	0.64
Croatia	53,900	3.9	2,700	0.20
Cyprus	8,900	0.9	300	0.03
Czechia	71,700	9.9	7,200	0.99
Denmark	36,200	5.0	6,700	0.93
Estonia	43,300	1.3	2,000	0.06
Finland	332,000	6.0	6,300	0.11
France	562,900	59.6	75,500	8.0
Germany	340,700	79.9	16,900	4.0
Greece	123,700	10.2	8,000	0.7
Hungary	80,900	8.7	12,000	1.3
Iceland	103,000	0.4	50	0.0002
Ireland	68,700	4.9	1,200	0.09
Italy	275,500	55.4	26,600	5.3
Latvia	60,700	1.8	3,800	0.13
Liechtenstein	160	0.04	0	0
Lithuania	58,800	2.6	6,500	0.29
Luxembourg	2,400	0.6	200	0.04
Malta	300	0.5	25	0.04
Netherlands	34,500	17.5	2,900	1.5
Norway	321,900	4.8	2,300	0.03
Poland	279,600	34.7	32,300	4.0
Portugal	87,300	9.9	4,800	0.6
Romania	214,000	17.8	24,500	2.0
Slovakia	45,300	5.1	3,700	0.4
Slovenia	19,700	2.0	600	0.06
Spain	459,300	43.2	46,600	4.4
Sweden	440,300	11.0	7,100	0.18
EEA (total)	4,335,000	423.1	317,000	34.6

*rounded to nearest 100 Km²

Data on environmental concentrations was identified and collated for surface water, drinking water, groundwater, and soil. Note that data for TFA in food was insufficient to make an assessment. This means that human exposure for the TFA calculations is based on consumption of drinking water only. Also, note that the data for soil was less well documented than water (i.e., much fewer datapoints). One author (Xie et al, 2019) states that because TFA is highly mobile, residence time in soil can be short which poses a challenge for monitoring TFA concentrations in soil. Therefore, data was gathered primarily from the two UBA studies (UBA, 2021, 2023), Arp et al. (2024), the NORMAN monitoring network for surface water (2023), and the JRC risk assessment on PFAS in groundwater (2023). Table D-2 provides the results of this collated data based on the minimum, maximum, and mean average concentrations across different studies. The “background” values are based on studies that expressly avoid agricultural area, while the elevated

concentrations come from studies in agricultural areas. Table D-2 TFA environmental concentrations used for this study as a baseline year of 2024.h

Compartment	Units	Background	Elevated
Drinking water	ng/l	700	3,900
Surface water	ng/l	4,700	23,900
Groundwater	ng/l	300	3,200
Soil	ng/kg	200	2,000

Information on blood serum concentrations for TFA is relatively limited and largely based on non-EU studies. Given this inherent weakness it was decided that the TFA example would focus only on environmental concentrations.

Ratios between emissions of fluorinated gases and environmental concentrations (drinking water, surface water, groundwater, and soil) were calculated (and are presented in Appendix B to Annex C1). These ratios determine that for every tonne of emissions from fluorinated gases; environmental concentrations increase by x ng/l for water or ng/kg for soil.

As a general comment, the scarcity of data makes calculations challenging, and poses questions around the certainty of the results. and the approach, assumptions and uncertainties are presented transparently in this report, noting that this is exploratory and intended to provide an indication of the scale of the TFA issue compared to the sum of PFAAs.

E. Additional sensitivity analysis for drinking water – Advanced treatment

Scenario 2 – Drinking Water Directive thresholds

For scenario 2, two sensitivity tests were applied, as follows:

- The main calculations assume compliance with the DWD 100 ng/l threshold. In reality, if advanced treatment was needed, it would reduce the concentration significantly. Therefore, based on the efficacy of granulated activated carbon (GAC), ion resin exchange (IOX), and membrane techniques such as reverse osmosis and nano filtration⁴¹, a 90% reduction in drinking water concentrations is assumed once treatment is applied.
- The scenario 2 assumes that there will only be treatment at drinking water facilities to meet the DWD thresholds. There could also be some source control to meet them, particularly if costs of treatment could be passed back through extended producer responsibility. This test applies a nominal 10% reduction in emissions to determine what effect it would have.

In the main calculations, the elevated-high sub-cohort reaches the 100ng/l immediately (2020) and then exceeds it. The elevated-low sub-cohort exceeds the 100ng/l by 2040. Table E-1 (below) provides the main results for scenario 2 plus the sensitivity test in blue italics. In the main calculations the capping of drinking water concentration reduced blood serum concentration by 1-2 µg/l by 2050 (compared to scenario 1). Table E-1 illustrates that if rather than capping concentrations at 100 ng/l, it is assumed that advanced treatment reduces concentrations well below 100 ng/l, a further 1 – 2 µg/l can be removed from blood serum concentrations. The drinking water concentrations themselves fall significantly compared to scenario 1. However, as with the main calculations, the reduction in intake via drinking water is offset by increased intake via food. This minimises the impact of the reduced drinking water concentrations.

Table E-1 Overview of scenario 2 – Test 1 – Effects of water treatment.*

<i>Elevated-high Sub-cohort</i>	<i>2020</i>	<i>2024</i>	<i>2030</i>	<i>2040</i>	<i>2050</i>
Population (Total) (millions)	12.2	12.4	12.6	13.3	14.2
Population (Adults) (millions)	10.4	10.6	10.9	11.6	12.7
Population (Children) (millions)	1.8	1.8	1.7	1.7	1.5
Blood serum concentration - adults (µg/l)	50.9	56.4	67.5	91.2	127.1
Blood serum concentration - Children (≤14 yrs) (µg/l)	33.8	37.5	44.8	60.5	84.2
<i>Blood serum concentration - adults (µg/l)</i>	<i>50.9</i>	<i>55.7</i>	<i>66.8</i>	<i>90.6</i>	<i>126.5</i>
<i>Blood serum concentration - Children (≤14 yrs) (µg/l)</i>	<i>33.8</i>	<i>36.8</i>	<i>44.2</i>	<i>59.9</i>	<i>83.6</i>
Drinking water concentration (ng/l)	100	100	100	100	100
<i>Drinking water concentration (ng/l)</i>	<i>100</i>	<i>12</i>	<i>15</i>	<i>21</i>	<i>32</i>

*results of sensitivity test in blue italics.

Based on expert judgment, a 10% reduction in emissions is assumed, reflecting that the additional costs for advanced water treatment would incentivise emission reductions.

⁴¹ Data collected as part of the ongoing study to support the European Commission with an assessment for water treatment techniques for PFAS, Bisphenol A, and pesticides, including consideration of extended producer responsibility.

Table E-2 illustrates a 10% reduction in environmental concentrations and blood serum concentrations in direct correlation to this emission reduction.

This suggests that the second test would have a bigger impact on the results than the first test.

The 10% emission reduction has been selected based on expert judgement to illustrate what some nominally additional source control would do to the results. Considering impact of source control to achieve DWD thresholds in the main calculations is challenging without a more robust justification, but the sensitivity test suggests that the outputs of scenario 2 may be an overestimate.

Table E-2 Overview of range for scenario 2 – Test 2 – increased source control.*

	2020	2024	2030	2040	2050
Background cohort					
Population (Total) (millions)	399	393	383	367	349
Blood serum concentration - adults (µg/l)	14.0	15.6	18.7	25.4	35.4
Blood serum concentration - Children (≤14 yrs) (µg/l)	9.3	10.4	12.4	16.8	23.5
<i>Blood serum concentration - adults (µg/l)</i>	<i>14.0</i>	<i>15.6</i>	<i>16.8</i>	<i>22.8</i>	<i>31.9</i>
<i>Blood serum concentration - Children (≤14 yrs) (µg/l)</i>	<i>10.4</i>	<i>10.4</i>	<i>11.2</i>	<i>15.2</i>	<i>21.2</i>
Elevated-high Cohort					
Population (Total) (millions)	12.2	12.4	12.6	13.2	14.2
Blood serum concentration - adults (µg/l)	50.9	56.4	67.5	91.2	127.1
Blood serum concentration - Children (≤14 yrs) (µg/l)	33.8	37.5	44.8	60.5	84.2
<i>Blood serum concentration - adults (µg/l)</i>	<i>50.9</i>	<i>56.4</i>	<i>60.8</i>	<i>82.2</i>	<i>114.5</i>
<i>Blood serum concentration - Children (≤14 yrs) (µg/l)</i>	<i>33.8</i>	<i>37.5</i>	<i>40.4</i>	<i>54.5</i>	<i>75.8</i>
Elevated-low Cohort					
Population (Total) (millions)	48.7	49.3	50.4	52.7	56.7
Blood serum concentration - adults (µg/l)	32.5	36.0	43.2	58.3	81.3
Blood serum concentration - Children (≤14 yrs) (µg/l)	21.6	23.9	28.7	38.6	53.8
<i>Blood serum concentration - adults (µg/l)</i>	<i>32.5</i>	<i>36.0</i>	<i>43.2</i>	<i>52.5</i>	<i>73.2</i>
<i>Blood serum concentration - Children (≤14 yrs) (µg/l)</i>	<i>21.6</i>	<i>23.9</i>	<i>28.7</i>	<i>34.8</i>	<i>48.5</i>
Occupational cohort					
Population (Total) (millions)	0.41	0.42	0.44	0.47	0.52
Blood serum concentration – current And retired worker (µg/l)	50.9	56.4	67.5	91.2	127.1
<i>Blood serum concentration – current And retired worker (µg/l)</i>	<i>50.9</i>	<i>56.4</i>	<i>60.8</i>	<i>82.2</i>	<i>114.5</i>

*results of sensitivity test in blue italics.

F. Additional graphs

Figure F-1 Comparison of surface water concentrations across scenarios 1 – 4

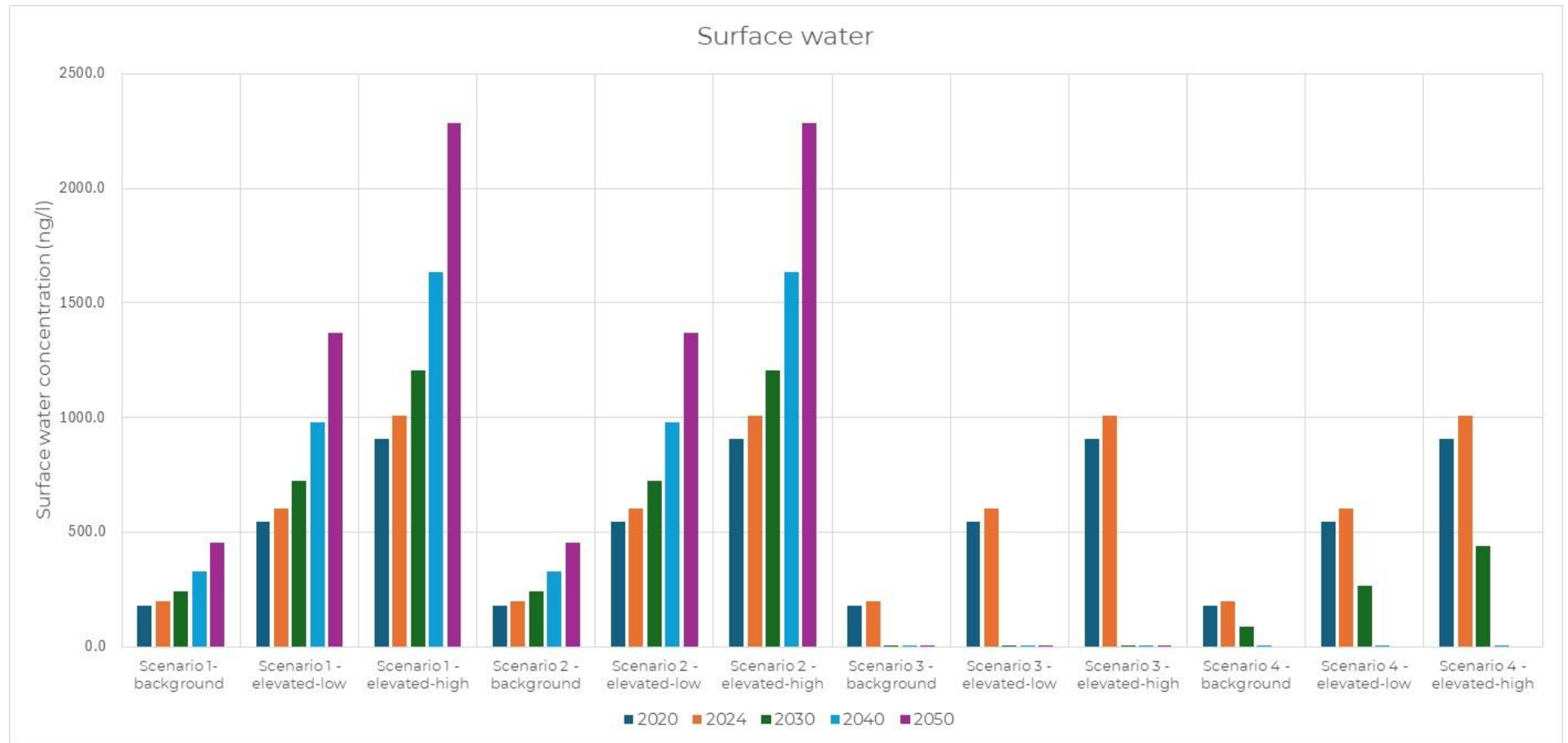


Figure F-2 Comparison of groundwater concentrations across scenarios 1 – 4

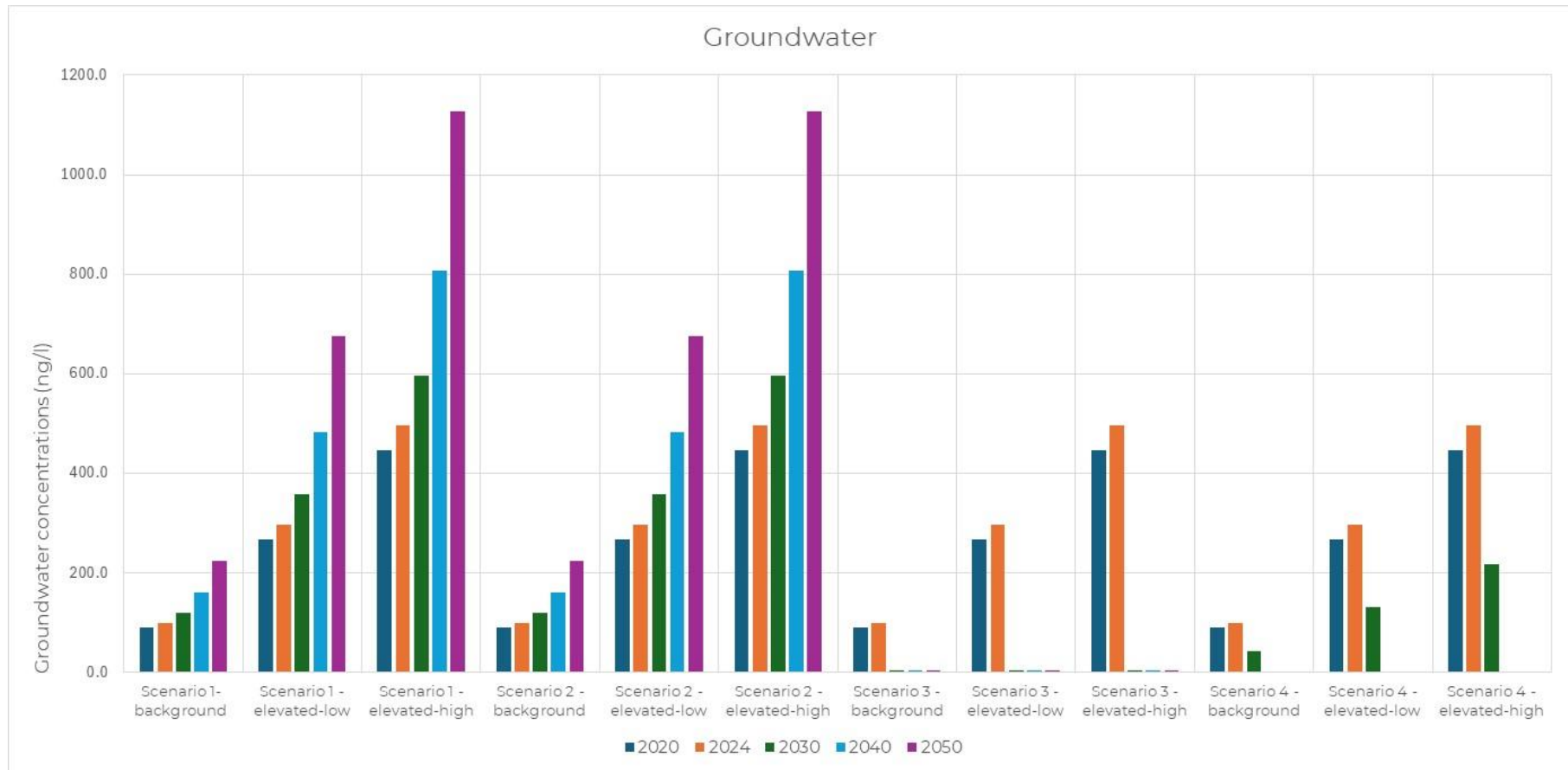
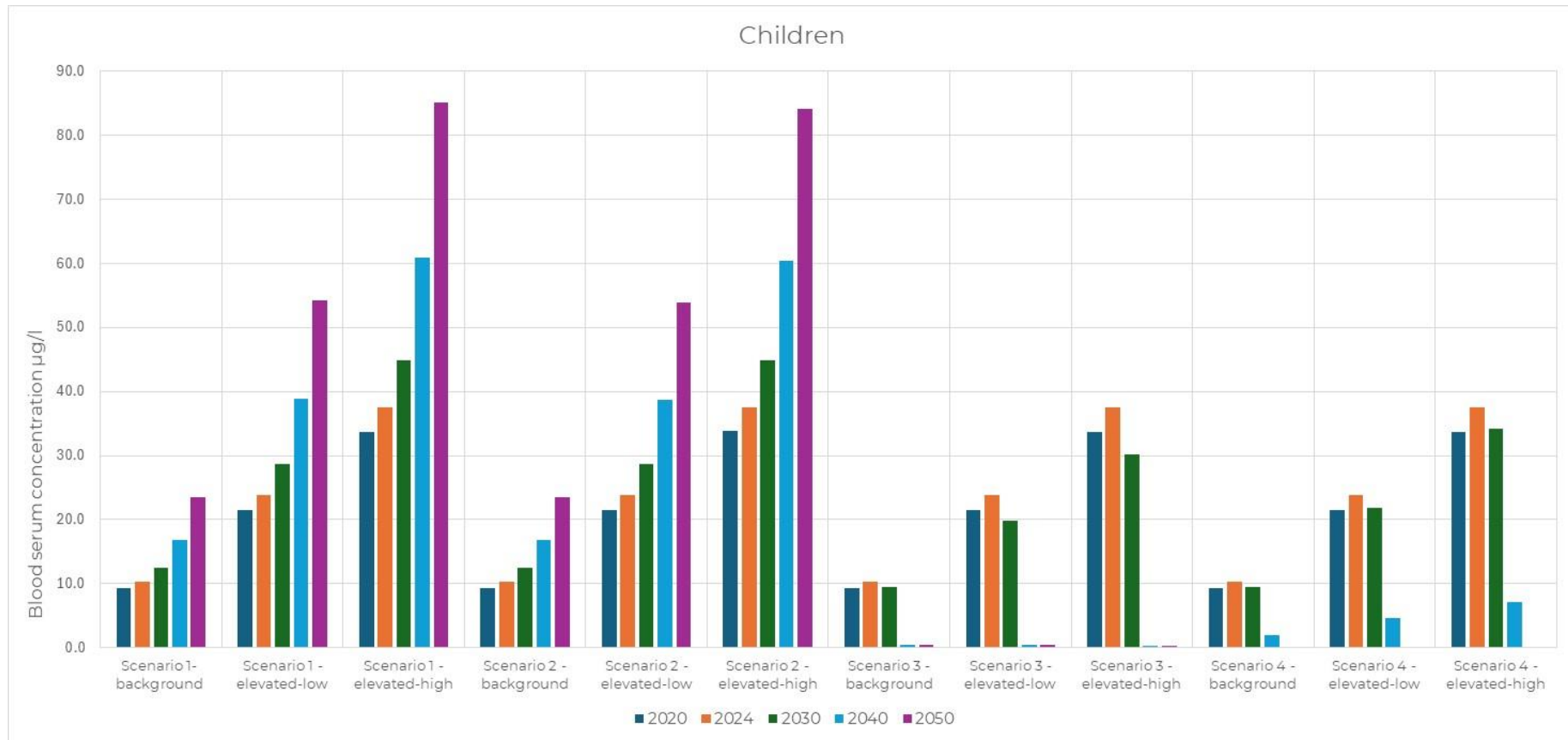


Figure F-3 Comparison of blood serum concentrations for children across scenarios 1 – 4



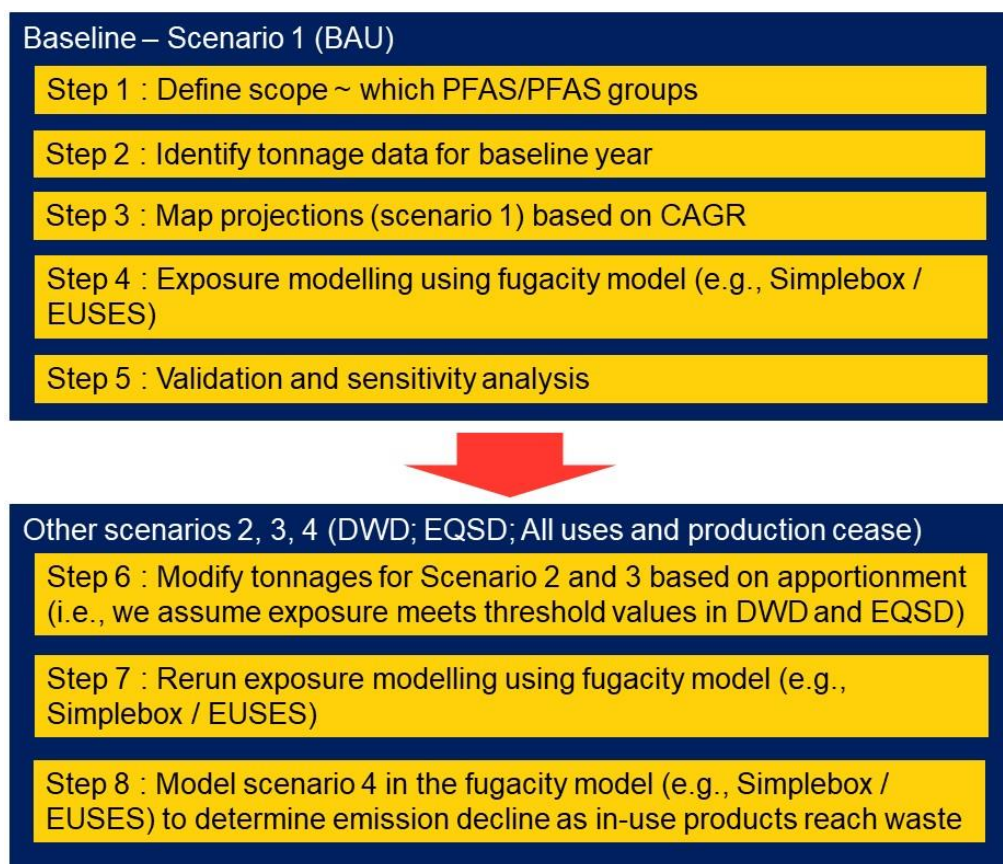
G. Original proposed methodology

G.1. Context and approach to date

G.1.1 Introduction

The Task 2 report sets out the approach for the assessment under Task 3, including the development of four scenarios. For ease of reference the workflow diagram (from the Task 2 report) is included below.

Figure 1 Task 3 workflow (from Task 2 report)



G.1.1.1 Gathering data for use in fugacity model

Under the original methodological approach, the work began by identifying data to help populate the EUSES model. The data from the universal PFAS restriction groups PFAS into three categories, which includes per fluoro alkyl acids (PFAAs) and their precursors, fluorinated gases, and polymeric PFAS. Note that side-chain fluorinated polymer has been grouped into the calculations for PFAAs and precursors on the basis that the side chains can break off creating PFAAs.

The drinking water directive (DWD) identifies 20 PFAS, 10 carboxylic acids (PFCAs), and 10 sulfonic acids (PFSAs). The Environmental Quality Standards (EQS) Directives for surface water and ground water identify 28 PFAS in total, with significant overlap to the DWD. During the inception meeting we were also asked to include trifluoroacetic acid (TFA) as an ultra-short chain PFAS. Based on the DWD, EQS and with the addition of TFA, we have 29 substances to include within the scope of the study to support the second and third scenario respectively. Additionally, during the inception meeting we were also specifically asked to include fluoropolymers within the assessment.

Based on the universal PFAS restriction, we assume that the 29 PFAA and precursors (e.g., the telomer alcohols, Gen-X and ADONA covered by the EQSD) are covered by the 'PFAAs and precursors' from the universal restriction. TFA is covered as a by-product and degradant of fluorinated gases, as well as some specific uses (consumer mixtures, textiles, explicitly outlined in the universal restriction with tonnage data separated from the other PFAAs). Polymers are outlined directly in the universal restriction.

Phys-chem properties were gathered for all 29 substances and formed the basis of a grouping approach, particularly where physical state (liquid/solid) and vapour pressure vary across the group. This was used to break the substances down into five separate groups. For each group a representative member was selected (shown in bold within the table below) to act as the basis for the phys-chem properties for the whole group.

As a general statement on representativeness for these substances compared to all PFAS (spanning up to 10,000 substances), it should be noted that the available data on tonnages of PFAS in use is incomplete, and knowledge of specific substances is limited to a small handful of PFAS, predominantly related to PFOS, PFOA, PFHxS and PFNA⁴². The data in the universal PFAS restriction effectively groups all non-polymeric, non-fluorinated gas into the "PFAAs and precursors" category. This means it likely could and does represent many more than the 29 substances include here. As a general comment, the definition used for PFAS is based on a simple chemical equation, hence why 10,000 substances are captured by the definition.

The approach in the universal PFAS restriction, groups all of these substances as PFAA precursors (along with PFAAs) on the basis that within the environment that acids are the final terminal product of any degradation.

This means that the tonnages used from the universal PFAS restriction likely represent an incomplete picture (on the one hand using the universal PFAS tonnages for all PFAAs and precursors likely overestimate the share for the 29 substances, but on the other hand there is likely missing data not submitted which means the overall tonnages are likely an underestimate). In lieu of better data, and to maintain continuity with the EU's singular most important body of data being used in a Europe wide regulatory process, we have adopted that data for the EUSES modelling.

Group	Members	Brief description of each grouping
1	TFA	This group covers the most mobile category. Physical state is as a liquid, with vapour pressure above 1,500 pascals at 25 Celsius.
2	PFBA, PFBS , PFPeA, GenX	Physical state is liquid. Vapour pressure between 0.5 and 1.2 pascals at 25 Celsius. Highly soluble in water >370 g/l at 20 Celsius.
3	PFPeS, PFHxA, PFHxS , PFPhA, PFPhS, ADONA	Physical state is liquid. Vapour pressure between 0.1 and 0.5 pascals at 25 Celsius.

⁴² Perfluorooctane sulphononic acid (PFOS); perfluorooctanoic acid (PFOA), perfluorohexane sulphononic acid (PFHxS) and perfluorononanoic acid (PFNA).

		Soluble in water between 30 and 400 g/l at 20 Celsius.
4	PFOA, PFOS, PFNA , Telomer alcohols 10:2, 8:2, 6:2	Physical state is solid. Vapour pressure between 0.02 to 0.1 pascals at 25 Celsius. Sparingly soluble in water between 0.05 to 3.4 g/l at 20 Celsius.
5	PFNS, PFDA, PFDS, PFunA, PFuNS, PFDODA, PFDODS, PFTTrDA , PFTTrDS, PFTeDA, PFTeDS, PFPeDA, PFPeDS, PFHxDA, PFHpDA, PFHxDS, PFOcDA, PFOcDS.	Physical state is solid. Vapour pressure between 0.5×10^{-6} to 0.02 pascals at 25 Celsius. Insoluble in water.

*Substance in bold denotes, the marker substance upon which physical properties have been based. Marker substances were chosen on the basis that they represent as close as possible to the mid-values for the range in their group, based on physical state, solubility, volatility, and specific gravity.

Based on the universal PFAS restriction, tonnage data for manufacture and import is provided, along with use data (tonnage) for 15 sectors (detailed within Appendix B.2 to Annex C1). This data provides estimates as the medium (for sake of brevity). The EUSES approach has modelled all three tiers as the basis for further comparison and validation against real-world monitoring data.

The universal PFAS restriction also provides environmental release categories (ERCs) for some sectors as default emission factors depending on the specific situation (again these are also provided in Appendix G.2 to Annex C1). Data has been collected for manufacture use spanning 15 sectors: (Food contact materials, metal plating and manufacture of metal products, consumer mixtures, cosmetics, ski-wax, application of F-gases, medical devices, transport, electronics and semiconductors, energy sector, construction, lubricants, petroleum and mining, firefighting foams, and textiles, upholstery, leather, apparel and carpets (TULAC). This was based on a combination of data from the universal PFAS restriction, and the related Annex XV dossier covering a REACH restriction for the use of PFAS in firefighting foams.

Where possible, tonnage data to the specific grouping has been used (e.g., if data for specific PFAS is provided), and where the restriction dossier does not provide that level of disaggregation at a sector level the total tonnage for PFAAs and precursors per sector were split evenly across groups 2 to 5, on the basis that in lieu of other data it is mathematically the most defensible. As a side comment, the data in the universal PFAS restriction was based on two surveys of industry conducted in 2021 and 2022, with the lion's share gathered in the first round. The baseline year is therefore assumed to be 2021. This is important because during that period a REACH restriction process was ongoing for perfluorocarboxylic acids (PFCAs) with chain lengths of C9 to C14, (largely represented here in group 5). The restriction on C9-C14 substances came into effect on the 25 February 2023, i.e., after the baseline year. Scenario 1 aims to understand a business-as-usual case from June 2024. Therefore, once the baseline year has been developed and growth rates applied, it takes into account the phase-out for a significant proportion of group 5.

For TFA, we conducted a literature review which suggests that between 20% and 70% of all fluorinated gases are converted to TFA in the atmosphere^{43,44,45,46}. The data from the universal PFAS restriction notes that for the high, medium and low emission estimates the same estimated tonnage for F-gas emissions is used in all estimates. We have used the conversion rates of F-gases into TFA to create a low, medium, and high estimate, based on the assumption that the low estimate equates to 20% of F-gas converted to TFA, the medium estimate 40% of F-gas converted to TFA and the high estimate that 70% of F-gas is converted to TFA. As with the other sectors and grouping, real-world monitoring data has been used to help compare and validate results to determine which set of estimates best reflect the real-world.

G.1.1.2 Developing data for projections

The details presented thus far cover the approach for developing estimates against a baseline year, assumed to be 2024 based on the data that was gathered. For all four scenarios there is a requirement to cover the current year (2025) and projections to 2050. The universal PFAS restriction makes use of predicted usage rates based on sales data and expert judgement including the use of compound annual growth rates (CAGR). This reflects that, for some sectors, the usage rates of PFAS increase, some decrease, and some stay broadly the same between now and 2050. This further recognises that market data was able to relatively confidently predict likely sales trends in the short term (to 2030) but becomes increasingly uncertain after this date.

Information on manufacture and usage trends was reported in the universal PFAS restriction for manufacture and all 15 sectors on a 'business as usual' basis. This includes the impacts to group 5 from the REACH restriction on C9-C14 PFCAs as of Spring 2023. These data were intended to be applied to the input tonnages and fugacity models to be created for reasonable time segments over the projection with linear extrapolation between segments.

G.1.1.3 Development of approach to determine blood serum concentrations

The Task 2 report noted that blood serum data from the US National Health and Nutrition Examination Survey (NHANES) is available from 2000 to 2020 in the general population for four PFAS, namely PFOS, PFOA, PFHxS and PFNA. This includes calculating trends for blood serum concentrations over that period. The outputs of Task 3 will provide data in the form

⁴³ Boutonnet et al, 1999, environmental risk assessment of trifluoroacetic acid. Published in Human and Ecological Risk Assessment (10-20% of all HFCs at sea level).

⁴⁴ Wallington et al, 2016, Atmospheric chemistry of CF₃CF=CH₂: products and mechanisms of Cl atom and OH radical initiated oxidation. Environmental science and technology vol 50 (for HFO-1234y yields of 50-70% TFA occur).

⁴⁵ UBA, 2021, reducing the input of chemicals into waters: trifluoroacetate as a PMT with many sources (for the primary HFC based air conditioners used in cars and homes, between 7-20% is converted. For HFO-1234y close to 100% conversion).

⁴⁶ Behringer et al, 2021, Persistente Abbauprodukte halogenerter Treib- und Kältemittel in der Umwelt: Art, Umweltkonzentrationen und Verbleib unter besonderer Berücksichtigung neuer halogenerter Ersatzstoffe mit kleinem Treibhauspotenzial, Abschlussbericht, UBA-Texte 36/2021 <https://www.umweltbundesamt.de/publikationen/persistente-abbauprodukte-halogenerter-kaelte> (Stand: 19.08.2021) (calculates that 50% of all HFC based air conditioners become TFA).

of exposure as drinking water and food concentrations. However, to support the cost calculations in Task 4, there is a missing step in terms of quantities uptake into the body, and quantities excreted, (i.e., if the rate of uptake is higher than the rate of excretion the concentration will increase). To help develop data in terms of blood serum concentrations (noting that the Task 2 report also notes that the health effects are most clearly defined for these four PFAS), we proposed the following approach.

Tonnage data for PFOS, PFOA, PFHxS, and PFNA has been gathered from 1990 to 2020 based on the UNEP Stockholm Convention dossiers for all four substances and global production and usage trends. Data was also gathered from literature, in particular Wang et al (2014), which details the major trends and changes in uses over the period from 1990 with projections for post 2020. The reason data has been gathered from 1990 is because for PFOS in particular (but latterly the other three) the phase-out of usage began in the early 2000s. Therefore, to properly understand the trend we need to look at the period before, during, and after the phase out.

Breakdown of use amongst sectors was also gathered for these four PFAS alongside the wider tranche of PFAAs (i.e., Wang et al, 2014, covers not only PFOA and PFNA, but the other PFCA members).

The intention was that, once the baseline year had been established and validated against real-world monitoring data, EUSES would be used to model the environmental concentrations and the trend in concentrations between 2000 and 2020. This trend would be compared against the blood serum data and current environmental monitoring data as a means of double validation over the range from 2000 to 2021 (baseline year). The relationship between emissions, environmental concentrations and blood serum concentrations would then be used to triangulate likely blood serum concentrations not just for the four named by NHANES but all 29 substances.

G.1.1.4 Model runs and outputs

The fugacity model EUSES was used with the tonnage and environmental release data described in the sub-sections above to model emissions to steady state, and determine predicted concentrations in drinking water, food, surface water, and soil at the regional scale (40,000 km² assuming a population of 2,000,000 people, hence a population density of 50 people per km²).

The results of the modelling were then compared to the real-world monitoring data. The first model run outputs provided results two to three orders of magnitude higher than real-world monitoring in drinking water, food, surface water, and soil, even in the 'low' scenario. For example, steady state in the low model run for drinking water estimated 100,000 ng/l for combined groups 2 – 5, when the real-world monitoring data predicts concentrations between 10 and 50 ng/l.

The model inputs have subsequently been amended and a further three model runs undertaken. This included the following amendments:

- Run 1: no amendments.

- Run 2 : Assume 30% of all manufactured PFAS is exported⁴⁷. Further tailor the tonnages of PFAS used within groups 2 – 5 based on the individual sector data, particularly PFAS. Amend the Henry's constant values to be aligned with the PFAS restriction which suggests PFAS is more volatile than the published data suggests.
- Run 3 : Review and update consumption rates for food based on EFSA 2022 food survey⁴⁸, this replaces the default values in the model.

The refinement of the model has meant the steady state concentrations have declined, but were still an order of magnitude higher than real world monitoring, e.g., steady state in the low model run for drinking water is now 4,000 ng/l compared to the real-world monitoring values (10 - 50ng/l in "background", and up to 100 ng/l in more affected areas).

Further refinements could be made, but this would require either a) new emission factors which is likely challenging given the complexity of the uses, b) new input tonnage data which would contradict the universal PFAS restriction, or c) further alteration of physical properties, which would then directly conflict with published values.

the validation step casts into doubt the potential of this approach, and therefore, an alternative approach is suggested based on the work to date.

The above approach was not be used because it does not reliably allow estimation of environmental concentrations that are in line with real-world concentrations without manipulation of the model/assumptions.

G.2. Emission release categories (ERCs) and emission factors used with EUSES approach

Information on release codes has been gathered from the universal PFAS restriction and restriction on the use of PFAS in firefighting foams. Note that where the dossier development for the universal restriction switched from life cycle emission estimates to air, land, water etc to a one compartment model (total environmental release), additional steps were needed to separate out the ERCs back to air, land, water.

Uses	Life Cycle Stage 1	ERC 1	Air 1	Water 1	Soil 1
Manufacturing	M	Custom	0.0006	0.0004	0
Import	n/a	n/a	n/a	n/a	n/a
FCM	IS	ERC5	0.5	0.5	0.01
Metals	IS	ERC5	0.5	0.5	0.01
Cosmetics	IS	ERC5	0.5	0.5	0.01
Consumer Mixtures	F	ERC2	0.025	0.02	0.0001
Ski Wax	F	ERC2	0.025	0.02	0.0001
Application of Gas	F	ERC2	0.025	0.02	0.0001
Med. Devices	F	ERC2	0.025	0.02	0.0001
Transport	F	ERC2	0.025	0.02	0.0001
Electronics	F	ERC2	0.025	0.02	0.0001
Energy Sector	IS	ERC5	0.5	0.5	0.01

⁴⁷ Cefic manufacturing statistics suggest that 40% of all organic basic chemicals manufactured in the EU are exported. Given the tightening regulatory landscape for PFAS, assume exports are more modest. Hence 30%.

⁴⁸ <https://www.efsa.europa.eu/en/microstrategy/foodex2-level-1>

Construction	F	ERC2	0.025	0.02	0.0001
Lubes	F	ERC2	0.025	0.02	0.0001
Mining	F	ERC2	0.025	0.02	0.0001
Firefighting Foams	F	ERC2	0.025	0.02	0.0001
TULAC	IS	ERC5	0.5	0.5	0.01

Uses	Life Cycle Stage 2	ERC 2	Air 2	Water 2	Soil 2
Manufacturing					
Import	n/a	n/a	n/a	n/a	n/a
FCM	SL	ERC10a	0.0005	0.032	0.032
Metals	SL	ERC12a	0.025	0.025	0.025
Cosmetics	PW/C	ERC8d	1	1	0.2
Consumer Mixtures	PW/C	ERC9b	0.05	0.05	0.05
Ski Wax	PW/C	Custom	0	0.5	0.5
Application of Gas	PW/C	ERC9b	0.05	0.05	0.05
Med. Devices	PW/C	ERC9a	0.05	0.05	n/a
Transport	IS	ERC5/7	0.5	0.5	0.05
Electronics	IS	ERC5/7	0.5	0.5	0.05
Energy Sector	SL	ERC11a	0.0005	0.0005	n/a
Construction	IS	ERC5	0.5	0.5	0.01
Lubes	PW/C	ERC8d	1	1	0.2
Mining	IS	ERC4	1	1	0.05
Firefighting Foams	IS	ERC7	0.05	0.05	0.05
TULAC	SL	ERC11b	1	1	n/a

Uses	Life Cycle Stage 3	ERC 3	Air 3	Water 3	Soil 3
Manufacturing					
Import	n/a	n/a	n/a	n/a	n/a
FCM					
Metals					
Cosmetics					
Consumer Mixtures					
Ski Wax					
Application of Gas					
Med. Devices					
Transport	SL	ERC10a	0.0005	0.032	0.032
Electronics	SL	ERC10a	0.0005	0.032	0.032
Energy Sector					
Construction	PW/C (0.81)	ERC8c/8f	0.15	0.1	0.2
Lubes	SL	ERC12c	0.0005	0.0005	n/a
Mining					
Firefighting Foams	PW/C	ERC9b	0.05	0.05	0.05
TULAC					

Uses	Life Cycle Stage 4	ERC 4	Air 4	Water 4	Soil 4
Manufacturing					
Import	n/a	n/a	n/a	n/a	n/a
FCM					
Metals					
Cosmetics					
Consumer Mixtures					
Ski Wax					
Application of Gas					
Med. Devices					
Transport					
Electronics					
Energy Sector					
Construction	SL (0.19)	ERC10a	0.0005	0.032	0.032
Lubes					
Mining					
Firefighting Foams					
TULAC					

Annex C2 – Blood serum concentrations for specific PFAS species by cohort and year

Table 47 – Scenario 1 blood serum concentrations (µg/l)

Cohort / PFAS species	2024	2030	2040	2050
<u>Background cohort</u>				
Adults	15.6	18.7	25.4	35.4
PFOA	1.81	1.71	1.55	1.44
PFOS	5.04	3.73	2.26	1.41
PFNA	0.77	0.90	1.16	1.54
PFHxS	0.68	0.61	0.51	0.44
Other PFAAs	7.30	11.78	19.89	30.60
Children (≤14 yrs)	10.4	12.4	16.8	23.5
PFOA	3.57	3.37	3.05	2.85
PFOS	1.64	1.21	0.73	0.46
PFNA	0.35	0.41	0.53	0.70
PFHxS	0.83	0.75	0.62	0.54
Other PFAAs	5.44	8.08	13.16	20.16
<u>Elevated - high cohort</u>				
Adults	56.4	67.7	91.7	128.1
PFOA	19.46	18.34	16.62	15.53
PFOS	5.65	4.18	2.53	1.58
PFNA	0.50	0.58	0.75	1.00
PFHxS	1.91	1.72	1.44	1.24
Other PFAAs	28.88	42.85	70.36	108.75
Children (≤14 yrs)	37.5	44.9	60.9	85.1
PFOA	22.58	21.28	19.29	18.02
PFOS	1.84	1.36	0.82	0.51
PFNA	0.23	0.26	0.34	0.45
PFHxS	2.22	2.00	1.67	0.00
Other PFAAs	10.48	19.94	38.69	64.57
<u>Occupational cohort</u>				
Adults	56.4	67.7	91.7	128.1
PFOA	19.460	18.345	16.624	15.533
PFOS	5.650	4.180	2.530	1.579
PFNA	0.500	0.582	0.751	0.999
PFHxS	1.910	1.717	1.438	1.242
Other PFAAs	28.880	42.854	70.356	108.746

Note: Concentrations for the elevated - low cohort are the average between the background and elevated - high cohorts.

Table 48 – Scenario 2 blood serum concentrations (µg/l)

Cohort / PFAS species	2024	2030	2040	2050
<u>Background cohort</u>				
Adults	15.6	18.7	25.4	35.4
PFOA	1.8	1.7	1.5	1.4
PFOS	5.0	3.7	2.3	1.4
PFNA	0.8	0.9	1.2	1.5
PFHxS	0.7	0.6	0.5	0.4
Other PFAAs	7.3	11.8	19.9	30.6
Children (≤14 yrs)	10.4	12.4	16.8	23.5
PFOA	2.1	2.0	1.8	1.7
PFOS	1.6	1.2	0.7	0.5
PFNA	0.4	0.4	0.5	0.7
PFHxS	0.8	0.7	0.6	0.5
Other PFAAs	5.4	8.1	13.2	20.2
<u>Elevated - high cohort</u>				
Adults	56.4	67.5	91.2	127.1
PFOA	19.5	18.3	16.5	15.4
PFOS	5.7	4.2	2.5	1.6
PFNA	0.5	0.6	0.7	1.0
PFHxS	1.9	1.7	1.4	1.2
Other PFAAs	28.9	42.8	70.0	107.9
Children (≤14 yrs)	37.5	44.8	60.5	84.2
PFOA	22.6	21.2	19.1	17.8
PFOS	1.8	1.4	0.8	0.5
PFNA	0.2	0.3	0.3	0.4
PFHxS	2.3	2.1	1.7	1.5
Other PFAAs	10.5	19.9	38.4	63.9
<u>Occupational cohort</u>				
Adults	56.4	67.5	91.2	127.1
PFOA	19.5	18.3	16.5	15.4
PFOS	5.7	4.2	2.5	1.6
PFNA	0.5	0.6	0.7	1.0
PFHxS	1.9	1.7	1.4	1.2
Other PFAAs	28.9	42.8	70.0	107.9

Note: Concentrations for the elevated - low cohort are the average between the background and elevated - high cohorts.

Table 49 – Scenario 3 blood serum concentrations (µg/l)

Cohort / PFAS species	2024	2030	2040	2050
<u>Background cohort</u>				
Adults	15.6	12.6	0.7	0.7
PFOA	1.810	1.149	0.042	0.028
PFOS	5.040	2.511	0.062	0.028
PFNA	0.770	0.604	0.032	0.030
PFHxS	0.680	0.412	0.014	0.009
Other PFAAs	7.300	7.931	0.543	0.598
Children (≤14 yrs)	10.4	9.5	0.5	0.5
PFOA	2.100	1.516	0.049	0.033
PFOS	1.640	0.929	0.020	0.009
PFNA	0.350	0.312	0.014	0.014
PFHxS	0.830	0.571	0.017	0.011
Other PFAAs	5.440	6.191	0.360	0.394
<u>Elevated - high cohort</u>				
Adults	56.4	45.4	0.5	0.5
PFOA	19.460	12.300	0.090	0.061
PFOS	5.650	2.803	0.014	0.006
PFNA	0.500	0.391	0.004	0.004
PFHxS	1.910	1.151	0.008	0.005
Other PFAAs	28.880	28.734	0.383	0.424
Children (≤14 yrs)	37.5	30.1	0.3	0.3
PFOA	22.578	14.271	0.105	0.070
PFOS	1.838	0.912	0.004	0.002
PFNA	0.227	0.178	0.002	0.002
PFHxS	2.331	1.405	0.010	0.006
Other PFAAs	10.480	13.370	0.210	0.251
<u>Occupational cohort</u>				
Adults	56.4	45.4	0.5	0.5
PFOA	19.4600	12.3001	0.0905	0.0605
PFOS	5.6500	2.8030	0.0138	0.0061
PFNA	0.5000	0.3905	0.0041	0.0039
PFHxS	1.9100	1.1514	0.0078	0.0048
Other PFAAs	28.8800	28.7336	0.3829	0.4236

Note: Concentrations for the elevated - low cohort are the average between the background and elevated - high cohorts.

Table 50 – Scenario 4 blood serum concentrations (µg/l)

Cohort / PFAS species	2024	2030	2040	2050
<u>Background cohort</u>				
Adults	15.6	14.3	3.0	0.0
PFOA	1.810	1.300	0.181	0.000
PFOS	5.040	2.841	0.264	0.000
PFNA	0.770	0.683	0.135	0.000
PFHxS	0.680	0.466	0.060	0.000
Other PFAAs	7.300	8.973	2.325	0.000
Children (≤14 yrs)	10.4	9.5	2.0	0.0
PFOA	2.100	1.508	0.210	0.000
PFOS	1.640	0.925	0.086	0.000
PFNA	0.350	0.311	0.061	0.000
PFHxS	0.830	0.569	0.073	0.000
Other PFAAs	5.440	6.160	1.539	0.001
<u>Elevated - high cohort</u>				
Adults	56.4	51.6	10.7	0.0
PFOA	19.46	13.98	1.94	0.00
PFOS	5.65	3.19	0.30	0.00
PFNA	0.50	0.44	0.09	0.00
PFHxS	1.91	1.31	0.17	0.00
Other PFAAs	28.88	32.65	8.22	0.00
Children (≤14 yrs)	37.5	34.2	7.1	0.0
PFOA	22.58	16.22	2.25	0.00
PFOS	1.84	1.04	0.10	0.00
PFNA	0.23	0.20	0.04	0.00
PFHxS	2.33	1.60	0.21	0.00
Other PFAAs	10.48	15.19	4.52	0.00
<u>Occupational cohort</u>				
Adults	56.4	51.6	10.7	0.0
PFOA	19.460	13.978	1.943	0.001
PFOS	5.650	3.185	0.296	0.000
PFNA	0.500	0.444	0.088	0.000
PFHxS	1.910	1.308	0.168	0.000
Other PFAAs	28.880	32.653	8.225	0.005

Note: Concentrations for the elevated - low cohort are the average between the background and elevated - high cohorts.

Annex D – Task 4 report (cost assessment)

Table of Contents

1. Introduction	3
1.1. This report.....	3
1.2. Project context	3
1.3. Task 4 purpose, scope, and method	3
2. Summary of Task 3 Scenario modelling results	5
3. Human health costs of PFAS pollution	7
3.1. Methodology.....	7
3.1.1. Overview	7
3.1.2. Step 1 Affected populations.....	10
3.1.3. Step 2 PFAS exposure	11
3.1.4. Step 3 Health risks and exposure-risk relationships.....	14
3.1.5. Step 4 Health impact analysis	16
3.1.6. Step 5 Human health cost valuation.....	19
3.1.7. Step 6 Sensitivity analysis	20
3.2. Results.....	22
3.2.1. Current costs of PFAS pollution.....	22
3.2.2. Future costs Scenario 1: Business as usual for emissions.....	28
3.2.3. Future costs Scenario 2: Drinking Water Directive (DWD).....	31
3.2.4. Future costs Scenario 3: Environmental Quality Standards (EQS)	32
3.2.5. Future costs Scenario 4: Total stop of production and use of PFAS	35
3.2.6. Comparison of scenarios.....	39
4. Direct ecosystem service costs	42
4.1. Methodology	42
4.2. Results	42
4.2.1. Potential pathways from PFAS exposure to ecosystem service impacts.....	42
4.2.2. Case study 1: Effects on algae and climate regulation	45
4.2.3. Case study 2: Effects on pollinators and food provisioning.....	49
4.2.4. Case study 3: Effects on poultry, livestock, and food provisioning.....	51
4.2.5. Case study 4: Effects on aquaculture and food provisioning	54
4.2.6. Considerations of future costs	56
4.2.7. Conclusions on ecosystem service costs from PFAS pollution and limitations in the assessment.....	57
5. Soil remediation and water treatment costs	58
5.1. Methodology.....	58

5.1.1. Step 1 Define PFAS concentration thresholds in water:	58
5.1.2. Step 2 Identify potential water treatment volumes and soil remediation sites: ...	59
5.1.3. Step 3 Apply unit costs for soil remediation and water treatment to sites/volumes:	60
5.1.4. Sensitivity analysis.....	61
5.2. Results.....	62
5.2.1. Current costs.....	62
5.2.2. Future costs Scenario 1: Business as usual	62
5.2.3. Future costs Scenario 2: Drinking Water Directive (DWD)	64
5.2.4. Future costs Scenario 3: Environmental Quality Standards (EQS)	66
5.2.5. Future costs Scenario 4: Total stop of production and uses of PFAS.....	67
5.2.6. Comparison of scenarios.....	68
6. Conclusions	69
6.1. Human health and environmental costs of PFAS pollution	69
6.1.1. Scenario 1 (Business as usual)	70
6.1.2. Scenario 2 (Drinking Water Directive).....	71
6.1.3. Scenario 3 (Environmental Quality Standards)	71
6.1.4. Scenario 4 (Total stop of production and uses of PFAS).....	72
6.1.5. Scenario Comparison	73
6.2. Gaps and limitations.....	76
6.2.1. Concerning the human health cost assessment.....	76
6.2.2. Concerning the ecosystem service cost assessment.....	79
6.2.3. Concerning the remediation/treatment cost assessment.....	80
Appendices to Annex D.....	82
A. Illustrating the estimation of attributable health impacts of PFAS exposure with an example (PFOS exposure through low (and very low) birth weight)	83
B. Water treatment unit costs	85

1. Introduction

1.1. This report

WSP and Ricardo are supporting DG ENV with a **study on the cost of PFAS pollution for our society**¹ under framework contract ENV.01/FRA/2023/0006 *Economic analysis of environmental policies and analytical support in the context of Better Regulation* led by Trinomics B.V.

This is the **'Task 4 Report'**, which uses the evidence collected (Task 1), methodology specified and agreed with the Commission (Task 2) and the scenario-based analysis of future PFAS pollution in the European Economic Area (EEA) (Task 3) to develop monetary estimates of current and possible future societal costs of PFAS pollution in the EU and the EEA (Task 4).

1.2. Project context

The objective of this study is to complement and update the existing sources of information (such as the Goldenman *et al.* (2019) study for the Nordic Council of Ministers²) on the overall external costs of PFAS pollution in the EU and in the EEA. More specifically, the objective of this contract is to present information on all components of the societal costs of PFAS pollution, expressed in monetary terms and based on an up-to-date list of impacts of PFAS on the environment and human health. This assessment will describe not only the cost of current pollution but also the future costs under a limited number of prospective scenarios representing hypothetical future developments, hence showing the current and future costs of inaction compared to alternative levels of action.

The project is organised in the following tasks:

- Task 1: Literature review of existing studies on the costs of PFAS pollution and identification of possible knowledge gaps
- Task 2: Development of a methodology to update and expand the existing knowledge on societal costs of current and future PFAS pollution in the EEA
- Task 3: Development of 4 prospective scenarios representing hypothetical PFAS future pollution levels in EEA
- Task 4: Assessment of the societal costs of current and future PFAS pollution (up to 2050, under hypothetical future scenarios)

1.3. Task 4 purpose, scope, and method

This task applies the methodology developed in Task 2 of this project to calculate monetary estimates of human health and environmental costs of PFAS pollution in the EU and the EEA under the scenarios from Task 3, accumulated over time until now, for 2030, for 2040 and for 2050. The report also presents an analysis of the results in terms of different cost

¹ Specific Contract No 090202/2024/924706/ENV.B2

² Goldenman *et al.* (2019). *The cost of inaction: A socioeconomic analysis of environmental and health impacts linked to exposure to PFAS*. Available at: [THE COST OF INACTION](#)

elements, costs borne by different parts of EU society, and differences between the scenarios, as well as sensitivity analysis.

The Table below summarises the scope of the methods and, thus, overall study.

Study dimension	Scope description
Geographies	EEA
Timeline	Present day (2024) up to 2050 under hypothetical, prospective scenarios (Task 3).
Base year	All monetary figures will be presented in constant, 2024 euros
Substances	There might be more than 10,000 per- and poly-fluoroalkyl substances (PFAS). ³ This study reviewed the available evidence for three major groups of PFAS: PFAAs and precursors to PFAAs, polymeric PFAS, and fluorinated gases, including some of the most common substances (i.e., PFOA, PFOS, PFHxS, TFA and PTFE, PVDF). The scope of substances covered by the cost estimates is based on the available evidence and methods to quantify the associated health and environmental costs. This is discussed in the methodology sections of this study.

Costs are presented for the years 2024, 2030, 2040 and 2050. For each scenario, they are presented as undiscounted annual values, as present values (PVs) of accumulated costs over the whole period based on a discount rate of 3%⁴ and as equivalent annual costs (EACs) for the comparison across scenarios. Square brackets indicate the potential range of values, taking into account the estimates from the sensitivity analysis⁵.

The rest of this document contains:

- A summary of the **scenario-based projects of PFAS pollution** based on modelling conducted under Task 3 (Section 2)
- The monetary estimates of **human health costs** attributable to PFAS pollution, including an overview of methods, results and sensitivity analysis (Section 3)
- The monetary estimates of **ecosystem service costs** attributable to PFAS pollution (Section 4)
- The monetary estimates of **remediation/treatment costs** attributable to PFAS pollution (Section 5)
- Concluding remarks (Section 6)
- Appendices with selected additional details on methodology and results

³ ECHA (2023). ECHA publishes PFAS restriction proposal. <https://echa.europa.eu/-/echa-publishes-pfas-restriction-proposal>

⁴ In line with the European Commission's Better Regulation Toolbox, Chapter 8.

⁵ For example, "€39.5 [0.005-600.5] billion" indicates a medium estimate of €39.5 billion, a low sensitivity estimate of €0.005 billion, and a high sensitivity estimate of €600.5 billion.

Previous task reports provide a detail account of findings from the literature review (Task 1 Report), the methodology (Task 2 Report) and the scenario modelling (Task 3 Report).

2. Summary of Task 3 Scenario modelling results

The objective of Task 3 was to determine the current and future pollution levels of PFAS in the European Economic Area (EEA) under four hypothetical 'what if' scenarios:

- **Scenario 1** – A business-as-usual (BAU) situation reflecting the regulatory status as of June 2024 (hence not reflecting the later implementation of the REACH restrictions on PFHxA, on PFAS in firefighting foams, nor the proposed universal PFAS restriction).
- **Scenario 2** – Full compliance with the recast Drinking Water Directive (DWD) thresholds of 100 ng/l for the sum of 20 PFAS and 500ng/l for "Total PFAS".
- **Scenario 3** – Full compliance with the Commission proposed quality standard of 4.4 ng/l PFOA-equivalent for the sum of 24 PFAS under the Environmental Quality Standards and Groundwater Directives (EQSD and GWD) for surface water and groundwater, respectively.
- **Scenario 4** – A total stop of production and uses of PFAS. It is assumed that certain uses will cease immediately, while consumer uses are phased out gradually to reflect that stockpiles of articles that are already in use would continue to be used until their end of life.

The overall approach was built on Goldenman et al. (2019), but incorporated new data, notably PFAS emission projections from the universal PFAS restriction proposal (2023 version of the Background Document) as well as PFAS manufacturing and PFAS using sites identified by the Forever Pollution project (which are assumed to be the main hotspots of PFAS contamination). In line with Goldenman et al. (2019), three exposure **cohort groups** were created to assess different levels of PFAS exposure, in addition to the background exposure cohort:

- Those who live far from the point of release and contamination, termed 'background' cohort⁶.
- Those who live close to sites of production and use of PFAS, termed the 'elevated' cohort. In our study, this has been further sub-divided into elevated – high for those living the closest to production/use sites and exposed to concentrations of $\geq 100\text{ng/l}$ and elevated – low for those living further away but still within the area of elevated

⁶ Clarifying note: Under the Water Framework Directive, "background concentrations" are a defined term relating to natural background concentrations, i.e., concentrations in water of named substances that occur naturally due to e.g., geological conditions, such as metals. In this report, 'background concentrations' and 'background cohort' have been used to align with the terminology presented in Goldenman et al. (2019) as the key reference used to help guide the methodology. PFAS are man-made chemicals and do not naturally occur. Therefore, some care is needed not to misinterpret or conflate 'background concentrations', with the WFD use of terminology.

concentrations (i.e., exposed to concentrations above background).

- Those who work directly in facilities producing and/or using PFAS where exposure occurs as part of their occupation (termed the 'occupational' cohort).

Task 3 then estimated, for each scenario and over time, the number of PFAS producing/using sites, as well as the population, area, concentrations in drinking water, surface water, groundwater and blood serum for each cohort.

The methodology and results are documented in detail in the Task 3 report. The results of Task 3 form the basis of the cost assessment (i.e., Task 4 estimates the societal costs associated with the pollution levels determined by Task 3). Therefore, a summary of the **key conclusions** is also provided in the following paragraphs.

The universal PFAS restriction dossier (2023 version of the Background Document) provides data for a business-as-usual scenario where emissions will multiply by 2.5 to 2.75 times between 2020 and 2050. This large increase in emissions means there could be a two and a half times increase of PFAS concentrations in the environmental media and human blood serum, and that, according to our calculations, there could be an increase in the area exposed to elevated concentrations of PFAS from 8% of the area of the EEA in 2020 to 10.5% by 2050, and subsequent increase in the exposed cohorts.

For the baseline year (2024), 86% of the EEA population is estimated to be in the background cohort, and 14% in the elevated cohort (comprising 3% in the elevated-high, and 11% in the elevated-low sub-cohorts), and <1% in the occupational cohort. Depending on the specific scenario, by 2030 between 80 and 99% of the population is in the background cohort. In scenarios 1 (BAU) and 2 (DWD implementation), the increase in emissions by two and a half times the baseline year (2020 in the universal REACH restriction dossier) could mean that, by 2050, 17% of the EEA population is in the elevated cohort.

Assuming drinking water threshold (100 ng/l) is respected everywhere in the EEA, scenario 2 is estimated to lead to a minor reduction in blood serum concentrations (<2µg/l). The majority of drinking water supplies are calculated as being well below the 100 ng/l in scenario 1, even by 2050. In cases where water was predicted to exceed the limit in scenario 1 (such as the elevated-high sub-cohort from 2020, and elevated-low sub-cohort by 2040), limiting the intake of PFAS via drinking water under scenario 2 resulted in limited reductions in blood serum concentrations, due to more significant intake of PFAS via other pathways such as food (along with dust and air, not included in the study).

The proposed water quality standard (4.4 ng/l PFOA-equivalent) considered in scenario 3 is very low compared to surface water and groundwater concentrations (in the tens to low hundreds of ng/l). Compliance with this proposed threshold in surface water and groundwater would be equivalent to a reduction of emissions by 99% compared to the year 2024. This could result in a reduction in blood serum concentration of a similar order (95-99%) by 2050. For the background cohort, adult blood serum concentrations could decline from 14 µg/l in 2020 to 0.7 µg/l in 2050. For the elevated-high cohort, blood serum concentrations could fall drastically from 51 µg/l in 2020 to 0.7 µg/l in 2050.

Scenario 4 (the stop of PFAS use and production) models a significant reduction in emissions from 2030 (64% reduction compared to 2024), with continued decline reaching zero by 2040. The results of scenario 4 show that blood serum concentrations could fall by 100% by 2050 (i.e., for both background and elevated cohorts (high and low), PFAS in blood

could be eliminated by 2050, assuming a complete stop of PFAS use and emissions from 2030). The rate of decline of PFAS in blood serum after limiting exposure could take between 15 and 20 years, depending on the initial concentration level (i.e. it takes longer for elevated concentrations to reach zero).

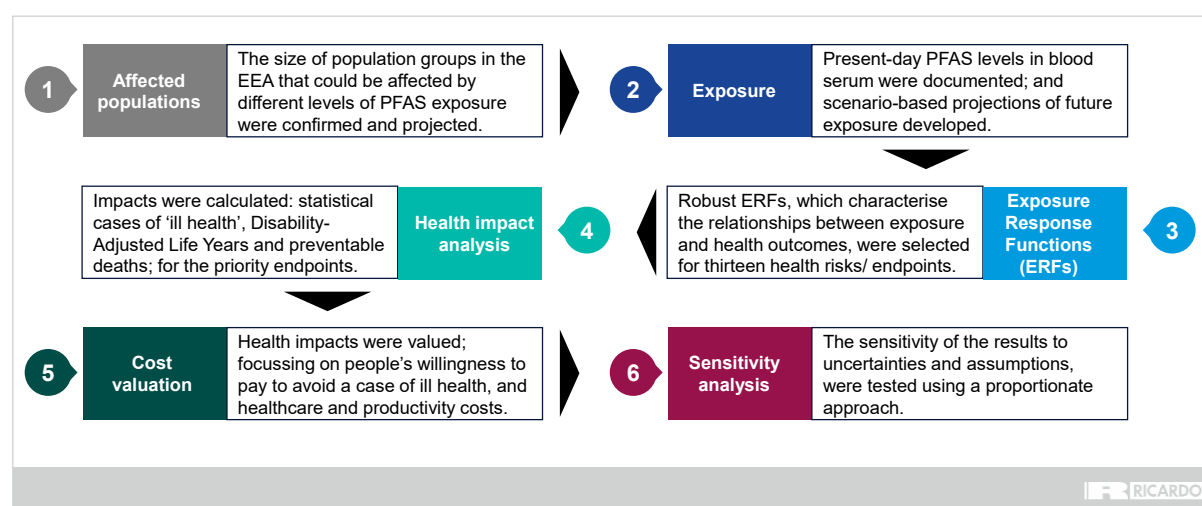
3. Human health costs of PFAS pollution

3.1. Methodology

3.1.1. Overview

We have followed the methodology developed and reviewed as part of this project (Task 2) **to quantify and value human health costs attributable to PFAS exposure in the EEA**. The methods applied build on the literature and evidence collected under Task 1, including Goldenman *et al.* (2019)⁷, best practice guidelines, and linked to the outputs of scenario modelling of future PFAS pollution under Task 3. The Figure below presents a diagrammatic overview of the methodology, followed by a stepwise description.

Figure 3-1 Method to quantify and value the human health costs of PFAS pollution



The Table below identifies the main inputs for each of these six steps, assumptions and sources of evidence. Further detail is provided in the following sections and the 'Task 2 Report' under this project.

⁷ Goldenman *et al.* (2019). *The cost of inaction: A socioeconomic analysis of environmental and health impacts linked to exposure to PFAS*. Nordic Council of Ministers. Available at: <https://norden.diva-portal.org/smash/get/diva2:1295959/FULLTEXT01.pdf>

Table 3-1 Summary of the steps for the human health cost assessment, including key inputs, core assumptions and main sources

Steps	Key inputs	Core assumptions	Main sources
1. Estimating the size of the population across relevant groups	Population data	Estimates in different population groups and future projections	Scenario modelling (Task 3 report), Eurostat, the World Bank
2. Establishing the levels of PFAS exposure across population groups	- Definition of exposure as PFAS levels in human blood serum - Recent monitoring and case studies (e.g., Forever Pollution project, scientific literature) - Estimated prospective blood serum levels of PFOA, PFOS, PFHxS and PFNA under prospective scenarios	Scenario projections for the future (Task 3)	HMB4EU and scientific literature (Task 2 report) ⁸ , Scenario modelling (Task 3 report)
3. Identification of relevant health risks or endpoints and ERFs	- Exposure-response functions (ERFs) for PFOA, PFOS, PFHxS and PFNA as outputs of scientific studies - Assessment of confidence or strength of evidence associated with up to 13 endpoints	- Levels of confidence or strength of evidence - Applicability	Scientific literature ⁹
4. Quantification of impacts	- Baseline levels of risk (incidence rates), and the population size and ERFs confirmed in previous steps - Disability-Adjusted Life Years (DALYs) attributable to a case of ill health, by endpoint	- Applicability - Projections for the drawing on historical trends and relationships	IHME, Goldenman <i>et al.</i> (2019), Plass <i>et al.</i> (2023), Obsekov, Kahn and Trasande (2023) and other literature studies
5. Monetary valuation of impacts	- Unit values, such as Value Of a Life Year (VOLY), Value of a Statistical Life (VSL) and/or reference case values based on willingness to pay studies - Typical care pathways and medical cost values per case - Sickness absence valuation - Factors, including GDP deflator, wages and salaries, etc.	Applicability, focusing on 'scale' or 'magnitude'	ECHA, OECD, Better Regulation Guidelines, Eurostat, and scientific and/or grey literature
6. Sensitivity analysis	Sensitivity scenarios developed based on the evidence collected and assessed in previous steps	Levels of confidence or strength of evidence	Previous sources and tailored analysis for this study

⁸ Sources include HMB4EU and related studies such as Richterova *et al.* (2023), Uhl *et al.* (2023), Fabelova *et al.* (2023); and other studies such as Andersen *et al.* (2024), Goen *et al.* (2023), Palesova *et al.* (2023), Plass *et al.* (2023), Rihackova *et al.* (2023), DeLuca *et al.* (2022), Papadopoulou *et al.* (2021), Gebbink *et al.* (2020), Pitter *et al.* (2020), Poonthong *et al.* (2020), Balk *et al.* (2019), etc.

⁹ Sources are detailed on the Task 1 Report, including Mahdavi *et al.* (2024), Ebel *et al.* (2023), Hu *et al.* (2023), Pan *et al.* (2023), Pinney *et al.* (2023), Plass *et al.* (2023), Obsekov, Kahn & Trasande (2023), Xu *et al.* (2023), Zhang *et al.* (2023), Costello *et al.* (2022), Bartell and Vieira (2021), Birru *et al.* (2021), Fenton *et al.* (2021), Dalsager *et al.* (2021), Steenland *et al.* (2021), Shearer *et al.* (2021), Banjabi *et al.* (2020), European Food Safety Authority (2020), Eves *et al.* (2020), Goldenman *et al.* (2019), Impinen *et al.* (2019), Govarts *et al.* (2018), Lauritzen *et al.* (2018), Liu *et al.* (2018), Steenland *et al.* (2018), Sun *et al.* (2018), Wielsøe *et al.* (2017), Dalsager *et al.* (2016), Khalil *et al.* (2016), Kim *et al.* (2016), Zhang *et al.* (2015), Johnson *et al.* (2014), Vagi *et al.* (2014), Eriksen *et al.* (2013), Wen *et al.* (2013), Buck Louis *et al.* (2012), Min *et al.* (2012), Steenland & Woskie (2012), Whitworth *et al.* (2012), Shankar *et al.* (2011), Stein *et al.* (2009).

This method has drawn on the evidence identified in the literature review conducted as part of this project, seeking to broaden and deepen analyses conducted in previous studies, such as Goldenman *et al.* (2019)¹⁰. More specifically, we have:

1. Expanded the analysis to cover additional health risks or endpoints (including 13 endpoints) associated with PFAS exposure and specific PFAS types (four substances, which is more than included in the literature precedent, typically two regulated PFAS), drawing on a literature review of the latest available evidence and the confidence in the findings of association of PFAS exposure to these health risks,
2. Reflected the latest available evidence in the exposure risk relationships employed in the study, and
3. Expanded the coverage of the types of costs included in the analysis beyond the monetisation of disease burden using non-market methods, by systematically including the indirect costs of healthcare and productivity losses.

However, **there remain gaps and limitations, primarily bound by the lack of evidence also faced by previous studies.** In brief, the main gaps include the:

- Lack of detailed evidence on the size of more or less exposed population groups.
- Lack of evidence of PFAS concentration in blood serum and future projections.
- Limited research into the association of PFAS in blood and health risks for the majority of PFAS, lack of quantitative exposure-risk relationships estimated, and limitations in confidence of available studies.
- Limited to no understanding of mixture/cumulative effects of exposure to multiple PFAS (and/or other chemicals or risk factors).
- Lack of readily accessible studies into the burden of disease, care pathways, medical costs, and sickness absence associated with each endpoint.

As a result, the study has limitations, primarily including **the lack of coverage of PFAS and health risks due to limitations in the availability and/or weight of evidence (i.e., the lack of PFAS substances studied, lack of endpoints examined in depth, limited understanding of the cumulative effects of PFAS exposure, etc).**

The methodology developed for this study excludes the quantitative analysis of substances for which there is no evidence of exposure, health risk association nor exposure-response functions (ERFs) characterised in the literature, which is considered reasonable and proportionate. The literature was also uncertain on whether the impacts represented by ERFs captured the isolated effects of a substance, despite other PFAS being present in human blood. Therefore, the methodology has considered the results for each endpoint or health risk to correspond to the maximum estimated health impact for one single PFAS out of all PFAS associated with that endpoint or health risk instead of aggregating the estimated impacts across all associated PFAS.

¹⁰ Goldenman *et al.* (2019). *The cost of inaction: A socioeconomic analysis of environmental and health impacts linked to exposure to PFAS*. Nordic Council of Ministers. Available at: <https://norden.diva-portal.org/smash/get/diva2:1295959/FULLTEXT01.pdf>

Overall, this has meant that **only four of potentially 10,000 substances have been considered quantitatively in this assessment, and in isolation from one another (i.e., no cumulative effects analysis)**. Furthermore, these four PFAS (namely PFOA, PFOS, PFHxS and PFNA) are already regulated in the EU in different ways, such as under POPs regulation, REACH, food safety rules, drinking water, and packaging legislation, and hence, the health impacts estimated here mainly consider the effects of legacy pollution.

This is the main limitation of this (and other studies), which, in our view, **suggests that the estimates of health costs attributable to PFAS exposure and associated monetary values in this study likely represent a lower bound to the total, potential health damage that PFAS exposure may be causing in the EEA.**

There are other limitations with quantification of health impacts, as well as their valuation (e.g., uncertainties in ERFs, monetary unit values, etc.). However, the evidence review conducted for this study suggests these limitations are dwarfed by the issues presented by the lack of coverage of PFAS and the lack of evidence on thousands of substances and the potential health risks associated with people's exposure to them.

3.1.2. Step 1 Affected populations

In 2024, there were 455,271,190 people living in the EEA¹¹. Scenario modelling was conducted to produce population estimates by cohort in the future (Task 3). We have used this and other available evidence (Eurostat, World Bank) to disaggregate this population further, into mutually exclusive groups of people with different levels of exposure and risk from PFAS pollution, such as adults (exposed workers), adults (other, general population), teenagers (general population), children in age groups (general population), pregnant women (general population) and a cross-cutting group of people living near PFAS-manufacturing or PFAS-using industrial sites in the EEA (which are excluded from the other groups). The Table below presents population estimates for 2024 and describes inputs from this project's Task 3 analysis and other key assumptions (see Task 3 Report for details).

Table 3-2 Potentially affected EEA populations by group (Sources: Task 3 of this project, Eurostat¹², WB¹³, Frick (2021)¹⁴ and Andersen *et al.* (2000)¹⁵)

Population group	Baseline population (2024)	Proportion of females in 2024 (% of group)	Inputs from Task 3 and other assumptions
Total population	455,271,190	51.1%	Estimate and evolution based on Task 3.
Adults (Exposed workers)	423,204	51.6%	Estimate and evolution of 'Occupational cohort' based on Task 3.

¹¹ Population estimates are derived from Task 3, based on data from Eurostat and the World Bank.

¹² <https://ec.europa.eu/eurostat/en/web/products-eurostat-news/w/ddn-20240711-1>;
<https://ec.europa.eu/eurostat/web/interactive-publications/demography-2024>

¹³ <https://databank.worldbank.org/source/population-estimates-and-projections>

¹⁴ Frick (2021). Advanced maternal age and adverse pregnancy outcomes. Available at:
<https://www.sciencedirect.com/science/article/pii/S1521693420301127>

¹⁵ Andersen *et al.* (2000). Maternal age and fetal loss: population-based register linkage study. *BMJ*. Jun 24; Available at
<https://pmc.ncbi.nlm.nih.gov/articles/PMC27416/>

Population group	Baseline population (2024)	Proportion of females in 2024 (% of group)	Inputs from Task 3 and other assumptions
Adults (20+) general population	350,039,568	51.0%	Estimate and evolution of 'Background cohort' and 'Elevated-Low cohort' based on Task 3, adjusted to exclude teenagers (15-19 years) and pregnant women
Teenagers (15-19 years)	23,405,944	48.8%	Estimate based on Eurostat; population groups and evolution (CAGR -1.0%) based on WB projections
Children (5-14 years)	46,393,393	48.8%	Estimate and evolution of 'Background', 'Elevated-Low' and 'Elevated-High' cohorts based on Task 3, adjusted to exclude newborns. Age group proportions based on WB projections.
Children (1-4 years)	16,615,945	48.8%	Estimate and evolution of 'Background', 'Elevated-Low' and 'Elevated-High' cohorts based on Task 3, adjusted to exclude newborns. Age group proportions based on WB projections.
Newborns (0 years)	3,726,318	48.7%	Estimate based on live births (Eurostat); evolution (CAGR -0.5%) based on WB projections
Pregnant women	4,108,444	100.0%	Estimate based on live births (Eurostat) and miscarriages (Frick (2021) and Andersen et al. (2000)); evolution (CAGR -0.5%) based on WB projections
People (15+) living near contaminated sites	10,558,373	51.4%	Estimate and evolution of 'Elevated-High cohort' ¹⁶ based on Task 3.

3.1.3. Step 2 PFAS exposure

We have gathered and reviewed available evidence of PFAS in the blood serum, in µg/L, of people living in the EEA across the relevant population groups¹⁷, as well as time trends. Scenario modelling was conducted to produce estimates of PFAS in the blood serum under prospective scenarios (Task 3), for three population cohorts, summarised in the Table below for Scenario 1. Similar estimates were developed for the other scenarios (refer to the 'Task 3 report' for details).

¹⁶ The 'Elevated-High' cohort corresponds to the definition of the 'elevated' exposure used by Goldenman et al. (2019), defined as being exposed to levels of PFAS above the action value of 90 ng/l, via drinking water.

¹⁷ Sources include HMB4EU and related studies such as Richterova et al (2023), Uhl et al (2023), Fabelova et al (2023); and other studies such as Andersen et al (2024), Goen et al (2023), Palesova et al (2023), Plass et al. (2023), Rihackova et al (2023), DeLuca et al (2022), Papadopoulou et al (2021), Gebbink et al (2020), Pitter et al (2020), Poonthong et al (2020), Balk et al (2019), etc.

Table 3-3 Blood serum levels of PFAS, in µg/L, across population cohorts for Scenario 1, estimated under Task 3. Estimates under other Scenarios can be found in the Task 3 Report and Sections 3.2.2-3.2.5 of the present report.

Cohort	PFAS type	2024	2030	2040	2050
Background cohort	PFOA	1.81	1.71	1.55	1.44
	PFOS	5.04	3.73	2.26	1.41
	PFNA	0.77	0.90	1.16	1.54
	PFHxS	0.68	0.61	0.51	0.44
	Other PFAS	7.30	11.78	19.89	30.60
Elevated-high cohort, and Occupational cohort	PFOA	19.46	18.34	16.62	15.53
	PFOS	5.65	4.18	2.53	1.58
	PFNA	0.77	0.90	1.16	1.54
	PFHxS	1.91	1.72	1.44	1.24
	Other PFAS	28.61	42.54	69.95	108.21

Please note that blood serum concentrations for the 'elevated-low' cohort are the average between the 'background' and 'elevated – high' cohorts.

Despite these estimates of 'all PFAS' exposure, and as noted, there remain severe gaps in the evidence available on PFAS exposure by specific substances, their association with health risks, and the characterisation of exposure-response functions. **The human health cost assessment and valuation conducted in this study have thus focused on four PFAA and PFAA precursor substances: PFOA, PFOS, PFNA and PFHxS, which have been investigated in more depth in the scientific literature and are regulated in the EU, especially in the case of PFOA, PFOS and PFHxS¹⁸.**

In addition, the evidence on exposure-response functions is available only for specific population groups, based on the relevant risks these groups face from some PFAS exposure. The groups found in the literature have been mapped against the analysis conducted under Task 3 (see Step 1). The historical evidence found in the literature for each of these groups has been triangulated with outputs from Task 3 to produce evidence-based assumptions of blood serum levels by group. The Table below provides these estimates under prospective Scenario 1, with similar approaches being employed to estimate equivalent values for Scenarios 2, 3 and 4. These estimates have been taken forward for use as inputs to the exposure-response functions (ERFs) as part of the analysis and valuation of human health impacts for Scenario 1 (see Step 3 in the following section).

¹⁸ Please note that these four PFAS are regulated in the EU in different ways, under POPs regulation, REACH, food safety rules, drinking water, and packaging legislation. More specifically, PFOA is banned under the EU POPs Regulation since 2020, listed as an SVHC under REACH, and covered under the Drinking Water Directive and food safety rules; PFOS is restricted under the EU POPs Regulation, listed as an SVHC under REACH, and covered under the Drinking Water Directive and food safety rules; PFHxS has been banned under the EU POPs Regulation since 2023, on the Candidate List of SVHC under REACH, and covered under the Drinking Water Directive and food safety rules;; and PFNA is covered under food safety rules.

Table 3-4 Blood serum levels of PFOA, PFOS, PFNA, and PFHxS, in µg/L, across European population groups in Scenario 1, calculated based on the Task 3 outputs. Similar approaches were employed to estimate equivalent values for Scenarios 2, 3 and 4.

Population group	PFAS type	2024	2030	2040	2050
Adults (20+) general population	PFOA	1.81 [0.40-12.01]	1.71 [0.38-11.32]	1.55 [0.34-10.26]	1.44 [0.32-9.59]
	PFOS	5.04 [1.27-22.78]	3.73 [0.94-16.85]	2.26 [0.57-10.20]	1.41 [0.35-6.37]
	PFNA	0.77 [0.22-2.08]	0.90 [0.26-2.42]	1.16 [0.33-3.12]	1.54 [0.44-4.15]
	PFHxS	0.68 [0.16-2.09]	0.61 [0.14-1.88]	0.51 [0.12-1.57]	0.44 [0.10-1.36]
Pregnant women, Newborns (0 years), Children (1-4 years), Children (5-14 years), Teenagers (15-19 years)	PFOA	2.04 [0.45-9.28]	1.92 [0.42-8.75]	1.74 [0.38-7.93]	1.63 [0.36-7.41]
	PFOS	10.54 [2.54-34.26]	7.80 [1.88-25.35]	4.72 [1.14-15.34]	2.95 [0.71-9.57]
	PFNA	0.56 [0.17-1.71]	1.23 [0.37-3.77]	1.59 [0.48-4.86]	2.11 [0.64-6.46]
	PFHxS	0.47 [0.04-1.11]	0.88 [0.08-2.09]	0.74 [0.06-1.75]	0.64 [0.05-1.51]
People (15+) living near contaminated sites, Adults (Exposed workers)¹⁹	PFOA	19.46 [1.45-396.48]	18.34 [1.37-373.76]	16.62 [1.24-338.71]	15.53 [1.16-316.46]
	PFOS	5.65 [1.65-54.35]	4.18 [1.22-40.21]	2.53 [0.74-24.34]	1.58 [0.46-15.19]
	PFNA	0.77 [0.77-61.138]	0.9 [0.9-71.22]	1.16 [1.16-91.84]	1.54 [1.54-122.11]
	PFHxS	1.91 [0.50-36.98]	1.72 [0.45-33.25]	1.44 [0.38-27.84]	1.24 [0.33-24.04]

Finally, following the approach from Obsekov, Kahn & Trasande (2023)²⁰, a reference level of exposure was estimated for PFOA, PFOS, PFNA and PFHxS and population group, corresponding to the 10th percentile of the population group's blood serum range. The health risks associated with the exposure were estimated relative to this reference level, below which no health impacts have been attributable to PFAS exposure.

¹⁹ Due to limited evidence regarding blood serum levels of exposed workers in Europe, it was assumed that exposed workers would typically live near contamination sites and, therefore, have blood serum levels of similar scale as that for people living near contaminated sites.

²⁰ Obsekov, Kahn & Trasande (2023). Leveraging Systematic Reviews to Explore Disease Burden and Costs of Per- and Polyfluoroalkyl Substance Exposures in the United States. *Expo Health* 15, 373–394. Available at: <https://doi.org/10.1007/s12403-022-00496-y>

3.1.4. Step 3 Health risks and exposure-risk relationships

We have conducted a literature review²¹ that resulted in a longlist of health risks and endpoints associated with PFAS exposure. Each health risk or endpoint identified was considered. Those for which there was limited weight of evidence and/or there were no exposure-response functions (ERFs) were excluded from further assessment (see Task 2 Report). The following thirteen health risks or endpoints with available and sufficient weight of evidence to justify their inclusion in the analysis were taken forward in the assessment: lower respiratory tract infections (LRTI), maternal hypertensive disorders²², low (and very low) birth weight, hypothyroidism, osteoporosis, kidney cancer, high LDL cholesterol, testicular cancer, obesity, high blood pressure, chronic kidney disease (CKD), endometriosis and female infertility.

The Table below organises these endpoints by the level of confidence of the association between the health risk and PFAS exposure (scored from 1 for 'no confidence', to 5 for 'high confidence'); and documents the affected population that has been studied in the literature, and which concerns the ERFs identified.

Table 3-5 Overview of health risks and Exposure Response Functions proposed for inclusion in the quantitative analysis and valuation of human health impacts of PFOA, PFOS, PFNA, and PFHxS exposure

Specific health risk/ endpoint in scope	Confidence (0=None, 5=High)	Affected population	Exposure response functions (ERFs) identified in the literature with sufficient weight of evidence
Lower respiratory tract infections (LRTI)	4	Children (1-4 years)	HR ²³ = 1.27 (95% CI: 1.01-1.59) per doubling of PFOA in maternal blood HR = 1.54 (95% CI: 1.11-2.15) per doubling of PFOS in maternal blood ²⁴
Maternal hypertensive disorders ²⁵	4	Pregnant women	RR ²⁶ = 1.41 (95% CI: 1.13-1.77) per ln-unit PFOS ²⁷

²¹ Sources are detailed on the Task 1 Report, including Mahdavi et al. (2024), Ebel et al. (2023), Hu et al. (2023), Pan et al. (2023), Pinney et al. (2023), Plass et al. (2023), Obsekov, Kahn & Trasande (2023), Xu et al. (2023), Zhang et al. (2023), Costello et al. (2022), Bartell and Vieira (2021), Birru et al. (2021), Fenton et al. (2021), Dalsager et al. (2021), Steenland et al. (2021), Shearer et al. (2021), Banjabi et al. (2020), European Food Safety Authority (2020), Eves et al. (2020), Goldenman et al. (2019), Impinen et al. (2019), Covarts et al. (2018), Lauritzen et al. (2018), Liu et al. (2018), Steenland et al. (2018), Sun et al. (2018), Wielsøe et al. (2017), Dalsager et al. (2016), Khalil et al. (2016), Kim et al. (2016), Zhang et al. (2015), Johnson et al. (2014), Vagi et al. (2014), Eriksen et al. (2013), Wen et al. (2013), Buck Louis et al. (2012), Min et al. (2012), Steenland & Woskie (2012), Whitworth et al. (2012), Shankar et al. (2011), Stein et al. (2009).

²² This includes gestational hypertension and preeclampsia.

²³ A hazard ratio (HR) is a measure used to compare the risk of a particular event occurring at any given point in time between two groups. It's commonly used in clinical trials and medical research to assess the effectiveness of treatments.

²⁴ Dalsager et al. (2021). Exposure to perfluoroalkyl substances during fetal life and hospitalization for infectious disease in childhood: A study among 1,503 children from the Odense Child Cohort, *Environment International*, Volume 149, 106395, ISSN 0160-4120. Available at: <https://doi.org/10.1016/j.envint.2021.106395>

²⁵ This includes gestational hypertension and preeclampsia.

²⁶ A risk ratio (RR) (also called a relative risk) is a measure used to compare the risk (or probability) of an event happening in an 'exposed' group to the risk of such a happening in a reference group. A RR = 1 implies no difference in risk between two groups, a RR > 1 implies a higher risk in the 'exposed' group compared to a reference group, and a RR < 1 implies a lower risk in the 'exposed' group. For example, evidence presented in this section suggests that there might be a RR of 1.27 for pneumonia and PFOA exposure, which means that individuals exposed to PFOA are 27% more likely to get pneumonia than those exposed to reference levels of PFOA.

²⁷ Hu et al. (2023). Perfluoroalkyl and polyfluoroalkyl substances and hypertensive disorders of pregnancy: A systematic review and meta-analysis. *Environmental research*, 231(Pt 2), 116064. Available at: <https://doi.org/10.1016/j.envres.2023.116064>

Specific health risk/ endpoint in scope	Confidence (0=None, 5=High)	Affected population	Exposure response functions (ERFs) identified in the literature with sufficient weight of evidence
Low (and very low) birth weight	4	Newborns (0 years)	$\beta^{28} = -10.5\text{g}$ (95% CI: -16.7--4.4) per $\mu\text{g/L}$ PFOA in maternal blood ²⁹ $\beta = -45.2\text{g}$ (95% CI: -76.8--13.6) per doubling of PFOS in maternal blood ³⁰
Hypothyroidism	4	Adult females	OR ³¹ = 1.68 (95% CI: 1.14--2.49) per ln-unit PFOA ³²
Osteoporosis	3	Adult females	OR = 1.84 (95% CI: 1.17-2.91) per ln-unit PFOA OR = 1.64 (95% CI: 1.14-2.38) per ln-unit PFHxS OR = 1.45 (95% CI: 1.02-2.05) per ln-unit PFNA ³³
Kidney cancer	3	Adults	RR = 1.16 (95%CI: 1.03-1.30) per 10 $\mu\text{g/L}$ PFOA ³⁴
High LDL cholesterol	3	Adults	$\beta = 1.57$ (95% CI: 0.02-3.13) mg/dL per $\mu\text{g/L}$ PFOA $\beta = 0.08$ (95% CI: -0.01-0.16) mg/dL per $\mu\text{g/L}$ PFOS ³⁵
Testicular cancer	2	Adult males	RR = 1.03 (95% CI: 1.02-1.04) per 10 $\mu\text{g/L}$ PFOA ³⁶
Obesity	2	Children (5-14 years) and Teenagers (15-19 years)	$\beta = 0.10$ (95% CI: 0.02-0.17) per $\mu\text{g/L}$ PFOA in maternal blood ³⁷ $\beta = 0.18$ (95% CI: 0.01-0.35) per ln-unit PFOS in maternal blood ³⁸
		Adults	$\beta = 1.5$ kg gained per unit PFOS (Tertile 1:<19.2 $\mu\text{g/L}$) (applied above the reference exposure value)

²⁸ Beta (β) represents the slope of a relationship between two variables.

²⁹ Steenland et al. (2018). Serum Perfluorooctanoic Acid and Birthweight: An Updated Meta-analysis With Bias Analysis. *Epidemiology* (Cambridge, Mass.), 29(6), 765-776. Available at: <https://doi.org/10.1097/EDE.0000000000000903>

³⁰ Meng et al. (2018). Prenatal Exposure to Perfluoroalkyl Substances and Birth Outcomes; An Updated Analysis from the Danish National Birth Cohort. *International journal of environmental research and public health*, 15(9), 1832. Available at: <https://doi.org/10.3390/ijerph15091832>

³¹ An odds ratio (OR) is a measure of association used to compare the odds of an event occurring in an 'exposed' group to the odds of such an event occurring in a reference group. An OR > 1 suggests a positive association between the exposure and the outcome, an OR = 1 suggests no association and an OR < 1 suggests a negative association. For example, evidence presented in this section concerning PFOA exposure and kidney cancer (renal cell carcinoma) presents an odds ratio of 1.71, which means that individuals with PFOA exposure are 1.71 times more likely to have cancer compared to those with reference PFOA exposure.

³² Melzer et al. (2010). Association between serum perfluorooctanoic acid (PFOA) and thyroid disease in the U.S. National Health and Nutrition Examination Survey. *Environmental health perspectives*, 118(5), 686-692. Available at: <https://doi.org/10.1289/ehp.0901584>

³³ Khalil et al. (2016). Association of perfluoroalkyl substances, bone mineral density, and osteoporosis in the U.S. population in NHANES 2009-2010. *Environ Health Perspect* 124:81-87. Available at: <https://doi.org/10.1289/ehp.1307909>

³⁴ Bartell and Vieira (2021). Critical review on PFOA, kidney cancer, and testicular cancer. *Journal of the Air & Waste Management Association* (1995), 71(6), 663-679. Available at: <https://doi.org/10.1080/10962247.2021.1909668>

³⁵ U.S. EPA (2024). Economic Analysis for the Final Per- and Polyfluoroalkyl Substances National Primary Drinking Water Regulation. EPA Document Number: EPA-815-R-24-001. Available at: https://www.epa.gov/system/files/documents/2024-04/pfas-npdwr-final-rule_ea.pdf

³⁶ Bartell and Vieira (2021). Critical review on PFOA, kidney cancer, and testicular cancer. *Journal of the Air & Waste Management Association* (1995), 71(6), 663-679. Available at: <https://doi.org/10.1080/10962247.2021.1909668>

³⁷ Liu et al. (2018a). Perfluorooctanoic Acid (PFOA) Exposure in Early Life Increases Risk of Childhood Adiposity: A Meta-Analysis of Prospective Cohort Studies. *International Journal of Environmental Research and Public Health*, 15(10), 2070. Available at: <https://doi.org/10.3390/ijerph15102070>

³⁸ Lauritzen et al. (2018). Prenatal exposure to persistent organic pollutants and child overweight/obesity at 5-year follow-up: a prospective cohort study. *Environmental health: a global access science source*, 17(1), 9. Available at: <https://doi.org/10.1186/s12940-017-0338-x>

Specific health risk/ endpoint in scope	Confidence (0=None, 5=High)	Affected population	Exposure response functions (ERFs) identified in the literature with sufficient weight of evidence
			$\beta = 1.8$ kg gained per unit PFNA (Tertile 1:<1.1 $\mu\text{g/L}$) ³⁹ (applied above the reference exposure value)
High blood pressure	2	Adult males	OR = 1.12 (95% CI: 1.02–1.23) per ln-unit PFOA OR = 1.19 (95% CI: 1.06–1.34) per ln-unit PFOS OR = 1.11 (95% CI: 1.04–1.19) per ln-unit PFNA ⁴⁰
Chronic kidney disease (CKD)	2	Adults	OR = 1.73 (95% CI: 1.04–2.88) for PFOA exposure >2.8 $\mu\text{g/L}$ OR = 1.82 (95% CI: 1.01–3.27) for PFOS exposure >11.7 $\mu\text{g/L}$ ⁴¹
Endometriosis	2	Adult females (18–49 years)	OR = 1.89 (95% CI: 1.17–3.06) per log-unit PFOA ⁴²
Time to pregnancy/ female infertility	2	Adult females (18–49 years)	Fecundability OR = 0.77 (95% CI: 0.67–0.89) per log-unit PFOA Fecundability OR = 0.83 (95% CI: 0.72–0.97) per log-unit PFOS ⁴³

Note: The following acronyms have been used in the Table - HR: Hazard ratio; OR: Odds ratio; RR: Relative risk.

Since these ERFs are non-linear in form, we have suitably transformed and evaluated these functions to calculate the health impact from exposure at the current and prospective future levels of PFAS in blood serum under prospective scenarios, compared to the reference levels (see Step 2 above). These ERFs were also expressed in terms of the fraction of baseline cases of ill health, by endpoint, which could be attributable to PFAS exposure.

3.1.5. Step 4 Health impact analysis

Building on the previous steps, we have quantified the statistical cases of ill health and the burden of disease, in terms of Disability-Adjusted Life Years (DALYs) and preventable deaths, attributable to PFOA, PFOS, PFHxS and PFNA exposure.

We found very limited to no understanding of any potential cumulative effects of PFAS exposure on health outcomes identified in the literature. When an endpoint was associated with exposure to different PFAS (e.g., PFOA and PFOS), we investigated the scientific literature underpinning the ERFs to confirm whether an attribution of health risks to the levels of specific PFAS in blood had been isolated for each individual substance (i.e., the effect of PFOA in isolation of the presence of PFOS in blood). This does not appear to be the case, however, in some cases, this remains uncertain. Thus, we have assumed that estimated health impacts from exposure to specific PFAS associated with any given

³⁹ Liu et al. (2018b). Perfluoroalkyl substances and changes in body weight and resting metabolic rate in response to weight-loss diets: A prospective study. *PLoS medicine*, 15(2), e1002502. Available at: <https://doi.org/10.1371/journal.pmed.1002502>

⁴⁰ Pan et al., (2023). The relationship between perfluoroalkyl substances and hypertension: A systematic review and meta-analysis. *Environmental Research*, 232, 116362. Available at: <https://doi.org/10.1016/j.envres.2023.116362>

⁴¹ Shankar et al. (2011). Perfluoroalkyl chemicals and chronic kidney disease in US adults. *American journal of epidemiology*, 174(8), 893–900. Available at: <https://doi.org/10.1093/aje/kwr171>

⁴² Buck Louis et al. (2012). Perfluorochemicals and endometriosis: the ENDO study. *Epidemiology (Cambridge, Mass.)*, 23(6), 799–805. Available at: <https://doi.org/10.1097/EDE.0b013e31826cc0cf>

⁴³ Bach et al. (2015). Perfluoroalkyl acids and time to pregnancy revisited: An update from the Danish National Birth Cohort. *Environmental health : a global access science source*, 14, 59. Available at: <https://doi.org/10.1186/s12940-015-0040-9>

endpoint (i.e., effects of PFOA and PFOS on the incidence of low birth weight) could not be aggregated. This means that for each endpoint or health risk, the results presented in this study correspond to the maximum estimated health impact for one single PFAS out of all PFAS associated with an endpoint (and for which ERFs have been identified in Step 3).

Mathematically, the 'statistical cases' of ill health of an endpoint i (e.g., cancer) attributable to PFAS pollution in period or year t are estimated as follows:

$$(1) SC_i^t = Impact_i * Pop_i^t * Risk_i$$

Where:

SC_i^t , refers to the 'statistical cases' of ill health for an endpoint i attributable to PFAS pollution in period or year t . This corresponds to the maximum of the estimated health impacts for one out of all PFAS types for which ERFs have been identified in Step 3.

$Impact_i$ refers to the maximum health impact for an endpoint i in the exposed group that is due to exposure to one out of all PFAS types for which ERFs have been identified in Step 3, expressed as a proportion of the baseline cases of ill health

Pop_i^t and $Risk_i$ refer to the affected population and baseline risk (incidence rate)⁴⁴, respectively, and for endpoint i in period or year t .

Following this, the cases of ill health associated with an endpoint i are used to estimate the burden of disease (in terms of Disability-Adjusted Life Years and preventable deaths) in period or year t as follows:

$$(2) DALY_i^t = SC_i^t * DALY/case_i^t$$

$$Preventable\ deaths_i^t = \frac{(DALY_i^t * \%YLL/DALY_i)}{YLL\ per\ death_i}$$

Where:

$DALY_i^t$ refers to the total Disability-Adjusted Life Years associated with an endpoint i that are attributable to PFAS pollution in period or year t .

$Preventable\ deaths_i^t$ refers to the preventable deaths associated with an endpoint i attributable to PFAS pollution in period or year t .

$DALY/case_i^t$ refers to the Disability-Adjusted Life Years attributable to a typical case of ill health for an endpoint i in period or year t , based on evidence from IHME global burden of disease studies.

$\%YLL/DALY_i$ refers to the years of life lost expressed as a proportion of the Disability-Adjusted Life Years attributable to a typical case of an endpoint i , based on evidence from IHME Global Burden of Disease studies.

⁴⁴ The incidence rates were sourced from evidence from the IHME Global Burden of Disease(2021). Available at: <https://vizhub.healthdata.org/gbd-results/> Any gaps were filled through desk-based research.

*YLL per death_i refers to the average years of life lost per preventable death for the affected population, where possible, associated with a specific endpoint *i* or more broadly otherwise, based on IHME Global Burden of Disease evidence for Europe.*

The values assumed for the $DALY/case_i$ and $\%YLL/DALY_i$ have been developed based on IHME Global Burden of Disease database and are represented in the Table below.

Table 3-6 DALY/case and % of YLL/DALY for a typical case across the selected endpoints, in the EU, based on IHME Global Burden of Disease (2021)⁴⁵

Specific health risk/ endpoint in scope	DALY/case	%YLL/DALY
Lower respiratory tract infections (LRTI)	0.40	99.7%
Maternal hypertensive disorders	0.01	24.0%
Low (and very low) birth weight	3.34	50.3%
Hypothyroidism	0.02	59.0%*
Osteoporosis	0.08	0.0%
Kidney cancer	3.35	95.3%
High LDL cholesterol	0.03	91.1%
Testicular cancer	1.06	80.2%
Obesity	0.06	59.1%
High blood pressure	0.17	89.7%
Chronic kidney disease (CKD)	0.22	71.1%
Endometriosis	0.66	0.1%
Time to pregnancy/ female infertility	0.01	0.0%

*Assumption developed to address gap, based on averaging evidence across all of the endpoints

We have employed the same methods to consider potential health impacts attributable to different levels of PFOA, PFOS, PFHxS and PFNA exposure under prospective scenarios. Given the large uncertainties already implicit in the ERFs and blood serum ranges presented by the literature, we have used 'main assumptions' only for the incidence rates, DALYs/case and YLL/DALY over time for the purposes of this study.

A worked illustration of the estimation of attributable health impacts of PFOS exposure for the low (and very low) birth weight endpoint is presented in Appendix A to Annex D.

⁴⁵ IHME Global Burden of Disease (2021). Available at: <https://vizhub.healthdata.org/gbd-results/>

3.1.6. Step 5 Human health cost valuation

We have reviewed the literature and valuation studies and guidelines from ECHA, OECD, etc., and developed estimates of the monetary values or costs associated with a statistical case of ill health for each of the 13 health risks or endpoints being assessed, as described in this project's 'Task 2' Report. These estimates comprise the valuation of non-market disease burden (e.g., people's willingness to pay to avoid one case of ill health), and additional healthcare and productivity (market) costs that could be incurred by each case of ill health.

The monetised disease burden or human health costs (HHC) attributable to PFAS pollution was quantified, for a given year t , as follows:

$$(3) \text{HHC}^t = \sum_i^{13} SC_i^t \times (NMDB_i^t + HC_i^t + w_i \times EPC_i^t)$$

Where:

HHC^t , refers to the sum of the, estimated human health costs attributable to PFAS pollution in period or year t .

SC_i^t , refers to the maximum number of 'statistical cases' of ill health for an endpoint i (e.g., cancer) attributable to exposure to one out of all types of PFAS pollution for which ERFs have been identified in Step 3, in period or year t .

$NMDB_i^t$, HC_i^t , EPC_i^t , refer to the monetary value of non-market disease burden, healthcare costs and economic productivity costs, respectively, per statistical case of ill health for an endpoint i (e.g., cancer) attributable to exposure to one type of PFAS pollution in period or year t .

w_i , refers to a weighting factor to reflect the 'statistical cases' of ill health for an endpoint i , equivalent to the proportion of the cases that might affect workers and thus result in sickness absence.

The Table below presents the monetary values (or costs) by health endpoint in scope and by cost 'category' (i.e., non-market disease burden, healthcare costs and economic productivity losses). Please note that the Table presents approximate values for total costs per statistical case, albeit in some cases, such as for chronic conditions with high survival rates, medical costs could be underestimated.

Table A.8: Monetary values or costs associated with a 'statistical' case of ill health (EUR₂₀₂₄/case)⁴⁶, by endpoint, and cost category

Specific health risk/ endpoint in scope	Non-market disease burden (EUR ₂₀₂₄ / case)	Healthcare costs (EUR ₂₀₂₄ / case)	Productivity Costs (EUR ₂₀₂₄ / case)
Kidney cancer	626,000	18,000	32,000
Low (and very low) birth weight	624,000	23,000	10,000
Testicular cancer	198,000	8,000	32,000

⁴⁶ All monetary values are presented in 2024 euros, having adjusted data from secondary sources using evidence from the GDP deflator where necessary.

Specific health risk/ endpoint in scope	Non-market disease burden (EUR ₂₀₂₄ / case)	Healthcare costs (EUR ₂₀₂₄ / case)	Productivity Costs (EUR ₂₀₂₄ / case)
Chronic kidney disease	175,000	5,000	13,000
Endometriosis	123,000	4,000	8,000
Lower respiratory tract infection	75,000	200	3,000
Time to pregnancy/ female infertility	41,000	8,000	3,000
High systolic blood pressure	32,000	900	3,000
Osteoporosis	14,000	2,000	3,000
Obesity	11,000	800	1,800
Maternal hypertensive disorders	6,000	4,000	10,000
High LDL cholesterol	5,000	5,000	3,000
Hypothyroidism	3,500	1,000	3,000

Note: Please see the Task 2 report for underpinning evidence/sources. In addition, please note that these figures are rounded to the nearest '000 euros, or '00 where relevant.

These values were used to calculate the monetary costs associated with the health impacts assessed under Step 4 and, thus, produce updated estimates of the human health costs from exposure to four PFAS in the EEA at present and under prospective scenarios. We have maintained the assumptions of the monetary value of a life year and/or statistical life, medical costs, and sickness absence constant in real terms over time, for the purposes of this study (explained under Task 2).

A worked illustration of the estimation of the health costs of PFOS exposure for the low (and very low) birth weight endpoint is presented in Appendix A to Annex D.

3.1.7. Step 6 Sensitivity analysis

Firstly, we conducted a quantitative sensitivity analysis by characterising low, medium and high scenarios of human health impacts and costs from exposure to four PFAS (PFOA, PFOS, PFNA, and PFHxS) and up to 13 health risks/endpoints; that is, the analysis is limited to the scope of the quantitative assessment that is viable and has been presented in previous steps. These sensitivity scenarios are explored to test how the uncertainties in the assumptions might affect the estimates of human health impacts and costs within this scope. The Table below summarises the sensitivity scenarios explored quantitatively.

Table 3-7 Scenarios to test the sensitivity of our results to uncertainties and assumptions

Variables	Medium scenario	Low scenario	High scenario
PFOA, PFOS, PFNA, and PFHxS levels in human blood serum (µg/L)	The historical average, minimum and maximum blood serum levels in the scientific literature by population group and PFAS type were calculated under Task 1, and this evidence was triangulated with the outputs of the dynamic modelling of prospective scenarios under Task 3.		
Health risks or endpoints included (binary, either included or excluded based on confidence ratings)	7 endpoints included (confidence rating >2): LRTI, low (and very low) birth weight, maternal hypertensive disorders, hypothyroidism,	4 endpoints included (confidence rating >3): LRTI, low (and very low) birth weight, maternal hypertensive disorders, hypothyroidism.	13 endpoints included (confidence rating >1): LRTI, low (and very low) birth weight, Maternal hypertensive disorders, hypothyroidism,

Variables	Medium scenario	Low scenario	High scenario
	osteoporosis, high cholesterol, kidney cancer.		osteoporosis, high cholesterol, kidney cancer, obesity, high blood pressure, CKD, testicular cancer, endometriosis, female infertility.
ERFs (Odds, risk or other ratios)	Central values	Lower bound	Upper bound
Non-market disease burden value per typical case (EUR/case)*	Central values	20% lower (or lower bound)	20% higher (or higher bound)
Medical costs per typical case (EUR/case)	Main evidence-based assumption	20% lower	20% higher
Sickness absence per typical case (Sick days/case)	Main evidence-based assumption	20% lower	20% higher

**This will embed sensitivities concerning both WTP inputs and DALY/case estimates.*

By definition, the low and high sensitivity scenarios produce estimates that are possible but unlikely to represent the actual human health costs of PFOA, PFOS, PFHxS and PFNA pollution and should be considered lower and upper bounds in this context. **The main drivers of uncertainty in these estimates are:**

- 1) the health risks or endpoints included in the analysis based on the level of confidence in the association between PFAS exposure and health risk; and
- 2) ERF sensitivities directly taken from scientific literature.

Beyond this, there are **additional gaps and limitations, especially three, which could have substantial implications** when considering the scale of all potential human health costs of all PFAS pollution but could not be considered quantitatively in the sensitivity analysis. These are:

- a) Human exposure to thousands of other PFAS (that is, all other PFAS which are not PFOA, PFOS, PFHxS and PFNA and are not regulated);
- b) additional health risks or endpoints which might be linked to PFAS exposure; and
- c) the cumulative/mixture effects of human exposure to multiple PFAS.

In more detail:

- There is a lack of evidence directly linking and/or characterising ERFs for other PFAS (i.e., PFAS which are not PFOA, PFOS, PFHxS and PFNA). However, the 'other PFAS' are estimated to be in the thousands, and are currently unregulated, so it is likely that their impact on health will become relatively more prominent in the future as regulatory action to address PFOA, PFOS and PFHxS pollution leads to the proliferation of alternative substances that take their place (in the absence of further policy action). *This suggests that the estimates produced in this study might only be a proportion, potentially small, of the total human health costs of all PFAS pollution.*

- Scientific literature currently identifies under 30 human health risks linked to PFAS exposure, however, the weight of evidence is limited and, in more than half of these cases, the literature does not provide quantitative exposure-response functions. In addition, the available studies focus on relatively well-known and already regulated PFAS, and evidence is lacking on other substances and/or their similarities. *This also suggests that the estimates produced in this study might only be a proportion, potentially small, of the total human health costs of all PFAS pollution.*
- Finally, there is very limited to no understanding of the mixture/cumulative effects of exposure to multiple PFAS in the literature found for this study. In this study, it has not been possible to quantify the cumulative impacts of human exposure to more than one of PFOA, PFOS, PFHxS and PFNA, due to the limitations and lack of clarity of the extent to which the individual impacts of specific PFAS have been isolated in the literature. *This also suggests that the estimates produced in this study might only be a proportion, potentially small, of the total human health costs of all PFAS pollution.*

Based on this, the study authors believe that the estimates of human health costs from PFOA, PFOS, PFHxS and PFNA exposure reported subsequently represent a lower bound for the total human health damage and costs that all PFAS pollution may cause in the EEA.

Section 6.2 presents a more detail outline of the study's gaps and limitations and what these could mean for the quantitative estimates of the human health costs of PFAS pollution.

3.2. Results

3.2.1. Current costs of PFAS pollution

Goldenman *et al.* (2019)⁴⁷ produced estimates of the monetary human health costs of PFAS pollution in the EEA ranging from €52 billion and €84 billion per year (equivalent to €64 billion and €104 billion per year in 2024 euros).

This is based on a quantification of impacts on human health for people facing different levels of PFAS exposure, following an impact pathway approach and 'what-if' scenarios that draw on selected studies. The total costs estimated by Goldenman *et al.* (2019), presented above, can be disaggregated as follows: €13-41 million (equivalent to €16-51 million in 2024 euros) in elevated mortality from kidney cancer due to occupational PFOA exposure; €11-35 billion (equivalent to €13-43 billion in 2024 euros) due to deaths linked to hypertension linked to PFOA exposure; and €41-49 billion (equivalent to €51-61 billion in 2024 euros) from all-cause premature mortality due to elevated PFAS exposure for people residing near contaminated sites, drawing on case study evidence associated with PFOA, PFOS, and PFHxS exposure. The Table below presents key insights.

⁴⁷ Goldenman *et al.* (2019). *The cost of inaction: A socioeconomic analysis of environmental and health impacts linked to exposure to PFAS*. Nordic Council of Ministers. Available at: <https://norden.diva-portal.org/smash/get/diva2:1295959/FULLTEXT01.pdf>

Table 3-8 Human health impacts quantified and monetised in Goldenman *et al.* (2019)

Affected populations	Health risk and impact quantified	Sources of evidence
Workers facing occupational exposure	Increased risk of premature mortality from attributable kidney cancer, leading to preventable deaths	Epidemiological evidence from a study of workers from West Virginia ⁴⁸ extrapolated to the European context.
People residing nearby contaminated sites	Increased risk of all-cause premature mortality, leading to preventable deaths	Differences in the risk of mortality (from all causes) for adult populations found in a study based in the Veneto Region, Italy ⁴⁹ when compared to the general population.
People drinking water and eating food with measurable PFAs concentration	Increased risk of premature mortality from attributable hypertension, leading to preventable deaths	Data from the US National Health and Nutrition Examination Survey to present quantitative differences in risk of developing hypertension (and attributable premature mortality) for people with different levels of PFOA concentration in their blood serum.

Building on this work, we have applied a revised and expanded methodology to produce updated monetary estimate of external human health costs of PFAS pollution in the EEA. More specifically, we have:

- Expanded the analysis to cover additional health risks or endpoints (including 13 endpoints) associated with PFAS exposure and specific PFAS types (four substances, which is more than included in the literature precedent, typically focussed on two regulated PFAS), drawing on a literature review of the latest available evidence and the confidence in the findings of association of PFAS exposure to these health risks,
- Reflected the latest available evidence in the exposure-risk relationships employed in the study, and
- Expanded the coverage of the types of costs included in the analysis beyond the monetisation of disease burden using non-market methods, by systematically including the indirect costs of healthcare and productivity losses.

The results suggest that, at present, monetary **human health costs of PFOA, PFOS, PFNA and PFHxS pollution could be €39.5 [0.005-600.5]⁵⁰ billion/year in 2024 alone**. These estimates are broadly aligned with the scale of human health costs estimated by Goldenman *et al.* (2019), despite the differences in the updated methodology. The Table below provides a breakdown of the estimates for the burden of disease of PFAS exposure in 2024, followed by a detailed comparison of methodology and results with Goldeman *et al.* (2019) in [Table 3-10](#).

⁴⁸ Steenland and Woskie (2012). Cohort mortality study of workers exposed to perfluorooctanoic acid. *American journal of epidemiology*. 176(10) pp.909–917.

⁴⁹ Mastrantonio et al. (2017). Drinking water contamination from perfluoroalkyl substances (PFAS): an ecological mortality study in the Veneto Region, Italy. *The European Journal of Public Health*. Feb 1;28(1):180–185.

⁵⁰ Square brackets indicate the potential range of values, considering the estimates from the sensitivity analysis described in Section 3.1.7. For example, “€39.5 [0.005-600.5] billion” indicates a medium estimate of €39.5 billion, a low sensitivity estimate of €0.005 billion, and a high sensitivity estimate of €600.5 billion.

Table 3-9 Estimates for human health costs of PFOA, PFOS, PFHxS and PFNA pollution in the EEA in 2024, by health endpoint associated with exposure (medium [low-high] sensitivities)

Endpoint	Relevant cases of ill health	Attributable cases	Attributable DALYs	Attributable statistical deaths	Cost valuation (Billion euros, 2024)
Lower respiratory tract infections (LRTI)	332,300	104,300 [0-283,700]	41,700 [0-113,500]	530 [0-1,430]	8.0 [0-26.5]
Maternal hypertensive disorders	192,500	35,700 [0-118,800]	400 [0-1,200]	2 [0-10]	0.5 [0-3]
Low (and very low) birth weight	261,500	9,500 [0-43,600]	31,800 [0-145,600]	200 [0-900]	6.5 [0-34.5]
Hypothyroidism	681,900	179,600 [900-599,600]	3,600 [20-12,000]	50 [0-180]	1.5 [0.005-5.5]
Osteoporosis	3,341,100	1,012,600 [5,200-3,069,800]	81,000 [400-245,600]	0	19.0 [0.08-70]
Kidney cancer	89,800	1,300 [3-19,300]	4,400 [10-64,600]	110 [0-1,620]	1.0 [0.002-15.5]
High LDL cholesterol	12,996,800	224,800 [20-3,109,100]	6,700 [1-93,300]	160 [0-2,240]	3.0 [0.0002-48.5]
Testicular cancer	19,500	100 [0-1,000]	100 [0-1,000]	1 [0-20]	0.01 [0.0001-0.5]
Childhood obesity	7,677,900	110,800 [0-2,779,700]	6,600 [0-166,800]	50 [0-1,370]	1.5 [0-45.5]
Adult obesity	54,153,200	3,195,000 [97,200-3,195,000]	191,700 [5,800-1,91,700]	2,990 [90-2,990]	43.5 [1.0-52.0]
High blood pressure	7,598,700	747,700 [1,500-3,209,200]	127,100 [300-5,45,600]	3,200 [10-13,740]	27.0 [0.04-138.5]
Chronic kidney disease (CKD)	2,383,300	15,100 [0-372,200]	3,300 [0-81,900]	60 [0-1,540]	3.0 [0-86]
Endometriosis	135,900	20,100 [100-88,600]	13,300 [100-58,500]	0	2.5 [0.01-14.5]
Time to pregnancy/ female infertility	3,298,300	206,700 [1,600-973,400]	2,100 [20-9,700]	0	10.5 [0.07-60.5]
Total*	93,162,900	1,567,800 [900-17,863,000]	169,600 [20-1,731,000]	1,050 [0-26,030]	39.5 [0.005-600.5]

* Please note that the 'Total' figures are not a simple sum of the rows, as they are based on the sensitivity scenarios defined in Section 3.1.7 (e.g., not all endpoints are included in the low and medium scenarios). Section 3.1.7 outlines clearly the endpoints which are included in the medium, low and high sensitivities. Please note also that any other differences between the sum of values and the 'total' are due to the rounding of estimates.

Despite following different methods, the results of this study and the conclusions from Goldeman *et al.* (2019) both suggest that the human health costs from PFAS pollution will be in the scale of multiple billions of euros per year. Given the gaps and limitations in the literature, both studies are likely to offer estimates that still represent a lower bound of total costs from all PFAS exposure in the EEA. A high-level qualitative comparison of key results across both studies is summarised in the Table below.

Table 3-10 Comparison of human health cost estimates between Goldenman *et al.* (2019) and this study

Indicator or similar	Goldenman <i>et al.</i> (2019)		Comparable estimate in this study		Commentary
	Methodology	Estimate	Methodology	Estimate	
Annual impacts associated with the effects of PFAS exposure through kidney cancer for exposed workers (2024€)	Assessed impacts based on an epidemiological study in West Virginia: standardised mortality rate = 3.67 for cumulative PFOA exposure $\geq 1,819$ ppm-years (with a 20-year lag). ⁵¹	3.6-11.8 attributable deaths €16-51 million/year	Assessed impacts based on the latest, robust ERF available: RR = 1.16 (95%CI: 1.03-1.30) per 10 µg/L PFOA ⁵² and population and blood serum levels for the 'occupational' cohort from the prospective scenario modelling.	1 [>0 -9] attributable deaths €17 [0.1-85] million/year	Estimates are broadly aligned in scale. The methods differ as Goldenman <i>et al.</i> (2019) assumes similar exposure and risk levels for the EEA workers as 1,308 workers from West Virginia from 1979–2004, whereas this study is based on the latest scientific evidence and blood serum evidence for the EEA.
Annual impacts associated with the effects of PFAS exposure through hypertension for the general population (2024€)	Assessed impacts based on two studies from the United States, with OR for hypertension = 1.63 [95% CI: 1.2-2.2] ⁵³ for PFOA exposure 4.0–5.5 ng/ml and an elevated risk of hypertension death RR= 0.012. ⁵⁴	3,066-10,035 attributable deaths €13-43 billion/year	Assessed impacts based on the latest, robust ERF available: OR = 1.19 (95% CI: 1.06–1.34) per ln-unit PFOS ⁵⁵ and population and blood serum levels for the 'background' cohort from the prospective scenario modelling.	2,998 [>0 -13,139] attributable deaths €25 [0-132] billion/year	These estimates are similar in scale. The methods differ, as Goldenman <i>et al.</i> (2019) assumes similar exposure and risk levels for the EEA as the US from 2003-2004 and 2005-2006. whereas this study is based on the latest scientific evidence and blood serum evidence for the EEA.

⁵¹ Steenland & Woskie (2012). Cohort mortality study of workers exposed to perfluorooctanoic acid. *American journal of epidemiology*, 176(10), 909–917. Available at: <https://doi.org/10.1093/aje/kws171>

⁵² Bartell and Vieira (2021). Critical review on PFOA, kidney cancer, and testicular cancer. *Journal of the Air & Waste Management Association* (1995), 71(6), 663–679. Available at: <https://doi.org/10.1080/10962247.2021.1909668>

⁵³ Min *et al.* (2012). Perfluorooctanoic acid exposure is associated with elevated homocysteine and hypertension in US adults. *Occupational and environmental medicine*, 69(9), 658–662. Available at: <https://doi.org/10.1136/oemed-2011-100288>

⁵⁴ Zhou *et al.* (2018). Uncontrolled hypertension increases risk of all-cause and cardiovascular disease mortality in US adults: the NHANES III Linked Mortality Study. *Scientific reports*, 8(1), 9418. Available at: <https://doi.org/10.1038/s41598-018-27377-2>

⁵⁵ Pan *et al.* (2023). The relationship between perfluoroalkyl substances and hypertension: A systematic review and meta-analysis. *Environmental Research*, 232, 116362. Available at: <https://doi.org/10.1016/j.envres.2023.116362>

Indicator or similar	Goldenman <i>et al.</i> (2019)		Comparable estimate in this study		Commentary
	Methodology	Estimate	Methodology	Estimate	
Annual impacts from all-cause premature mortality due to elevated PFAS exposure for people residing near contaminated sites (2024€)	Assessed impacts based on an epidemiological study using 1980-2013 evidence from the Veneto Region, Italy: RR =1.11 [95% CI: 1.10-1.12] in contaminated areas with PFAS in excess of at least one of the Italian National Health Institute (ISS) performance limits of 30 ng/l for PFOS, 500 ng/l for PFOA and 500 ng/l for the other PFAS in drinking water. ⁵⁶	11,745-13,843 attributable deaths €51-61 billion/year	Assessed impacts based on the latest, robust ERFs available across 13 endpoints (in the high sensitivity scenario) and population and blood serum levels for the 'exposed' cohort from the prospective scenario modelling.	<i>High sensitivity:</i> 4,053 attributable deaths 93.5 billion/year	Estimates developed by Goldman <i>et al.</i> (2019) are comparable in scale, and the approach and evidence comparable in level of confidence to the high-sensitivity scenario from this current study. The methods differ in the way exposure is defined, as Goldenman <i>et al.</i> (2019) is based on drinking water levels whereas this study is based on blood serum levels and ERF employed. In addition, Goldenman <i>et al.</i> (2019) assume that 3% of the population is exposed to source levels of PFAS above the limit value via municipal drinking water ⁵⁷ whereas this study uses the latest evidence from the Forever Pollution project (Task 3 report).
Total, annual impacts on human health from PFAS exposure (2024€)	The study assessed impacts as described above: kidney cancer due to occupational PFOA exposure; hypertension linked to background PFOA exposure; and all-cause premature mortality due to elevated PFAS exposure	14,815-23,890 attributable deaths €64-104 billion/year	This study assessed impacts based on the latest, robust ERFs available across 13 endpoints (in the high sensitivity scenario), using population and blood serum from the prospective scenario modelling.	<i>High sensitivity:</i> 26,030 attributable deaths 600.5 billion/year	The methods are substantially different, as described above. The approach employed by Goldman <i>et al.</i> (2019) is comparable in level of confidence captured in the high-sensitivity scenario of this current study, which presents a 5-10x larger estimate of human health costs compared to Goldenman <i>et al.</i> (2019).

⁵⁶ Mastrantonio *et al.* (2017). Drinking water contamination from perfluoroalkyl substances (PFAS): an ecological mortality study in the Veneto Region, Italy. *European journal of public health*, 28(1), 180–185. Available at: <https://doi.org/10.1093/eurpub/ckx066>

⁵⁷ Holmström *et al.* (2014). Nationell screening av perfluorerade föreningar (PFAA) i dricksvatten. Rapport no 2014/20 (In Swedish). Available at: https://vav.griffel.net/filer/SVU-rapport_2014-20.pdf

3.2.2. Future costs Scenario 1: Business as usual for emissions

Under this Scenario 1 (Business-as-usual scenario reflecting the regulatory status as of June 2024), the predicted emissions from the universal PFAS restriction dossier (published in 2023) suggest that between 2020 and 2050, PFAS emissions could increase by two and a half times from 11,600 tonnes per annum in 2020 to 29,400 tonnes per annum in 2050. This study's Task 3 has estimated that total blood serum levels of PFAS concentrations could also more than double in line with emissions, for example from 15.6 µg/l for adults in the background cohort in 2024 to 35.4 µg/l in 2050.

However, as observed in historical trends driven, at least partly, by PFAS-related restrictions in place, the levels of PFOA, PFOS and PFHxS in human blood would continue to decline over time whereas the levels of other PFAS, including PFNA, might increase also in line with historical trends (see previous reports, including an evidence review and methodological specification, which support this Task 4 Report).

The Table below presents the estimated blood serum levels for PFOA, PFOS, PFNA, PFHxS and 'other PFAS' from the Task 3 modelling. The estimation of human health impacts and costs in this study is based upon the estimated levels of PFOA, PFOS, PFNA and PFHxS and the identified ERFs.

Table 3-11 Blood serum levels of PFAS, in µg/L, across population cohorts for Scenario 1, estimated under Task 3.

Cohort	PFAS type	2024	2030	2040	2050
Background cohort	PFOA	1.81	1.71	1.55	1.44
	PFOS	5.04	3.73	2.26	1.41
	PFNA	0.77	0.90	1.16	1.54
	PFHxS	0.68	0.61	0.51	0.44
	Other PFAS	7.30	11.78	19.89	30.60
Elevated-high cohort, and Occupational cohort	PFOA	19.46	18.34	16.62	15.53
	PFOS	5.65	4.18	2.53	1.58
	PFNA	0.77	0.90	1.16	1.54
	PFHxS	1.91	1.72	1.44	1.24
	Other PFAS	28.61	42.54	69.95	108.21

The declining blood serum levels of PFOA, PFOS and PFHxS, coupled with a declining population between 2024-2050, could result in a decline in the combined disease burden of PFOA, PFOS, PFHxS, and PFNA exposure. However, the rapidly increasing blood serum levels of 'other PFAS' types that are not yet sufficiently studied in the scientific literature could result in an increase in the combined disease burden from all PFAS pollution between 2025-2050.

Monetary human health costs associated with exposure to the four substances studies could decline from €39.5 [0.005-600.5] billion/year in 2024 to €27.0 [0.004-456.5] billion in 2040 and increase slightly to €29.5 [0.004-426.0] billion by 2050, in Scenario 1. The slight increase in disease burden and human health costs from 2040 to 2050 is driven by a potential increase in PFNA levels in blood serum, which is sufficient in scale to reverse the

declining trend driven by the general decline in PFOS, PFOA, and PFHxS blood serum levels. The Table below presents estimates of disease burden and human health costs for 2024, 2030, 2040 and 2050 in Scenario 1.

Table 3-12 Estimates of disease burden and human health costs per year attributable to PFOA, PFOS, PFHxS and PFNA pollution in the EEA, capturing health endpoints for which evidence is available: Scenario 1 (medium [low-high] sensitivities)

Metrics	2024	2030	2040	2050
Attributable DALYs	169,600 [20-1,731,000]	126,100 [20-1,526,600]	113,900 [10-1,330,000]	125,400 [10-1,264,100]
Attributable statistical deaths	1,050 [0-26,030]	640 [0-22,220]	460 [0-19,310]	400 [0-18,640]
Human health costs (Billion euros, 2024€)	39.5 [0.005-600.5]	29.5 [0.005-529.5]	27.0 [0.004-456.5]	29.5 [0.004-426.0]

Note: The sensitivities are based on the sensitivity scenarios defined in Section 3.1.7 (e.g., not all endpoints are included in the low and medium scenarios). Please refer to Section 3.1.7 for the endpoints which are included in the medium, low and high sensitivities.

In the medium scenario, around 60-80% of the human health costs from PFOA, PFOS, PFHxS and PFNA exposure are attributable to cases of osteoporosis in women, followed by cases of LRTI in children aged 1-4 years, which accounts for 10-15% of total health costs per year over the period. In the high-sensitivity scenario, however, 13-15% of total human health costs from exposure are attributable to osteoporosis cases, whereas 22-24% of the total costs per year are attributable to high blood pressure cases, and 9-14% to chronic kidney disease.

Non-market disease burden accounts for the majority of the estimated human health costs, followed by productivity costs and healthcare costs. The Table below provides a breakdown of the estimated costs by cost category for 2024, 2030, 2040 and 2050.

Table 3-13 Estimates of human health costs per year attributable to PFOA, PFOS, PFHxS and PFNA pollution in the EEA, by cost category, capturing health endpoints for which evidence is available: Scenario 1 (Billion euros, 2024€) (medium [low-high] sensitivities)

Cost category	2024	2030	2040	2050
Non-market disease burden (Billion euros, 2024€)	30.5 [0.002-477.0]	23.5 [0.002-421.0]	22.5 [0.002-364.5]	25.5 [0.001-339.0]
Healthcare costs (Billion euros, 2024€)	2.5 [0.002-45.0]	2.0 [0.002-40.0]	1.5 [0.002-34.5]	1.5 [0.001-33.0]
Productivity costs (Billion euros, 2024€)	6.0 [0.001-78.5]	4.0 [0.001-68.5]	3.0 [0.001-57.5]	3.0 [0.001-54.0]
Total human health costs (Billion euros, 2024€)	39.5 [0.005-600.5]	29.5 [0.005-529.5]	27.0 [0.004-456.5]	29.5 [0.004-426.0]

Note: The sensitivities are based on the sensitivity scenarios defined in Section 3.1.7 (e.g., not all endpoints are included in the low and medium scenarios). Please refer to Section 3.1.7 for the endpoints which are included in the medium, low and high sensitivities. Please note also that any other differences between the sum of values and the 'total' are due to the rounding of estimates.

The majority of the population in the EEA is exposed to background levels of PFOA, PFOS, PFHxS and PFNA and, thus, this cohort accounts for the majority of the human health costs from exposure in the medium and high-sensitivity scenarios. However, high levels of

exposure in the elevated cohort drive the human health costs in the low-sensitivity scenario. The Table below provides a breakdown of the estimated costs by cohort for 2024, 2030, 2040 and 2050.

Table 3-14 Estimates of human health costs per year attributable to PFOA, PFOS, PFHxS and PFNA pollution in the EEA, by cohort capturing health endpoints for which evidence is available: Scenario 1 (Billion euros, 2024€) (medium [low-high] sensitivities)

Cohort	2024	2030	2040	2050
Background cohort (Billion euros, 2024€)	32.5 [0-506.5]	24.5 [0-446.5]	22.0 [0-385.5]	24.0 [0-359.5]
Elevated cohort (Billion euros, 2024€)	7.0 [0.005-93.5]	5.0 [0.005-82]	5.0 [0.004-70.5]	5.5 [0.004-65.5]
Occupational cohort (Billion euros, 2024€)	0.1 [0.0002-1.0]	0.08 [0.0002-1.0]	0.08 [0.0002-1.0]	0.09 [0.0001-0.5]
Total human health costs (Billion euros, 2024€)	39.5 [0.005-600.5]	29.5 [0.005-529.5]	27.0 [0.004-456.5]	29.5 [0.004-426.0]

Note: The sensitivities are based on the sensitivity scenarios defined in Section 3.1.7 (e.g., not all endpoints are included in the low and medium scenarios). Please refer to Section 3.1.7 for the endpoints which are included in the medium, low and high sensitivities. Please note also that any other differences between the sum of values and the 'total' are due to the rounding of estimates.

The majority of the population in the EEA are adults over 20 years of age, which means that, in absolute terms, the majority of human health costs are attributable to this group. However, human health costs estimated per person are especially high for newborns (0 years), children (1-4 years), people (15+ years) residing near contaminated sites, and exposed workers. The Table below provides a breakdown of the estimated costs per person by population group for 2024, 2030, 2040 and 2050.

Table 3-15 Estimates of human health costs per person per year attributable to PFOA, PFOS, PFHxS and PFNA pollution in the EEA, by population group, capturing health endpoints for which evidence is available: Scenario 1 (Euros/person, 2024€) (medium [low-high] sensitivities)

Population group	2024	2030	2040	2050
Adults (20+) (General population) (Euros/person, 2024€)	100 [0-2,800]	100 [0-2,600]	100 [0-2,400]	100 [0-2,400]
Newborns (0 years) (Euros/person, 2024€)	1,700 [0-9,200]	1,000 [0-7,700]	300 [0-5,300]	300 [0-4,800]
Children (1-4 years) (Euros/person, 2024€)	1,000 [0-3,200]	600 [0-3,000]	500 [0-2,600]	400 [0-2,600]
Children (5-14 years) (Euros/person, 2024€)	0 [0-1,300]	0 [0-1,200]	0 [0-1,000]	0 [0-800]
Teenagers (15-19 years) (Euros/person, 2024€)	0 [0-600]	0 [0-600]	0 [0-500]	0 [0-500]
Pregnant women (Euros/person, 2024€)	200 [0-700]	100 [0-600]	0 [0-300]	0 [0-30]
People (15+) living near contaminated sites (Euros/person, 2024€)	400 [1-3,800]	300 [1-3,200]	300 [1-2,700]	300 [1-2,300]

Population group	2024	2030	2040	2050
Adults (Exposed workers) (Euros/person, 2024€)	400 [1-3,500]	300 [1-2,900]	300 [1-2,400]	300 [1-2,100]

Note: The sensitivities are based on the sensitivity scenarios defined in Section 3.1.7 (e.g., not all endpoints are included in the low and medium scenarios). Please refer to Section 3.1.7 for the endpoints which are included in the medium, low and high sensitivities.

3.2.3. Future costs Scenario 2: Drinking Water Directive (DWD)

In this scenario, Task 3 finds that the overall impact on blood serum concentrations is minimal because drinking water accounts only for a relatively small share of human exposure. Moreover, food is the dominant pathway for human exposure and the reduction in exposure from drinking water is offset by the increases in food concentrations as irrigation, rainfall, and existing concentrations in soil and groundwater are all unaffected by drinking water treatment. Therefore, the blood serum levels of PFOA, PFOS, PFHxS and PFNA are similar to the business-as-usual trends from Scenario 1. The Table below presents the estimated blood serum levels for PFOA, PFOS, PFNA, PFHxS and 'other PFAS' from the Task 3 modelling. The estimation of human health impacts and costs in this study is based upon the estimated levels of PFOA, PFOS, PFNA and PFHxS and the identified ERFs.

Table 3-16 Blood serum levels of PFAS, in µg/L, across population cohorts for Scenario 2, estimated under Task 3.

Cohort	PFAS type	2024	2030	2040	2050
Background cohort	PFOA	1.81	1.71	1.55	1.44
	PFOS	5.04	3.73	2.26	1.41
	PFNA	0.77	0.90	1.16	1.54
	PFHxS	0.68	0.61	0.51	0.44
	Other PFAS	7.30	11.78	19.89	30.60
Elevated-high cohort, and Occupational cohort	PFOA	19.46	18.34	16.62	15.53
	PFOS	5.65	4.18	2.53	1.58
	PFNA	0.77	0.90	1.16	1.54
	PFHxS	1.91	1.72	1.44	1.24
	Other PFAS	28.61	42.54	69.95	108.21

The estimated disease burden in Scenario 2 is similar to Scenario 1, with a slightly lower number of attributable DALYs and statistical deaths in 2040 and 2050. Overall, the monetary human health costs associated with exposure to these four substances are comparable to Scenario 1 and could decline from €39.5 [0.005-600.5] billion/year in 2024 to €27.0 [0.004-456.5] billion in 2040 and increase slightly to €29.5 [0.004-426.0] billion by 2050. However, the rapidly increasing blood serum levels of 'other PFAS' types that are not yet sufficiently studied in the scientific literature could result in an increase in the combined disease burden from all PFAS pollution between 2025-2050.

The slight increase in disease burden and human health costs from 2040 to 2050 is driven by a potential increase in PFNA levels in blood serum, which is sufficient in scale to reverse the declining trend driven by the general decline in PFOS, PFOA, and PFHxS blood serum

levels. The Table below presents the estimated burden of disease and human health costs for 2024, 2030, 2040 and 2050.

Table 3-17 Estimates of disease burden and human health costs per year attributable to PFOA, PFOS, PFHxS and PFNA pollution in the EEA, capturing health endpoints for which evidence is available: Scenario 2 (medium [low-high] sensitivities)

Metrics	2024	2030	2040	2050
Attributable DALYs	169,600 [20-1,731,000]	126,100 [20-1,526,600]	113,800 [10-1,329,900]	125,300 [10-1,264,100]
Attributable statistical deaths	1,050 [0-26,030]	640 [0-22,220]	460 [0-19,300]	400 [0-18,640]
Human health costs (Billion euros, 2024€)	39.5 [0.005-600.5]	29.5 [0.005-529.5]	27.0 [0.004-456.5]	29.5 [0.004-426.0]

Note: The sensitivities are based on the sensitivity scenarios defined in Section 3.1.7 (e.g., not all endpoints are included in the low and medium scenarios). Please refer to Section 3.1.7 for the endpoints which are included in the medium, low and high sensitivities.

The detailed description and breakdown of costs by endpoint, cost category, cohort and population group under Scenario 2 is similar to that in Scenario 1.

3.2.4. Future costs Scenario 3: Environmental Quality Standards (EQS)

Under Scenario 3, compliance with the EQS levels proposed by the Commission is modelled to be achieved from 2030. Further, it is assumed that PFAS blood serum concentrations decay with a half-life of 5 years, which means a 100% reduction in blood serum could be realised only after 10 years from when intake is totally stopped. Therefore, the benefits of capping groundwater and surface water concentrations from 2030 onwards (and the resulting decreases in PFAS intake via drinking water and food) would be fully realised by 2040.

As a result, the prospective analysis under Task 3 finds that blood serum concentrations of PFAS could decline by more than 95% (compared to 2024 levels) by 2050. For the 'background' cohort, adult blood serum concentrations decline from 15.6 µg/l in 2024 to 0.7 µg/l in 2050. For the elevated-high exposure cohort, the biggest declines are seen, falling from 56.4 µg/l in 2024 to 0.5 µg/l in 2050. The Table below presents the estimated blood serum levels for PFOA, PFOS, PFNA, PFHxS and 'other PFAS' from the Task 3 modelling. The estimation of human health impacts and costs in this study is based upon the estimated levels of PFOA, PFOS, PFNA and PFHxS and the identified ERFs.

Table 3-18 Blood serum levels of PFAS, in µg/L, across population cohorts for Scenario 3, estimated under Task 3.

Cohort	PFAS type	2024	2030	2040	2050
Background cohort	PFOA	1.81	1.15	0.04	0.03
	PFOS	5.04	2.51	0.06	0.03
	PFNA	0.77	0.60	0.03	0.03
	PFHxS	0.68	0.41	0.01	0.01
	Other PFAS	7.30	7.93	0.54	0.60

Cohort	PFAS type	2024	2030	2040	2050
Elevated-high cohort, and Occupational cohort	PFOA	19.46	12.30	0.09	0.06
	PFOS	5.65	2.80	0.01	0.01
	PFNA	0.77	0.60	0.03	0.03
	PFHxS	1.91	1.15	0.01	0.00
	Other PFAS	28.61	28.52	0.36	0.40

The decline in PFAS pollution and thus people's exposure to PFAS estimated under Scenario 3, coupled with a declining population, could result in a decrease of attributable health burden and monetary costs over the period, with an evolution from €39.5 [0.005-600.5] billion/year in 2024 to €12.0 [0.001-373.5] billion in 2030. The prospective scenario analysis expects negligible levels of PFAS in human blood serum in 2040 and 2050, which translates to no health impacts or monetary costs in the medium and low-sensitivity scenarios over this period, although some health impacts are estimated in the high-sensitivity scenario with monetary costs of €3.5 billion in 2040 and €3.2 billion in 2050. In addition, the blood serum levels of 'other PFAS' types that are not yet sufficiently studied in the scientific literature (and thus not quantified) could result in additional disease burden between 2025-2050.

The Table below presents the estimated burden of disease and human health costs for 2024, 2030, 2040 and 2050.

Table 3-19 Estimates of disease burden and human health costs per year attributable to PFOA, PFOS, PFHxS and PFNA pollution in the EEA, capturing health endpoints for which evidence is available: Scenario 3 (medium [low-high] sensitivities)

Metrics	2024	2030	2040	2050
Attributable DALYs	169,600 [20-1,731,000]	50,300 [0-1,160,700]	0 [0-12,500]	0 [0-11,700]
Attributable statistical deaths	1,050 [0-26,030]	240 [0-16,180]	0 [0-180]	0 [0-170]
Human health costs (Billion euros, 2024€)	39.5 [0.005-600.5]	12.0 [0.001-373.5]	0 [0-3.5]	0 [0-3.2]

Note: The sensitivities are based on the sensitivity scenarios defined in Section 3.1.7 (e.g., not all endpoints are included in the low and medium scenarios). Please refer to Section 3.1.7 for the endpoints which are included in the medium, low and high sensitivities.

In the medium scenario, around 70% of the human health costs from PFOA, PFOS, PFHxS and PFNA exposure in 2030 are attributable to cases of osteoporosis in women, followed by cases of LRTI in children aged 1-4 years, which accounts for 15% of total costs in 2030. In the high-sensitivity scenario, 17% of total human health costs from exposure is attributable to osteoporosis cases; 23%, attributable to high blood pressure cases; and 14%, attributable to adult obesity in 2030. In 2040 and 2050, adult obesity, osteoporosis and high blood pressure account for the entirety of the disease burden and costs to human health, at around 60%, 25% and 15% respectively.

Non-market disease burden accounts for most of the estimated human health costs, followed by productivity costs and healthcare costs. The Table below provides a breakdown of the estimated costs by cost category for 2024, 2030, 2040 and 2050.

Table 3-20 Estimates of human health costs per year attributable to PFOA, PFOS, PFHxS and PFNA pollution in the EEA, by cost category, capturing health endpoints for which evidence is available: Scenario 3 (Billion euros, 2024€) (medium [low-high] sensitivities)

Cost category	2024	2030	2040	2050
Non-market disease burden (Billion euros, 2024€)	30.5 [0.002-477.0]	10.0 [0.0003-291.5]	0 [0-2.9]	0 [0-2.6]
Healthcare costs (Billion euros, 2024€)	2.5 [0.002-45.0]	0.5 [0.0003-31.0]	0 [0-0.2]	0 [0-0.2]
Productivity costs (Billion euros, 2024€)	6.0 [0.001-78.5]	1.5 [0.0002-51.0]	0 [0-0.4]	0 [0-0.4]
Total human health costs (Billion euros, 2024€)	39.5 [0.005-600.5]	12.0 [0.001-373.5]	0 [0-3.5]	0 [0-3.2]

Note: The sensitivities are based on the sensitivity scenarios defined in Section 3.1.7 (e.g., not all endpoints are included in the low and medium scenarios). Please refer to Section 3.1.7 for the endpoints which are included in the medium, low and high sensitivities. Please note also that any other differences between the sum of values and the 'total' are due to the rounding of estimates.

The majority of the population in the EEA is exposed to background levels of PFAS and, thus, this cohort accounts for the majority of the human health costs from PFAS exposure in the medium and high-sensitivity scenarios. However, high levels of exposure in the elevated cohort drive the human health costs in the low-sensitivity scenario. The Table below provides a breakdown of the estimated costs by cohort for 2024, 2030, 2040 and 2050.

Table 3-21 Estimates of human health costs per year attributable to PFOA, PFOS, PFHxS and PFNA pollution in the EEA, by cohort capturing health endpoints for which evidence is available: Scenario 3 (Billion euros, 2024€) (medium [low-high] sensitivities)

Cohort	2024	2030	2040	2050
Background cohort (Billion euros, 2024€)	32.5 [0-506.5]	9.5 [0-316.5]	0 [0-3.0]	0 [0-2.8]
Elevated cohort (Billion euros, 2024€)	7.0 [0.005-93.5]	2.0 [0.001-56.5]	0 [0-0.5]	0 [0-0.4]
Occupational cohort (Billion euros, 2024€)	0.1 [0.0002-1]	0 [0-0.5]	0	0
Total human health costs (Billion euros, 2024€)	39.5 [0.005-600.5]	12.0 [0.001-373.5]	0 [0-3.5]	0 [0-3.2]

Note: The sensitivities are based on the sensitivity scenarios defined in Section 3.1.7 (e.g., not all endpoints are included in the low and medium scenarios). Please refer to Section 3.1.7 for the endpoints which are included in the medium, low and high sensitivities. Please note also that any other differences between the sum of values and the 'total' are due to the rounding of estimates.

The majority of the population in the EEA are adults over 20 years of age, which means that, in absolute terms, the majority of human health costs are attributable to this group.

However, human health costs estimated per person in 2030 are especially high for newborns (0 years), children (1-4 years), people (15+ years) residing near contaminated sites, and exposed workers. In 2040 and 2050, the costs are borne entirely by adults in the general population, people (15+ years) residing near contaminated sites, and exposed workers as these are the groups affected by osteoporosis, high blood pressure and adult obesity. The Table below provides a breakdown of the estimated costs per person by population group for 2024, 2030, 2040 and 2050.

Table 3-22 Estimates of human health costs per person per year attributable to PFOA, PFOS, PFHxS and PFNA pollution in the EEA, by population group, capturing health endpoints for which evidence is available: Scenario 3 (Euros/person, 2024€) (medium [low-high] sensitivities)

Population group	2024	2030	2040	2050
Adults (20+) (General population) (Euros/person, 2024€)	100 [0-2,800]	50 [0-2,000]	0 [0-15]	0 [0-10]
Newborns (0 years) (Euros/person, 2024€)	1,700 [0-9,200]	100 [0-5,800]	0	0
Children (1-4 years) (Euros/person, 2024€)	1,000 [0-3,200]	200 [0-2,300]	0	0
Children (5-14 years) (Euros/person, 2024€)	0 [0-1,300]	0 [0-600]	0	0
Teenagers (15-19 years) (Euros/person, 2024€)	0 [0-600]	0 [0-300]	0	0
Pregnant women (Euros/person, 2024€)	200 [0-700]	0 [0-400]	0	0
People (15+) living near contaminated sites (Euros/person, 2024€)	400 [1-3,800]	100 [0-2,300]	0 [0-15]	0 [0-10]
Adults (Exposed workers) (Euros/person, 2024€)	400 [1-3,500]	100 [0-2,000]	0 [0-15]	0 [0-10]

Note: The sensitivities are based on the sensitivity scenarios defined in Section 3.1.7 (e.g., not all endpoints are included in the low and medium scenarios). Please refer to Section 3.1.7 for the endpoints which are included in the medium, low and high sensitivities.

3.2.5. Future costs Scenario 4: Total stop of production and use of PFAS

In this scenario, Task 3 finds that there could be a rapid decline of PFAS emissions around 2030, but the remaining in-use consumer stockpiles continue to produce emissions, leading to a slower subsequent decline, reaching zero PFAS emissions by 2040. In more detail, under this scenario, a 64% reduction in PFAS emissions is estimated for 2030, and a 100% reduction by 2040, when compared to 2024.

As a result, blood serum concentrations are estimated to reach zero levels by 2050, due to the assumed half-life of 5 years and 10-year lag in the elimination of blood serum concentrations after new exposure ceases. The Table below presents the estimated blood serum levels for PFOA, PFOS, PFNA, PFHxS and 'other PFAS' from the Task 3 modelling. The

estimation of human health impacts and costs in this study is based upon the estimated levels of PFOA, PFOS, PFNA and PFHxS and the identified ERFs.

Table 3-23 Blood serum levels of PFAS, in µg/L, across population cohorts for Scenario 4, estimated under Task 3.

Cohort	PFAS type	2024	2030	2040	2050
Background cohort	PFOA	1.81	1.30	0.18	0.00
	PFOS	5.04	2.84	0.26	0.00
	PFNA	0.77	0.68	0.14	0.00
	PFHxS	0.68	0.47	0.06	0.00
	Other PFAS	7.30	8.97	2.33	0.00
Elevated-high cohort, and Occupational cohort	PFOA	19.46	13.98	1.94	0.00
	PFOS	5.65	3.19	0.30	0.00
	PFNA	0.77	0.68	0.14	0.00
	PFHxS	1.91	1.31	0.17	0.00
	Other PFAS	28.61	32.41	8.18	0.00

Similar to Scenario 3, **the decline and subsequent elimination of PFAS pollution and exposure estimated under Scenario 4, coupled with a declining population, could result in a decrease of the human health burden and monetary costs over the period from €39.5 [0.005-600.5] billion/year in 2024 to €17 [0.002-412.5] billion in 2030, and decline further to €0.5 [0-21.5] billion/year in 2040. In 2050, the prospective scenario analysis estimates zero levels of PFAS in human blood serum and, thus, no health impacts or monetary costs are estimated. In addition, the blood serum levels of ‘other PFAS’ types that are not yet sufficiently studied in the scientific literature (and thus not quantified) could result in additional disease burden between 2025-2040.** The Table below presents the estimated burden of disease and human health costs for 2024, 2030, 2040 and 2050.

Table 3-24 Estimates of disease burden and human health costs per year attributable to PFOA, PFOS, PFHxS and PFNA pollution in the EEA, capturing health endpoints for which evidence is available: Scenario 4 (medium [low-high] sensitivities)

Metrics	2024	2030	2040	2050
Attributable DALYs	169,600 [20-1,731,000]	71,600 [0-1,257,600]	2,300 [0-51,600]	0
Attributable statistical deaths	1,050 [0-26,030]	340 [0-17,710]	0 [0-910]	0
Human health costs (Billion euros, 2024€)	39.5 [0.005-600.5]	17.0 [0.002-412.5]	0.5 [0-21.5]	0

Note: The sensitivities are based on the sensitivity scenarios defined in Section 3.1.7 (e.g., not all endpoints are included in the low and medium scenarios). Please refer to Section 3.1.7 for the endpoints which are included in the medium, low and high sensitivities.

In the medium scenario, around 65-85% of the human health costs from PFOA, PFOS, PFHxS and PFNA exposure in 2030 and 2040 are attributable to cases of osteoporosis in women, whereas LRTI in children aged 1-4 years accounts for 15% of total costs in 2030, but

negligible costs thereafter. In the high-sensitivity scenario, however, 16% of total human health costs from exposure in 2030 is attributable to osteoporosis cases; 23% is attributable to high blood pressure cases; and 12% each attributable to adult obesity and female infertility in 2030. High blood pressure (20%), chronic kidney disease (20%) and high LDL cholesterol (20%) account for more than half of the disease burden and costs to human health in the high-sensitivity scenario in 2040.

Non-market disease burden accounts for the majority of the estimated human health costs, followed by productivity costs and healthcare costs. The Table below provides a breakdown of the estimated costs by cost category for 2024, 2030, 2040 and 2050.

Table 3-25 Estimates of human health costs per year attributable to PFOA, PFOS, PFHxS and PFNA pollution in the EEA, by cost category, capturing health endpoints for which evidence is available: Scenario 4 (Billion euros, 2024€) (medium [low-high] sensitivities)

Cost category	2024	2030	2040	2050
Non-market disease burden (Billion euros, 2024€)	30.5 [0.002-477.0]	14.0 [0.001-323.5]	0.5 [0-18.0]	0
Healthcare costs (Billion euros, 2024€)	2.5 [0.002-45.0]	1.0 [0.001-33.5]	0 [0-1.5]	0
Productivity costs (Billion euros, 2024€)	6.0 [0.001-78.5]	2.0 [0-55.5]	0 [0-2.0]	0
Total human health costs (Billion euros, 2024€)	39.5 [0.005-600.5]	17.0 [0.002-412.5]	0.5 [0-21.5]	0

Note: The sensitivities are based on the sensitivity scenarios defined in Section 3.1.7 (e.g., not all endpoints are included in the low and medium scenarios). Please refer to Section 3.1.7 for the endpoints which are included in the medium, low and high sensitivities. Please note also that any other differences between the sum of values and the 'total' are due to the rounding of estimates.

The majority of the population in the EEA is exposed to background levels of PFAS and, thus, this cohort accounts for the majority of the human health costs from PFAS exposure in the medium and high-sensitivity scenarios. However, high levels of exposure in the elevated cohort drive the human health costs in the low-sensitivity scenario. The Table below provides a breakdown of the estimated costs by cohort for 2024, 2030, 2040 and 2050.

Table 3-26 Estimates of human health costs per year attributable to PFOA, PFOS, PFHxS and PFNA pollution in the EEA, by cohort capturing health endpoints for which evidence is available: Scenario 4 (Billion euros, 2024€) (medium [low-high] sensitivities)

Cohort	2024	2030	2040	2050
Background cohort (Billion euros, 2024€)	32.5 [0-506.5]	14.0 [0-349.0]	0.5 [0-17.7]	0
Elevated cohort (Billion euros, 2024€)	7.0 [0.005-93.5]	3.0 [0.002-62.5]	0 [0-3.7]	0
Occupational cohort (Billion euros, 2024€)	0.1 [0.0002-1]	0 [0-0.5]	0 [0-0.1]	0

Cohort	2024	2030	2040	2050
Total human health costs (Billion euros, 2024€)	39.5 [0.005-600.5]	17.0 [0.002-412.5]	0.5 [0-21.5]	0

Note: The sensitivities are based on the sensitivity scenarios defined in Section 3.1.7 (e.g., not all endpoints are included in the low and medium scenarios). Please refer to Section 3.1.7 for the endpoints which are included in the medium, low and high sensitivities. Please note also that any other differences between the sum of values and the 'total' are due to the rounding of estimates.

The majority of the population in the EEA are adults over 20 years of age, which means that, in absolute terms, the majority of human health costs are attributable to this group. However, human health costs estimated per person in 2030 are especially high for newborns (0 years), children (1-4 years), people (15+ years) residing near contaminated sites, and exposed workers.

In 2040, the costs could be entirely borne by adults in the general population, people (15+ years) residing near contaminated sites, and exposed workers. This is because these are the groups affected by the endpoints contributing to the attributable costs in these years (i.e., adult obesity, CKD, high blood pressure, high LDL cholesterol, hypothyroidism, osteoporosis, kidney cancer, endometriosis and female infertility). The Table below provides a breakdown of the estimated costs per person by population group for 2024, 2030, 2040 and 2050.

Table 3-27 Estimates of human health costs per person per year attributable to PFOA, PFOS, PFHxS and PFNA pollution in the EEA, by population group, capturing health endpoints for which evidence is available: Scenario 4 (Euros/person, 2024€) (medium [low-high] sensitivities)

Population group	2024	2030	2040	2050
Adults (20+) (General population) (Euros/person, 2024€)	100 [0-2,800]	100 [0-2,200]	5 [0-110]	0
Newborns (0 years) (Euros/person, 2024€)	1,700 [0-9,200]	300 [0-6,400]	0	0
Children (1-4 years) (Euros/person, 2024€)	1,000 [0-3,200]	300 [0-2,500]	0	0
Children (5-14 years) (Euros/person, 2024€)	0 [0-1,300]	0 [0-700]	0	0
Teenagers (15-19 years) (Euros/person, 2024€)	0 [0-600]	0 [0-400]	0	0
Pregnant women (Euros/person, 2024€)	200 [0-700]	0 [0-400]	0	0
People (15+) living near contaminated sites (Euros/person, 2024€)	400 [1-3,800]	200 [0-2,500]	10 [0-160]	0
Adults (Exposed workers) (Euros/person, 2024€)	400 [1-3,500]	200 [0-2,200]	10 [0-150]	0

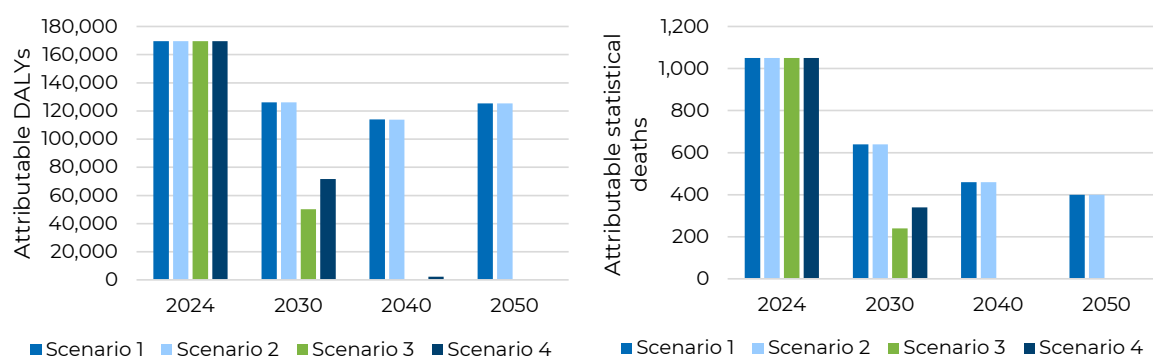
Note: The sensitivities are based on the sensitivity scenarios defined in Section 3.1.7 (e.g., not all endpoints are included in the low and medium scenarios). Please refer to Section 3.1.7 for the endpoints which are included in the medium, low and high sensitivities.

3.2.6. Comparison of scenarios

In comparison, Scenario 1 and Scenario 2 could lead to the highest disease burden and costs to human health, followed by Scenario 4 and Scenario 3, primarily driven by the reductions in PFAS emissions and human health exposure estimated under these prospective scenarios in Task 3.

The medium sensitivity estimates for attributable DALYs and statistical deaths per year across scenarios are presented in the Figure below for an easier visualisation of the evolution over time across scenarios.

Figure 3-2 Estimates of DALYs and statistical deaths per year attributable to PFOA, PFOS, PFHxS and PFNA pollution in the EEA, by scenario (medium sensitivity)



The Table below presents a comparison of the total human health costs per year attributable to PFOA, PFOS, PFHxS and PFNA pollution in the EEA, across the four scenarios.

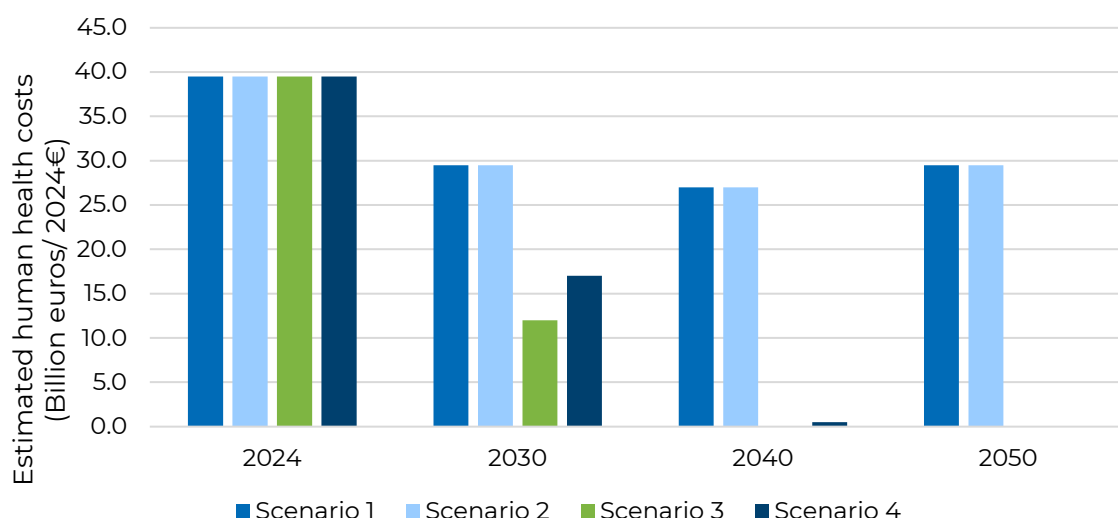
Table 3-28 Estimates of human health costs per year attributable to PFOA, PFOS, PFHxS and PFNA pollution in the EEA, by scenario, capturing health endpoints for which evidence is available (Billion euros, 2024€) (medium [low-high] sensitivities)

Scenario	2024	2030	2040	2050
Scenario 1: Business-as-usual for emissions	39.5 [0.005-600.5]	29.5 [0.005-529.5]	27.0 [0.004-456.5]	29.5 [0.004-426.0]
Scenario 2: Drinking Water Directive (DWD)	39.5 [0.005-600.5]	29.5 [0.005-529.5]	27.0 [0.004-456.5]	29.5 [0.004-426.0]
Scenario 3: Environmental Quality Standards (EQS)	39.5 [0.005-600.5]	12.0 [0.001-373.5]	0 [0-3.5]	0 [0-3.2]
Scenario 4: Total stop of production and use of PFAS	39.5 [0.005-600.5]	17.0 [0.002-412.5]	0.5 [0-21.5]	0

Note: The sensitivities are based on the sensitivity scenarios defined in Section 3.1.7 (e.g., not all endpoints are included in the low and medium scenarios). Please refer to Section 3.1.7 for the endpoints which are included in the medium, low and high sensitivities.

The Figure below presents the medium sensitivity estimates of human health costs over 2024-2050 to visualise, with more ease, the evolution of human health costs comparatively across scenarios.

Figure 3-3 Estimates of human health costs per year attributable to PFOA, PFOS, PFHxS and PFNA pollution in the EEA, by scenario (Billion euros, 2024€) (medium sensitivity)



Scenario 1 (business-as-usual for emissions) projects increasing emissions of PFAS and associated pollution. However, this does not apply to all PFAS. There is a small subset of PFAS that are already regulated in the EU, namely PFOA, PFOS, and PFHxS, for which historical evidence presents declining trends in emissions and blood serum levels. These also happen to be the most investigated PFAS, for which there is an evidence base of exposure links to health impacts. A fourth substance, PFNA, for which there is also evidence of exposure links to human health was considered in this analysis, which follows an increasing trend instead. **Under this Scenario 1, the present value of human health costs from PFOA, PFOS, PFHxS and PFNA pollution over the period 2024-2050 is estimated at €360 [0.052-5,750] billion, which is equivalent to an annualised cost of €19 [0.003-313] billion per year.**

The results from the implementation of the DWD thresholds under Scenario 2 are comparable to Scenario 1, since drinking water only accounts for a small fraction of human exposure and the majority of drinking water supplies might be below the threshold, even by 2050, under a baseline case. The present value of human health costs from PFOA, PFOS, PFHxS and PFNA pollution over 2024-2050 under Scenario 2 is therefore also estimated at €360 [0.051-5,750] billion, which is equivalent to an annualised cost of €19 [0.003-313] billion per year.

Under Task 3, compliance with the EQS threshold in Scenario 3 is modelled to be equivalent to a 99% reduction in emissions in 2030 (compared to 2024), which results in a decline of more than 95% in blood serum levels of PFAS across exposure cohorts by 2040 (compared to 2024). Under this Scenario 3, the present value of human health costs from PFOA, PFOS, PFHxS and PFNA pollution over the period 2024-2050 is estimated at €240 [0.03-4,350] billion euros, equivalent to an annual cost of €13 [0.002-237] billion per year.

The total stop of production and use of PFAS in Scenario 4 is modelled to lead to a 64% reduction in emissions by 2030 and nearly 100% by 2040 (compared to 2024). As a result, for all exposure cohorts, PFAS in blood could decline by around 60% in 2040 (compared to 2024) and could be eliminated by 2050. Compared to Scenario 3, the decline in blood serum concentrations occurs later on in Scenario 4 due to the continuing (but declining)

emissions from in-use stockpiles. As a result, the present value of human health costs from PFOA, PFOS, PFHxS and PFNA pollution over the period 2024-2050 under Scenario 4 is slightly higher than under Scenario 3, estimated at €260 [0.033-4,500] billion euros, equivalent to an annual cost of €14 [0.002-245] billion per year.

The Table below presents these results, along with the annual average burden of disease for the four scenarios over the period 2024-2050.

Table 3-29 Prospective human health costs of PFOA, PFOS, PFHxS and PFNA pollution in the EEA, as average/year and total over the period 2024-2050

Metrics	Scenario 1 (business-as-usual for emissions)	Scenario 2 (DWD)	Scenario 3 (EQS)	Scenario 4 (stop of production and use)
Attributable DALYs (average/year)	131,200 [16-1,489,500]	131,180 [15-1,489,500]	56,310 [5-892,400]	65,030 [6-942,700]
Attributable statistical deaths (average/year)	660 [0-21,850]	660 [0-21,850.0]	320 [0-12,980]	360 [0-13,820]
Equivalent Annual Cost to human health (Billion euros/year, 2024€)	19 [0.003-313]	19 [0.003-313]	13 [0.002-237]	14 [0.002-245]
Present Value of total costs to human health over 2024-2050 (Billion euros, 2024€)	360 [0.052-5,750]	360 [0.051-5,750]	240 [0.03-4,350]	260 [0.033-4,500]

Note: The sensitivities are based on the sensitivity scenarios defined in Section 3.1.7 (e.g., not all endpoints are included in the low and medium scenarios). Please refer to Section 3.1.7 for the endpoints which are included in the medium, low and high sensitivities.

When compared against Scenario 1 (business as usual for emissions), Scenario 2 results in negligible differences in costs to human health because, as noted, drinking water only accounts for a small fraction of human exposure and the majority of drinking water supplies might be below the threshold, even by 2050. Compared to Scenario 4, Scenario 3 results in a larger reduction against Scenario 1 in 2030 and 2040, eventually leading to comparable results in 2050. The percentage reductions against Scenario 1 are presented in the Table below.

Table 3-30 Estimates of percentage reduction in human health costs attributable to PFOA, PFOS, PFHxS and PFNA pollution in the EEA, when compared to Scenario 1 (medium [low-high] sensitivities)

Scenario (compared to Scenario 1: Business as usual for emissions)	2030	2040	2050
Scenario 2: Drinking Water Directive (DWD)	-0.01% [0% , -0.5%]	-0.02% [0% , -1.4%]	-0.03% [0% , -2.5%]
Scenario 3: Environmental Quality Standards (EQS)	-60% [-29% , -86%]	-100% [-99% , -100%]	-100% [-99% , -100%]

Scenario (compared to Scenario 1: Business as usual for emissions)	2030	2040	2050
Scenario 4: Total stop of production and use of PFAS	-43% [-22% , -64%]	-98% [-95% , -100%]	-100%

Note: The sensitivities are based on the sensitivity scenarios defined in Section 3.1.7 (e.g., not all endpoints are included in the low and medium scenarios). Please refer to Section 3.1.7 for the endpoints which are included in the medium, low and high sensitivities.

In summary, the persistence of PFAS in human blood serum (represented by an average half-life of 5 years) implies a lag between action and impact, with a delay in the estimated decline in blood serum levels and knock-on implications in the human health costs of PFAS pollution. The results suggest that **early action can lead to a faster reduction in the level of PFAS in human blood serum, and as a result, a faster, larger reduction in total human health costs of PFAS exposure.**

4. Direct ecosystem service costs

4.1. Methodology

As summarised in the Task 2 report, some effects of PFAS are understood for some individual organisms, but the effects on ecosystems, and consequently ecosystem services are unknown due to methodological, knowledge and data gaps. In light of these gaps, (eco)toxicological evidence and possible pathways to impacts (considering the affected species and their role in ecosystem service provisioning) can be considered to infer what ecosystem service losses and consequent costs to society may be taking place. The methodology for this task looks at the possible effects of PFAS on ecosystem services broadly (section 4.2.1), and then looks at four specific case studies of ecosystem services (section 4.2.2 to 4.2.5). This chapter does not include an assessment of the total value of ecosystem service costs resulting from PFAS pollution, due to the limitations mentioned above. Future costs are not estimated in this section, although a commentary is provided in section 4.2.6.

While this section does not present a monetary valuation of ecosystem service costs due to data gaps and uncertainties, it is still important to demonstrate that those costs could be significant. Ecosystem service costs are not covered directly by the assessment in section 5 of this report (which presents the cost to society of achieving a clean environment, rather than the actual market costs incurred by the (eco)toxic effects of PFAS). As such, this section improves the comprehensiveness of the assessment, despite being of a qualitative nature.

4.2. Results

4.2.1. Potential pathways from PFAS exposure to ecosystem service impacts

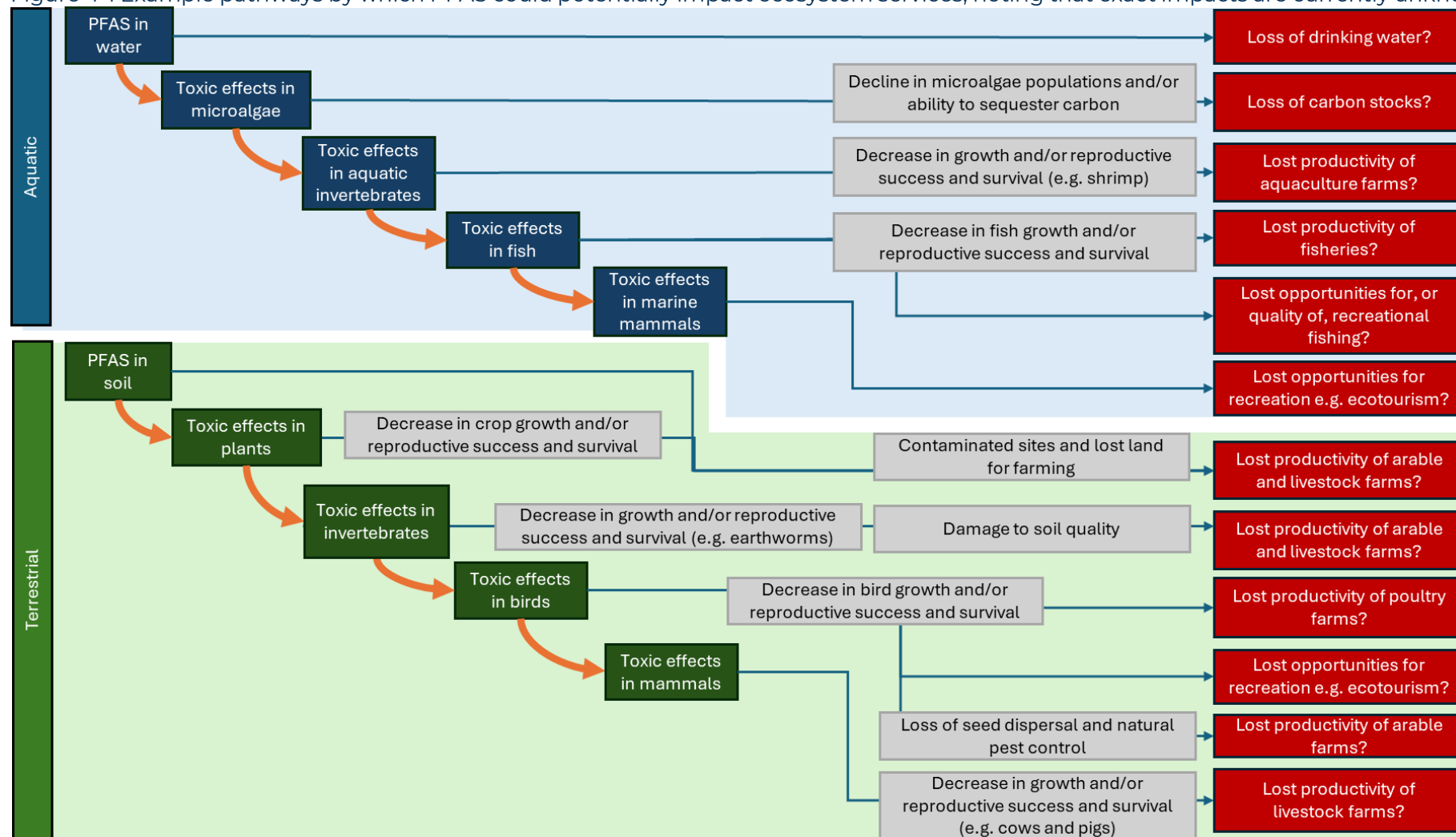
The scientific evidence is clear that some PFAS have the potential to harm aquatic and terrestrial animals and plants due to their (eco)toxicological properties, their persistence, their ability to bioaccumulate in organisms and biomagnify in food webs, and their additive

(and sometimes synergistic) effects.⁵⁸ Adverse effects have been observed in fish, crustaceans, amphibians, terrestrial invertebrates, birds, mammals, algae, and plants. These effects relate to reproduction, development, behaviour, neurology, lethality, the liver, and the immune system. If realised in the environment, these toxic effects in organisms could lead to ecosystem damage (e.g. through reduced survival, growth, and reproductive success of organisms), which could lead to societal costs through damage to associated ecosystem services.

Most studies on the effects of PFAS are based on traditional chemical risk assessment methods which look at the effects of substances on individual organisms under controlled conditions. These studies cannot be used to accurately predict ecosystem service losses and costs because of the differences between study conditions (e.g. in laboratories) and the real world (with many uncontrolled variables). However, through analysing the types of organisms that may be adversely affected by PFAS, and the role of those organisms in contributing to ecosystem services, the plausibility of potential ecosystem service impacts of PFAS can be assessed. The figure below considers the various types of biological organisms for which there is evidence of adverse effects of PFAS, and links them to some key ecosystem services, to demonstrate possible ecosystem service impacts. The figure focuses on market impacts due to focus of this project on monetised impacts.

⁵⁸ Ankley et al. (2020) *Assessing the Ecological Risks of Per- and Polyfluoroalkyl Substances: Current State-of-the Science and a Proposed Path Forward*. Available at: <https://setac.onlinelibrary.wiley.com/doi/epdf/10.1002/etc.4869> ; Banyoi et al. (2022) *The effects of exposure to environmentally relevant PFAS concentrations for aquatic organisms at different consumer trophic levels: Systematic review and meta-analyses*. Available at: <https://www.sciencedirect.com/science/article/pii/S0269749122016360>

Figure 4-1 Example pathways by which PFAS could potentially impact ecosystem services, noting that exact impacts are currently unknown.



This diagram visualises how PFAS exposure in water and soil could potentially lead to some ecosystem service effects (non-exhaustive). Exposure to different types of organisms, e.g. from algae to invertebrates, fish, birds, and mammals, could lead to different types of effects.

To confirm whether these ecosystem service impacts are taking place, and to discern the scale of these impacts, more evidence is needed (e.g. from field studies or modern/advanced risk assessment methods⁵⁹).

Four qualitative case studies are included below to explore the potential societal impacts of PFAS in terms of ecosystem services. The approach does not fully overcome the lack of quantitative evidence on the impacts of PFAS, but it does build a weight of evidence that suggests impacts from PFAS may be occurring. As noted above, PFAS could influence all types of ecosystem services (due to their possible effects on primary producers which support all ecosystems), therefore the section below only paints a small part of the overall picture.

It is important to note that effects of PFAS (described in the case studies below) have been modelled and observed at a range of concentrations, depending on the PFAS substance studied, the type of biological organism exposed, the type of effect studied, and the duration of exposure to PFAS before effects are measured. These concentrations range from less than 10 ng/L to thousands of mg/L. The specificity of each data point and number of variables means that the overall state of knowledge on ecosystem impacts (and ecosystem service impacts) is far from complete. Concentrations at which effects have been observed are summarised in the sections below: where they are comparable to environmental levels, this is indicative of probable adverse effects on the environment. However, even where environmental concentrations of PFAS are below the concentrations where effects have been observed in studies, there is a strong possibility that impacts may still be occurring. This is because (at least some) PFAS bioaccumulate in organisms, biomagnify in food webs, and can have chronic effects after prolonged exposure (over an organism's lifetime and multiple generations⁶⁰, which is longer than typically studied in (eco)toxicological studies⁶¹). The effects of PFAS may also be additive, or synergistic, meaning that concentrations of individual PFAS may be low enough to not elicit toxic effects on their own, but the combined combination of PFAS in the environment could lead to negative effects. In the absence of any evidence, it is best practice to assume that risks are additive/cumulative. Moreover, some studies may not have exposed organisms to PFAS at levels lower than the reported concentrations at which effects were observed.

4.2.2. Case study 1: Effects on algae and climate regulation

Key points

- *In the face of the current climate crisis, climate regulation ecosystem services have a clear societal value. Carbon sequestration in the EU in 2021 has been valued at over EUR 11 billion. A wide range of estimates are available*

⁵⁹ See e.g.: Forbes and Galic (2016). Next-generation ecological risk assessment: Predicting risk from molecular initiation to ecosystem service delivery, Available at: <https://doi.org/10.1016/j.envint.2016.03.002>.

Maltby et al. (2021). Assessing chemical risk within an ecosystem services framework: Implementation and added value. Available at: <https://doi.org/10.1016/j.scitotenv.2021.148631>.

⁶⁰ Haimbaugh et al. (2022) Multi- and Transgenerational Effects of Developmental Exposure to Environmental Levels of PFAS and PFAS Mixture in Zebrafish (*Danio rerio*). Available at: <https://pmc.ncbi.nlm.nih.gov/articles/PMC9228135/>

⁶¹ "Chronic" toxicity studies, designed to assess toxicity due to long-term exposure, often only assess effects after 21 days of exposure.

of the social cost of carbon, e.g. from tens of EUR per tonne of CO₂ to hundreds of thousands of EUR per tonne of CO₂.

- *Algae play a critical role in climate regulation, as they have a higher capacity for absorbing carbon than plants.*
- *A large body of evidence suggests that some PFAS are toxic to algae at concentrations as low as 10 ng/L. This is lower than surface water concentrations in Scenario 1. In Scenario 3 and 4 the concentrations are expected to fall below this level over the time horizon.⁶²*
- *Harm to algae caused by PFAS could be leading to significant ecosystem service costs by affecting chlorophyll content and photosynthetic capacity and could be compromising society's ability to mitigate climate change.*

Natural processes that facilitate climate regulation have a clear societal importance due to their role in mitigating the impacts of climate change (e.g. displacement due to flooding, deaths due to heat stroke). A significant contributor to climate regulation is freshwater and oceanic algae.⁶³ Phytoplankton absorb between 20 to 35% of global annual CO₂ emissions,⁶⁴ which is estimated to be four Amazon forests' worth⁶⁵. It has been reported that, when cultivating algae in natural conditions, a pond with a volume of 4000 m³ can absorb about 2,200 tonnes of CO₂ /year.⁶⁶ The carbon absorbed by algae can be removed from the atmosphere for a long time, as animals consume the algae, die, and sink to the ocean floor / sediment.⁶⁷ Algae have a high photosynthetic efficiency and remove carbon from the atmosphere at a higher rate than terrestrial plants.⁶⁸

Although many organisms are involved in carbon regulating processes and may be affected by PFAS pollution, algae are highlighted in this report because several studies on the effects of PFAS on algae have been undertaken, and it has been observed that algae (specifically microalgae) are particularly sensitive to the effects of PFAS.⁶⁹

At the time of writing (July 2025), there are 1,956 data points on the toxicity of PFAS to algae in the US EPA Ecotox Knowledgebase.⁷⁰ The Ecotox Knowledgebase is a database of toxicity

⁶² Note that average concentrations of the sum of PFAS (the results of Task 3) cannot be directly compared to effect thresholds of individual PFAS to predict the impacts on ecosystem services. See the final paragraph in section 2.4.1 on uncertainties.

⁶³ Naselli-Flores and Padisak (2023) Ecosystem services provided by marine and freshwater phytoplankton. Available at: <https://link.springer.com/article/10.1007/s10750-022-04795-y>

⁶⁴ Khatiwala et al. (2009) Reconstruction of the history of anthropogenic CO₂ concentrations in the ocean. Available at: <https://www.nature.com/articles/nature08526>

⁶⁵ Chami et al. (2019). Nature's solution to climate change. Available at: <https://www.imf.org/en/Publications/fandd/issues/2019/12/natures-solution-to-climate-change-chami>

⁶⁶ Iglina et al. (2022) Industrial CO₂ Capture by Algae: A Review and Recent Advances. Available at: <https://www.mdpi.com/2071-1050/14/7/3801>

⁶⁷ Naselli-Flores and Padisak (2023) Ecosystem services provided by marine and freshwater phytoplankton. Available at: <https://link.springer.com/article/10.1007/s10750-022-04795-y>

⁶⁸ Chen et al. (2024) Assessing global carbon sequestration and bioenergy potential from microalgae cultivation on marginal lands leveraging machine learning. Available at: <https://www.sciencedirect.com/science/article/pii/S0048969724046102#s0005>

⁶⁹ Banyoi et al. (2022). The effects of exposure to environmentally relevant PFAS concentrations for aquatic organisms at different consumer trophic levels: Systematic review and meta-analyses. Available at: <https://www.sciencedirect.com/science/article/pii/S0269749122016360>

⁷⁰ <https://cfpub.epa.gov/ecotox/search.cfm>

data compiled from peer-reviewed studies that have methods considered relevant and acceptable. For PFAS toxicity data based on algae, the Knowledgebase covers 58 PFAS substances and PFAS salts, 84 studies, 83 effect types, and 34 species of algae. Concentrations at which effects have been observed range from 10 ng/L to 20,250 mg/L⁷¹, with a median of 78 mg/L⁷². In comparison, surface water concentrations modelled in Task 3 for scenarios 1 and 2 range between 201 ng/L in the background cohort in 2024 and 2,285 ng/L (=0.002 mg/L) in the elevated-high cohort in 2050. In scenarios 3 and 4, the modelled surface water concentrations fall below 10 ng/L by 2030 (scenario 3) or 2040 (scenario 4) in all cohorts. Some effects listed in the database include:

- Changes in chlorophyll (indicating reduced carbon capture potential) have been observed for 13 types of PFAS across 12 species of algae. For example, effects have been observed in blue-green algae (*Microcystis aeruginosa*) exposed to at 0.0054 mg/L of PFOS exposure. Effects have also been observed at higher PFOS concentrations in other species, e.g. 51 mg/L in one type of green algae (*Scenedesmus acutus var. acutus*) and 88 mg/L in another type of green algae (*Chlorella vulgaris*).
- Changes in species abundance (a general measure of population health) have been observed in 17 species of algae, for 32 types of PFAS, at many different concentrations. In *Chlorella pyrenoidosa* (a freshwater green algae) and *Microcystis aeruginosa*, effects on abundance have been observed with PFOA exposure at 0.0001 mg/L. Effects on abundance of *Chlorella pyrenoidosa* and *Symbiodiniaceae* have also been observed with exposure to GenX/ HFPO-DA at the same concentration. At 0.01 mg/L exposure to PFBS, effects on species abundance of *Chlorella pyrenoidosa* have been observed.

Details of some specific study results are included below to further demonstrate the effects of PFAS on algae.

- Reduced growth has been observed when marine *Chlorella sp.* (a type of microalgae) was exposed to 6:2 Cl-PFAES (at 10 ng/L) and HFPO-DA (at 100 ng/L).⁷³
- Disruption of photosynthesis, metabolism, DNA replication, and growth has been observed when *Chlorella pyrenoidosa* was exposed to PFOS and PFBS.⁷⁴ Synergistic effects were observed (as the effects from exposure to a mixture of PFOS and PFBS were greater than the sum of effects of from exposure to PFOS and PFBS individually). Significant growth inhibition was observed at 100 mg/L.
- Decreased photosynthetic efficiency of phytoplankton communities (including various species collected from the Gulf of Mexico) has been

⁷¹ 1 ng/L = 1×10^{-6} mg/L

⁷² Taking into account the following types of effect measures: EC10, EC20, EC25, EC30, EC40, EC50, EC90, IL50, IC10, IC20, IC25, IC50, IC80, LOEC. NOELs and NOECs were excluded because they represent concentrations at which effects are not observed. If NOELs and NOECs were included the median effect concentration would be 20 mg/L.

⁷³ Niu et al. (2019)

⁷⁴ Liu et al. (2022) Joint toxicity mechanisms of binary emerging PFAS mixture on algae (*Chlorella pyrenoidosa*) at environmental concentration. Available at: <https://www.sciencedirect.com/science/article/abs/pii/S0304389422011487>

observed after exposure to PFOS in bioassays.⁷⁵ Different concentrations (5 mg/L and 30 mg/L) led to shifts in the identity of algae present, and decreased Shannon diversity (a measure of biodiversity) significantly. Notably, in the same study, 6:2 FTS did not alter the growth or health of phytoplankton communities, demonstrating differences in toxicity between types of PFAS.

- Decreased cell viability, growth, chlorophyll levels, and protein levels were observed in two green microalgae species (*Chlorella vulgaris* and *Scenedesmus obliquus*) exposed to mixtures of PFOS and PFOA at 1 – 10 mg/L for up to 7 days.⁷⁶

Overall, the evidence suggests that some PFAS exhibit toxicity to algae which could disrupt carbon capture and storage. Some toxic effects have been observed at environmentally relevant concentrations (i.e. 1,000 - 3,260 ng/L). As such, there is a clear risk to algae and their ecosystem services, which include climate regulation.

The ecosystem service of climate regulation provided by the marine ecosystem (including algae) has been valued at about EUR 200 /ha/year globally.⁷⁷ For rivers and lakes (including algae), it has been valued at about 250 EUR /ha/year globally. Carbon sequestration in the EU in 2021 has been valued at over EUR 11 billion⁷⁸, however, it is not clear whether this value takes into account carbon sequestered by algae, or what the value of carbon sequestration by algae is. Other research considers the costs of climate change, e.g., one paper suggests that 1 °C of warming would reduce worldwide GDP by 12%.⁷⁹ The paper suggests a social cost of carbon of around EUR 1,150 per tonne. Other estimates of the social cost of carbon range from around tens of EUR per tonne to EUR 750,000 per tonne.^{80,81} This highlights that impacts of PFAS pollution on algae could have substantial monetary implications in terms of climate change costs.

Although this case study is limited in scope and detail, the possible social cost of carbon (EUR 1,150 per tonne), alongside the role of algae in removing carbon from the atmosphere (e.g. claims that a 4000 m³ pond can absorb about 2,200 tonnes of CO₂ /year), indicates that any effects of PFAS on algae could have a significant economic cost to society. The EU has over 100,000 surface water bodies,⁸² each with different types and levels of algae in them.

⁷⁵ Davis et al. (2024). Life in the PFAS lane: The impact of perfluoroalkyl substances on photosynthesis, cellular exudates, nutrient cycling, and composition of a marine microbial community. Available at: <https://www.sciencedirect.com/science/article/abs/pii/S004896972402120X>

⁷⁶ Mojiri et al. (2023) Decreased cell viability, growth, chlorophyll levels, and protein levels were observed in two green microalgae species (*Chlorella vulgaris* and *Scenedesmus obliquus*) exposed to mixtures of PFOS and PFOA at 1 – 10 mg/L for up to 7 days. Available at: <https://www.mdpi.com/1422-0067/24/3/2446>

⁷⁷ Brander et al. (2024) Economic values for ecosystem services: A global synthesis and way forward. Available at: <https://www.sciencedirect.com/science/article/pii/S2212041624000123#s0045>. Converted from USD 2020 value to EUR 2025 value.

⁷⁸ <https://ecosystem-accounts.jrc.ec.europa.eu/accounting-tables/global-climate-regulation-use-sequestration-2021-monetary>

⁷⁹ Bilal and Känzig (2024). The Macroeconomic Impact of Climate Change: Global vs. Local Temperature. Available at: https://www.nber.org/papers/w32450?utm_campaign=ntwh&utm_medium=email&utm_source=ntwg1

⁸⁰ Tol (2023). Social cost of carbon estimates have increased over time. Available at: <https://www.nature.com/articles/s41558-023-01680-x>

⁸¹ Archer et al. (2020) The ultimate cost of carbon. Available at: <https://link.springer.com/article/10.1007/s10584-020-02785-4>

⁸² https://environment.ec.europa.eu/topics/water/surface-water_en

It should be noted that algae can have negative effects on climate change if excessive nutrient pollution leads to algal bloom, however, in natural conditions algae are largely beneficial to society due to their carbon sequestration potential.

Overall, while the costs of PFAS to society resulting from impacts on algae and climate regulation cannot be quantified, there is evidence to suggest that: a) algae play a critical role in climate regulation; b) climate regulation is of high economic value to society; c) many types of PFAS are toxic to algae and therefore have potential to cause economic losses through disruption to climate regulation.

Further work to understand the societal costs from the effects of PFAS on algae and climate change could investigate:

- The net rate of absorption of carbon by algal communities in different types of surface waters. The rate mentioned above (2,200 tonnes of CO₂/year) is unlikely to be consistent across water bodies as environmental conditions (e.g. temperature, concentration and type of algae, concentration of nutrients, salinity, water flow rate / dynamics) vary between surface waters. The volume of carbon released by surface waters should also be considered (e.g. related to the distribution of algal bloom and considering releases of carbon by algae).
- The effects of PFAS on algal communities. Existing data suggests that algae are affected by PFAS, however, further research is needed to build a weight of evidence to conclude that effects are taking place. Moreover, there is a lack of data on the quantitative extent to which carbon absorption by algae is reduced by PFAS exposure.

4.2.3. Case study 2: Effects on pollinators and food provisioning

Key points

- *Pollinators are essential for EU food security and support 5 to 15 billion EUR of the EU's agricultural output.*
- *Some evidence of adverse effects of PFAS on key pollinator species is available, indicating that environmentally relevant concentrations of PFAS could be causing mortality, reduced growth and development, and behavioural changes in bees.*
- *Effects of PFAS could reduce crop pollination rates, e.g. by affecting the numbers of pollinators and/or health of pollinators.*
- *Pollinators are threatened globally and the causes are not fully understood. More work is needed to understand whether, and the extent to which, PFAS are influencing pollinator decline.*

Crop pollination is required for approximately 84% of crops in the EU, supporting between 5 to 15 billion EUR of the EU's agricultural output.⁸³ Pollinators such as bees, butterflies, hoverflies, and moths are essential for food security, however, many pollinator species are threatened with extinction.⁸⁴ There is significant scientific and political concern regarding the global decline of pollinators, which has been associated with habitat loss and fragmentation, pesticide use, invasive species, climate change, and other drivers.⁸⁵ The 2020 JRC assessment of EU ecosystem services highlighted that, between 2000 and 2012, the EU demand and use of the crop pollination ecosystem service increased, but the ecosystem service potential decreased by 1%.⁸⁶ Given the current trends in human population growth and continued decline in pollinator species, it is expected that this trend is ongoing.

Limited research on the effects of PFAS on pollinators has been undertaken, however, there is some evidence for some key pollinator species, identified via the US EPA Ecotox Knowledgebase. For honeybees (*Apis mellifera*), which are the most widespread managed pollinators in the world,⁸⁷ data is available on the toxicity of nine PFAS and PFAS salts, including PFOS and a PFOS salt, as well as other lesser known PFAS. Sonter et al. (2021) exposed a colony of honeybees to PFOS in sugar syrup at environmentally relevant concentrations.⁸⁸ The lowest concentration of exposure (0.02 mg/L) prevented bee eggs and larvae from growing / maturing, and affected bee temperament and hive defence. At 0.8g mg/L, bee mortality increased significantly. Other studies have also observed effects of PFOS on honeybees, e.g. a dose of 0.48 ug per organism (ingested via food) was associated with mortality in 50% of bees in a sample.⁸⁹

Effects have also been observed on bumble bees (*Bombus terrestris* and *Bombus impatiens*). At 1 mg/L exposure to a salt of PFOS via the diet, 50% of bees in a sample died and effects on reproduction were observed.⁹⁰ Effects on mortality and reproduction of bumble bees have also been observed following exposure to lufenuron and flubendiamide at higher concentrations (50 – 5000 mg/L). As of 2019 and 2024 respectively, these PFAS pesticides are no longer approved for use in the EU.⁹¹

⁸³ EEA (2025) Protecting and restoring Europe's wild pollinators and their habitats. Available at: <https://www.eea.europa.eu/en/analysis/publications/protecting-and-restoring-europes-wild-pollinators-and-their-habitats>

⁸⁴ https://environment.ec.europa.eu/topics/nature-and-biodiversity/pollinators_en

⁸⁵ Lima et al. (2022) Editorial: The decline of wild bees: Causes and consequences. Available at: <https://doi.org/10.3389/fevo.2022.1027169>

⁸⁶ JRC (2020). Mapping and Assessment of Ecosystems and their Services: An EU ecosystem assessment Available at: <https://publications.jrc.ec.europa.eu/repository/handle/JRC120383>

⁸⁷ European Parliament (2021) Protecting pollinators in the EU. Available at: [https://www.europarl.europa.eu/RegData/etudes/BRIE/2021/696175/EPRS_BRI\(2021\)696175_EN.pdf](https://www.europarl.europa.eu/RegData/etudes/BRIE/2021/696175/EPRS_BRI(2021)696175_EN.pdf)

⁸⁸ Sonter et al. (2021) Biological and behavioral responses of European honey bee (*Apis mellifera*) colonies to perfluorooctane sulfonate exposure. Available at: <https://doi.org/10.1002/ieam.4421>

⁸⁹ The primary study has not been identified, but is referenced in the US EPA Knowledgebase as Wilkins (2001) Perfluorooctanesulfonate, Potassium Salt (PFOS): An Acute Oral Toxicity Study with the Honey Bee.

⁹⁰ Mommaerts et al. (2011). Impact of a perfluorinated organic compound PFOS on the terrestrial pollinator *Bombus terrestris* (Insecta, Hymenoptera). Available at: <https://pubmed.ncbi.nlm.nih.gov/21253836/>

⁹¹ <https://ec.europa.eu/food/plant/pesticides/eu-pesticides-database/start/screen/active-substances>

For wasps, evidence of toxicity of one PFAS substance, E(FOSA), was identified.⁹² Effects on development were observed at concentrations of 50 ug / organism and effects on behaviour and population abundance were observed at exposure of 1% of diet.

There are many gaps in knowledge for some pollinator species and PFAS, however, the available evidence suggests there could be a significant risk from PFAS, particularly PFOS, to crop pollination. One study in Austria monitored and detected various PFAS in bees and pollen, indicating that European bees are exposed to PFAS,⁹³ however, more information on exposure levels and toxicity would be needed to conclude on risks.

Economic losses from reduced pollinator populations have been estimated to be significant. It is predicted that if pollinator habitats in the EU were restored and the use of harmful chemicals reduced, the ecosystem service value of crop pollination could be doubled.⁹⁴ In 2021, crop pollination provided an estimated 6.4 billion EUR of value in the EU in 2021.⁹⁵ It is therefore important to understand whether, and the extent to which, PFAS is contributing to pollinator decline.

Given the societal value of crop pollination as an ecosystem service, any effects of PFAS on pollinators could represent a significant societal cost of PFAS. It should also be noted that the causes of the global decline of pollinators are not fully understood,⁹⁶ and chemical pollution (beyond the use of agrochemicals) has received little attention in research on pollinator decline.

4.2.4. Case study 3: Effects on poultry, livestock, and food provisioning

Key points

- *Annual poultry sales in the EU are worth 32 billion EUR and the livestock farming industry contributes around 168 billion EUR per year to the EU economy.*
- *There is evidence of toxicity of PFAS in chickens, including evidence of reduced survival and growth. Some evidence of PFAS toxicity to pigs (based on cellular / molecular effects) is available, but no studies on PFAS toxicity to cows was identified. At the same time, farmers have observed cattle death in regions of the US with high levels of PFAS contamination.*
- *Toxic effects of PFAS in farmed animals could be causing reduced productivity (e.g. through death of animals or reduced size of animals), resulting in economic losses. This cannot be predicted quantitatively in this study, but could be significant given the value of animal farming in the EU.*

⁹² Harris and Etheridge (2001). Comparison of Baits Containing Fipronil and Sulfuramid for the Control of *Vespula* Wasps. Available at: <https://www.tandfonline.com/doi/abs/10.1080/03014223.2001.9518255>

⁹³ Müller et al. (2025) Pfas in the Buzz: Seasonal Biomonitoring of Honey Bees (*Apis Mellifera*) and Pollen. Available at: https://papers.ssrn.com/sol3/papers.cfm?abstract_id=5263775

⁹⁴ Eurostat (2021). Accounting for ecosystems and their services in the European Union. Available at: <https://ec.europa.eu/eurostat/en/web/products-statistical-reports/-/ks-ft-20-002>

⁹⁵ <https://ecosystem-accounts.jrc.ec.europa.eu/national-data/crop-pollination-complementary-tables-use-monetary>

⁹⁶ Lima et al. (2022) Editorial: The decline of wild bees: Causes and consequences. Available at: <https://doi.org/10.3389/fevo.2022.1027169>

- *Commission Regulation 2022/2388/EU sets maximum cumulative concentrations for PFAS in animal products. If PFAS exceed these concentrations, animal produce should be discarded, resulting in a loss of sales. Some case studies indicate that animal produce has been discarded in Belgium in order to protect human health, but evidence to facilitate a broader assessment of these costs has not been identified.*

This third case study explores the evidence of PFAS toxicity to farmed poultry and livestock, as toxicity could lead to reduced growth and survival, which could lead directly to reduced profits (through reduced number, or weight, of produce that can be sold). At the same time, poultry and livestock contaminated with PFAS can lead to costs indirectly, as produce may be discarded (rather than sold) in order to protect human health. Further indirect costs could be plausible if contaminated produce is not discarded but consumed by humans, leading to costs through human health impacts.

In 2023, 13.3 million tonnes of the meat produced in Europe was poultry.⁹⁷ Annual sales are worth over 32 billion EUR, with over 300,000 people working in the sector.⁹⁸ The livestock sector contributes around 168 billion EUR annually to the EU economy, with 30 million people employed in the sector.⁹⁹ Livestock and poultry farming therefore have a clear economic importance to the EU.

Considering the first possible cost type mentioned above (toxicity to farmed animals and reduced weight or number of animals farmed), some evidence is available on the US EPA Ecotox Knowledgebase which suggests PFAS could have negative effects on chickens. Data on various effects is available for 37 PFAS and PFAS salts, including some well-known PFAS, e.g. PFOA, PFDA, PFHpA, and PFHpS. For example, mortality was observed in 50% of eggs in a sample exposed to 3.3 ug of PFOA per egg. A range of effects of PFOA have been observed in embryos exposed at 0.5 mg per kg of egg, from effects on heart rate, to size and weight. Mortality in embryos was observed at 2 mg/kg of egg. Molecular effects were observed in chicken liver tissue culture exposed to PFDA at 10 uM. Molecular effects were also observed in tissue exposed to 10 uM of PFHpA and PFHpS. Additional studies are available in the scientific literature, for example, Peden-Adams et al. (2009)¹⁰⁰ exposed chicken eggs to three different concentrations of PFOS solution (1, 2.5, and 5mg/kg egg wt). In all exposed samples, chicks developed shorter right wings. At the two higher concentrations, an increase in body length was observed. These concentrations are higher than the average concentrations for PFAS in food modelled in Task 3, however, as described in section 4.2.1, even where monitored concentrations are below effect thresholds, it cannot be concluded that effects are not taking place.

⁹⁷ https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Agricultural_production_-_livestock_and_meat

⁹⁸ <https://avec-poultry.eu/what-we-do/working-groups/trade/#:~:text=Annual%20sales%20of%20poultry%20meat%20in%20Europe%20are,trade%20partner%20in%20the%20global%20poultry%20meat%20market.>

⁹⁹ https://animaltaskforce.eu/wp-content/uploads/2024/11/Facts-and-figures-sustainable-and-competitive-livestock-sector-in-EU_FINAL.pdf#:~:text=The%20livestock%20sector%20contributes%20substantially%20to%20the%20European,and%20creates%20employment%20for%20almost%2030%20million%20people.

¹⁰⁰ Peden-Adams et al. (2009) Developmental toxicity in white leghorn chickens following in ovo exposure to perfluorooctane sulfonate (PFOS). Available at: <https://pubmed.ncbi.nlm.nih.gov/19071210/>

The evidence of toxicity suggests that PFAS exposure could reduce the productivity of poultry farms, however, the effects of PFAS on chickens are not concretely understood. More evidence on the effects of PFAS on chicken survival, development, and reproduction is needed to understand the scale and probability of societal costs from the effects of PFAS on poultry farm productivity.

For pigs, the US EPA Knowledgebase indicates that molecular effects of PFOA and HFOA have been observed in the lab at exposures of 134 - 380 μM (for PFOA) and 1560 - 1590 μM (for HFOA), which are suggestive of liver toxicity. Generally, data on the effects of PFAS on pig survival, development, and reproduction is lacking.

No evidence for cows was identified on the US EPA Ecotox Knowledgebase. One laboratory study identified via a literature search indicates that PFOS, PFBS, PFOA and PFBA impair cellular processes in brain cells of cows.¹⁰¹ Moreover, despite the general lack of toxicity studies, farmers have observed deaths of cows in several regions of the US with high levels of PFAS contamination.¹⁰² There is also increasing attention on the occurrence of PFAS in cattle as an exposure route to humans.¹⁰³

Indirectly, PFAS can have effects on poultry and livestock farm productivity as a result of protective measures to reduce human exposure to, and health impacts from, PFAS. Studies have revealed that eggs and chickens may be a source of PFAS exposure to humans, for example, in Poland, four PFAS (PFOS, PFOA, PFNA, and PFHxS) were measured in chickens' eggs with a combined concentration of 0.096 $\mu\text{g/kg}$, and in chicken livers with a combined concentration of 0.17 $\mu\text{g/kg}$.¹⁰⁴ Commission Regulation 2022/2388/EU sets a maximum cumulative concentration of these PFAS in eggs of 1.7 $\mu\text{g/kg}$ and chicken of 0.2 $\mu\text{g/kg}$.¹⁰⁵ The monitored levels in Poland were below the limits, however, the situation could differ in other contaminated areas in the EU. For example, in a contaminated region of Belgium, residents were advised to avoid the consumption of eggs.¹⁰⁶

The maximum level of 0.2 $\mu\text{g/kg}$ combined PFAS in chicken meat also applies to the meat of cows, sheep, and pigs. In Belgium, at least one livestock farm is expected to face productivity losses, as testing by Belgian authorities has revealed PFAS contamination in cattle on the farm, resulting in an obligation to test meat for PFAS before it can be sold.¹⁰⁷

¹⁰¹ Gonella et al. (2025) Exposure to PFOS, PFBS, PFOA and PFBA impairs cell cycle progression in bovine brain (Bos taurus) endothelial cells. Available at: <https://www.sciencedirect.com/science/article/pii/S0034528825000591>

¹⁰² The Guardian (2024), Texas farmers claim company sold them PFAS-contaminated sludge that killed livestock. Available at: <https://www.theguardian.com/environment/2024/mar/01/texas-farmers-pfas-killed-livestock> ; Dinis-Oliveira (2024). A tribute to Robert Bilott and one of the major toxicological discoveries: "Dark Waters" and the poison truth behind the Teflon nightmare. Available at: <https://publicacoes.cespu.pt/index.php/sl/article/view/186>

¹⁰³ E.g. Death et al. (2021) Per- and polyfluoroalkyl substances (PFAS) in livestock and game species: A review. Available at: <https://www.sciencedirect.com/science/article/abs/pii/S0048969720383285>

¹⁰⁴ Mikołajczyk et al. (2024) Chickens' eggs and the livers of farm animals as sources of perfluoroalkyl substances. Available at: <https://sciencedirect.com/pdf/10.2478/jvetres-2024-0034>

¹⁰⁵ Commission Regulation 2022/2388/EU on maximum levels of PFAS in certain foodstuffs. Available at: <https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32022R2388>

¹⁰⁶ RTBF Actus (2021) Flanders shaken by an environmental scandal that concerns us all. Available at: <https://www.rtbef.be/article/la-flandre-secouee-par-un-scandale-environnemental-qui-nous-concerne-tous-10781726>

¹⁰⁷ La Libre (2024) PFAS pollution: Meat production at Stabroek farm restricted after PFAS discovery. Available at: <https://www.lalibre.be/planete/sante/2024/05/02/pollution-aux-pfas-la-production-de-viande-dune-ferme-de-stabroek-restreinte-apres-la-decouverte-de-pfas-2RGJKA4KFREWZETY2LGPDYZWCE/>

In Italian precooked meat samples, PFBA was detected with a mean concentration of 0.22 ± 0.36 ug/kg and a highest concentration of 1.81 ug/kg.¹⁰⁸ PFBA is not covered by the regulation mentioned above, therefore this may not lead to a societal cost due to disposal of produce, but could lead to a cost due to health effects. The same study looked at PFOS concentrations in canned meat and pre-cooked meat, which on average were below the limits of detection, but reached a maximum of 0.13 ug/kg in pre-cooked meat. These concentrations are lower than the limits set in Regulation 2022/2388/EU.

It is currently unclear what proportion of livestock and poultry is contaminated with PFAS at a level that causes toxic effects on survival, reproduction, and development, or which causes exceedance of the maximum levels of PFAS set out in Regulation 2022/2388/EU. The societal cost could be significant given the multi-billion Euro market of the animal farming industry in the EU. Further research on the effects of PFAS on livestock herds and chickens would benefit this assessment.

4.2.5. Case study 4: Effects on aquaculture and food provisioning

Key points

- *Aquaculture farming in the EU generated 4.8 billion EUR in 2023. In 2022, 30 billion EUR of seafood was imported and 8.1 billion EUR was exported.*
- *There is a large body of evidence of PFAS toxicity to fish and crustaceans, including those which constitute a large portion of seafood produced and consumed in the EU. Some evidence suggests that PFAS can limit the growth, development, and survival of aquatic species, which could be causing economic losses through reduced productivity of aquaculture farms.*
- *Commission Regulation 2022/2388/EU sets maximum cumulative concentrations for PFAS in fish and crustaceans. If PFAS exceed these concentrations, produce should be discarded, resulting in a loss of sales.*

The fourth case study draws parallels with the one above, looking at ecosystem service losses in terms of food provisioning by aquaculture, by considering the (eco)toxic effects PFAS can have on fish and other organisms consumed in the EU as seafood, and the potential losses from discarding contaminated seafood.

The most consumed seafood in the EU is tuna, followed by salmon, shrimps, Alaska pollock, and cod.¹⁰⁹ By production value, the most produced seafood is trout, followed by seabass, seabream, oyster, and mussels.¹¹⁰ In 2022, 3.9 million tonnes of seafood were produced in the EU. 8.8 million tonnes were imported (worth about 30 billion EUR) and 2.2 million

¹⁰⁸ Nobile et al. Prevalence of perfluoroalkyl substances in paired batches of precooked and canned bovine meat and their implication on consumer safety. Available at: <https://www.sciencedirect.com/science/article/pii/S0278691524004769#sec3>

¹⁰⁹ DG MARE, EUMOFA (2024) The EU fish market. Available at: <https://op.europa.eu/en/publication-detail/-/publication/22f27511-b382-11ef-acb1-01aa75ed71a1>

¹¹⁰ https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Aquaculture_statistics#Aquaculture_species_and_specialisation

tonnes were exported (worth about 8.1 billion EUR).¹¹¹ A separate source reports that aquaculture farming in the EU in 2023 yielded 1.1 million tonnes of seafood worth 4.8 billion EUR.¹¹²

Some fish have been relatively well-studied in the context of PFAS toxicity. The US EPA Ecotox Knowledgebase holds 29,600 data points on PFAS toxicity to fish. Filtering to tuna, salmon, shrimp, prawn, pollock, cod, trout, seabass, seabream, oyster, and mussel, yields 2,436 results. No results were identified for tuna, sea bass, or pollock, but other results related to the key species consumed in the EU are summarised below.

For rainbow trout (*Oncorhynchus mykiss*), there is toxicity data for 30 PFAS substances and PFAS salts, demonstrating effects on behaviour, mortality, molecular / cellular effects, growth, size and weight, and tumour formation. The lowest effect concentration recorded is 0.0005 mg/L for PFOA, corresponding to molecular effects on liver tissue. Survival was affected at 0.21 mg/L of E(FOSA), causing 50% of trout in a sample to die. These concentrations are higher than the average concentrations of PFAS modelled in each scenario in Task 3, however, as noted in section 4.2.1, concentrations of PFAS below thresholds may still elicit effects.

Cellular effects of fulvestrant (a medicinal PFAS product) on the liver tissue of sea bream (*Sparus aurata*) have been studied and observed at concentrations of 4 mg/Kg body weight. For the Pacific oyster (*Crassostrea gigas*), PFOA toxicity has been demonstrated at 0.68 mg/L, which elicited cellular / molecular effects. Cellular / molecular effects have also been observed in blue mussels (*Mytilus edulis*) exposed to 0.02 mg/L PFOA. For the common shrimp (*Crangon crangon*), hexaflumuron (a PFAS insecticide) toxicity has been observed at 2.28 mg/L, leading to mortality of 50% of the sample population. For Atlantic cod (*Gadus morhua*), cellular / molecular effects of PFNA have been observed at 4.1 mg/L and cellular / molecular effects of PFOS effects have been observed at 0.2 mg/L. As above, these concentrations are higher than the average concentrations of PFAS modelled in each scenario in Task 3.

For salmon, there is toxicity data for 6 PFAS substances and PFAS salts. Effects of PFOA and a salt of PFOS on size and weight, heart rate, were observed at exposure to 0.1 mg/L of each substance individually. Cellular / molecular effects of other PFAS have been studied and observed, e.g. at concentrations of 0.1 mg/L PFOS, and at concentrations of 25 mg/L PFOSA. As above, these concentrations are higher than the average concentrations of PFAS modelled in each scenario in Task 3.

The evidence suggests that several PFAS have the potential to cause harm to fish and crustaceans, which could damage ecosystem services through reduced survival, growth, and/or reproduction of organisms, leading to reductions in fish and aquaculture stocks. Moreover, Commission Regulation 2022/2388/EU sets a maximum cumulative concentration of PFAS (PFOS, PFOA, PFNA, and PFHxS) in fish of 1.7 ug/L. Similar to poultry and livestock, an additional cost may arise from the need to discard fish produce which exceeds the maximum limits in order to protect human health. Monitoring studies indicate

¹¹¹ DG MARE, EUMOFA (2024) The EU fish market. Available at: <https://op.europa.eu/en/publication-detail/-/publication/22f27511-b382-11ef-acb1-01aa75ed71a1>

¹¹² https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Aquaculture_statistics#Highlights

that these limits are exceeded in some fish in the EU,¹¹³ however, these values are below the average concentrations in fish modelled in the baseline year in Task 3.

Overall, ecosystem service losses through damages to fish and aquaculture stocks could be having a significant cost to society through impacts on the multi-billion Euro fishing industry.

4.2.6. Considerations of future costs

Future decisions could change the use, emissions, remediation / clean-up, and environmental exposure patterns of PFAS (explored in Task 3), which could have consequences for the future ecosystem service costs of PFAS. For example:

- In scenarios 1 and 2, where environmental exposure is expected to increase, the costs of PFAS pollution, in terms of ecosystem services, are also expected to increase over time.
- In scenarios 3 and 4, ecosystem service losses over time are not expected to be as severe. Costs are expected to continue, and potentially increase, for some time, but in the long-term, costs may gradually decrease as PFAS emissions decrease, and as PFAS exposure decreases. It is not possible within the scope of this project to predict specific magnitudes or timescales for these trends because of the limited understanding of the ecosystem service costs.

The potential increase in costs, even with decreasing environmental exposure, is noted because bioaccumulation and biomagnification may lead to continued increasing internal exposure and effects in organisms. Similar problems have been observed with other persistent organic pollutants banned decades ago which are still present in the environment, e.g. polychlorinated biphenyls (PCBs) in whales.¹¹⁴ Effects may also be prolonged for organisms with longer life spans, e.g. where exposure to a foetus can lead to effects through the foetus' lifespan, and potentially effects on the eventual offspring of the foetus.¹¹⁵ Of the ecosystem services mentioned in this report, this could be most relevant to food provisioning related to livestock farming.

Climate change may also influence the future costs of PFAS to society (in all scenarios). Climate change can change the sensitivity of organisms to the toxic effects of PFAS.¹¹⁶ This could lead to increased or decreased toxicity to different species, although more research

¹¹³ Rüdel et al. (2022) Tissue concentrations of per- and polyfluoroalkyl substances (PFAS) in German freshwater fish: Derivation of fillet-to-whole fish conversion factors and assessment of potential risks. Available at: <https://doi.org/10.1016/j.chemosphere.2021.133483>; Langberg et al. (2024) Human exposure to per- and polyfluoroalkyl substances (PFAS) via the consumption of fish leads to exceedance of safety thresholds. Available at: <https://doi.org/10.1016/j.envint.2024.108844>; Teunen et al. (2021) PFAS accumulation in indigenous and translocated aquatic organisms from Belgium, with translation to human and ecological health risk. Available at: <https://link.springer.com/article/10.1186/s12302-021-00477-z>

¹¹⁴ Megson et al. (2022) Polychlorinated biphenyl (PCB) concentrations and profiles in marine mammals from the North Atlantic Ocean. Available at: <https://www.sciencedirect.com/science/article/pii/S004565352103111>

¹¹⁵ Haimburgh et al. (2022) Multi- and Transgenerational Effects of Developmental Exposure to Environmental Levels of PFAS and PFAS Mixture in Zebrafish (*Danio rerio*). Available at: <https://pmc.ncbi.nlm.nih.gov/articles/PMC9228135/>

¹¹⁶ Chung et al. (2024) Effects of Temperature and Salinity on Perfluorooctane Sulfonate (PFOS) Toxicity in Larval Estuarine Organisms. Available at: <https://pmc.ncbi.nlm.nih.gov/articles/PMC11053673/>; Alum (2025) The role of toxicology in climate change: Understanding the risks of novel environmental toxins. Available at: <https://www.tandfonline.com/doi/full/10.1080/27658511.2025.2467485#abstract>

is needed to better understand the expected changes in toxicity and impacts. Melting permafrost (as a result of climate change) can also release PFAS, enabling it to mobilise in the environment, potentially increasing the societal costs of PFAS.¹¹⁷ Climate change may also change the societal value of ecosystem services, e.g. climate regulation and food provisioning may become more valuable, which could increase the costs of PFAS pollution in terms of losses to these services.

4.2.7. Conclusions on ecosystem service costs from PFAS pollution and limitations in the assessment

Overall, the four case studies highlight the significant economic importance of ecosystem services related to climate regulation, pollination and crop provisioning, and animal / aquaculture farming. Each of these services contributes several billion Euros to the EU annually.

There is evidence of PFAS toxicity to several biological species upon which ecosystem services are dependent. This includes evidence of reduced survival, growth, and reproduction as a result of exposure to PFAS, which is indicative that PFAS could reduce the ability of some species to support ecosystem services. Many of the toxicity studies identified look at molecular / cellular effects which are suggestive of negative impacts, but do not confidently prove that PFAS cause negative impacts on the survival, growth, and/or reproduction of the target species at environmentally relevant concentrations. There are data gaps for some biological species and for many types of PFAS, leaving the overall picture fragmented. A large portion of the available data looks at PFOA and PFOS, while thousands of other PFAS remain unstudied. Some studies point towards additive or synergistic effects, which raises significant concerns about what the unstudied cumulative effects of PFAS on the environment look like.

Toxicity thresholds and environmental concentrations cannot be used to conclude on the level of risks from PFAS to the species involved in ecosystem service provisioning because of the lack of ability to consider additive and synergistic effects, long-term exposure, bioaccumulation, and biomagnification. Moreover, the scale and likelihood of impacts on ecosystem services cannot be concluded on due to uncertainties about the real world effects of PFAS (compared to effects in controlled studies).

Modern/advanced chemical risk assessments to extrapolate interspecies toxicity¹¹⁸ could be useful in the future to better understand the risks and impacts from PFAS to the species involved in ecosystem provisioning (e.g. for pollinators, livestock, and fish where toxicity data is currently lacking). Emerging methods to assess how toxicity data translates to real world ecological risks¹¹⁹ might also support a future assessment of ecosystem service costs.

¹¹⁷ Mahmoudnia et al. (2022) Change in global PFAS cycling as a response of permafrost degradation to climate change. Available at: <https://www.sciencedirect.com/science/article/pii/S2772416621000383>

¹¹⁸ E.g. methods described by Colbourne et al. (2022) Toxicity by descent: A comparative approach for chemical hazard assessment. Available at: <https://www.sciencedirect.com/science/article/pii/S2666765722001223>

¹¹⁹ E.g. Fantke et al. (2018) Toward harmonizing ecotoxicity characterization in life cycle impact assessment. Available at: <https://onlinelibrary.wiley.com/doi/abs/10.1002/etc.4261>

This assessment highlights the potential costs of PFAS on ecosystem services, which could be significant across the EU, even though their economic value has not been quantitatively assessed because of methodological and data gaps.

5. Soil remediation and water treatment costs

5.1. Methodology

The following stepwise methodology was used to estimate the costs for the remediation of PFAS-polluted soil and the treatment of PFAS-polluted water in the EEA. This methodology was developed in Task 2 and based on literature and evidence collected under Task 1, as well as the outputs of the scenario analysis undertaken under Task 3. The steps are summarised below.

5.1.1. Step 1 Define PFAS concentration thresholds in water:

PFAS concentration thresholds for water are defined for specific scenarios. For any site exceeding these thresholds, water treatment costs will be considered in the analysis. For water treatment, thresholds have been selected to reflect the following assumptions:

In **scenario 1** (business as usual for emissions), it is expected that no significant additional wastewater treatment is implemented to address PFAS¹²⁰. Since the effects of the Recast Drinking Water Directive (DWD) limits are assessed separately in scenario 2, no EU-wide concentrations thresholds for drinking water are assumed in scenario 1. However, some additional drinking water treatment to address PFAS could still be implemented if required due to European or national limit values. National limit values for drinking water can vary between 0.002 and 7 µg/L for different PFAS species or groups, but they cover only some countries and PFAS species¹²¹. The exposure modelling (Task 3) estimates concentrations of up to around 0.23 µg/L for the sum of 20 PFAS in drinking water by 2050, which would suggest that limits would not be exceeded in most cases. For simplicity, it has therefore been assumed that no additional drinking water treatment is implemented under scenario 1.

In **scenario 2**, additional drinking water treatment is expected to be implemented to fully comply with the proposed Recast Drinking Water Directive (DWD) limits of 0.1 µg/L for the sum of 20 PFAS and 0.5 µg/L for total PFAS.

In **scenario 3**, it is expected that all wastewater treatment plants will require additional treatment to achieve compliance with proposed EQSD limits.

¹²⁰ See e.g. EurEau (2021): PFAS and waste water – Current knowledge from the European water sector and the case for control at source. Briefing Note, May 2021. [https://www.eureau.org/resources/briefing-notes/5612-briefing-note-on-pfas-and-waste-water/file#:~:text=Waste%20water%20treatment%20plants%20\(WWTP,effluent%20or%20in%20sewage%20sludge](https://www.eureau.org/resources/briefing-notes/5612-briefing-note-on-pfas-and-waste-water/file#:~:text=Waste%20water%20treatment%20plants%20(WWTP,effluent%20or%20in%20sewage%20sludge). (accessed 27 June 2025).

¹²¹ ITRC (2024): PFAS Environmental Media Values Table Excel file. (accessed 12 June 2025)

In **scenario 4**, no specific thresholds are applied to trigger drinking water treatment or wastewater treatment, but it is assumed that the production and use of PFAS cease in the EEA, which is expected to lead to fewer contaminated sites requiring soil remediation and water treatment compared to the other scenarios.

Note that our assessment of **soil** remediation costs is based on numbers of contaminated sites (see next step), and not on specific thresholds. Soil remediation could not be linked to specific thresholds, because (1) the need for soil remediation of PFAS contamination is typically determined on a case-by-case basis by competent authorities following a more detailed assessment triggered when concentrations exceed national intervention values or screening thresholds, (2) for many countries and PFAS species, there are no legal limits (e.g. intervention values or screening values), and (3) it has not been possible to link monitored PFAS concentrations to specific sites¹²².

5.1.2. Step 2 Identify potential water treatment volumes and soil remediation sites:

For drinking water and wastewater, treatment costs are based on the volume of water treated. As a proxy for **drinking water**, the volume of public water supply to households is taken from Eurostat¹²³ and converted to cubic meters per capita per year. For countries for which there are gaps in the Eurostat dataset, the weighted average volume per capita per year from EEA countries where data is available (45m³ per capita per year) is applied. The per capita volume of each country is then multiplied by the population of different cohorts with different concentrations of PFAS (background, elevated-low, elevated-high and occupational) as projected by the exposure model (Task 3).

For **wastewater**, the volume of total discharges of wastewater treatment plants (urban and other) is taken from Eurostat¹²⁴. For countries for which there are gaps in the Eurostat dataset, the volume is estimated by applying the weighted average volume per capita per year from EEA countries where data is available (96m³ per capita per year) to the population of the country. Wastewater volume is projected to decrease proportionally to the EEA population in future years, which is consistent with the exposure model (Task 3).

For **soil remediation**, the most comprehensive dataset of contaminated sites potentially requiring remediation in Europe was created by the Forever Pollution Project and has been further developed by the French National Centre for Scientific Research (Centre national pour la recherche scientifique, CNRS). It is available on the CNRS PFAS Data Hub¹²⁵ and has also been used in the most recent and most comprehensive estimate of PFAS remediation

¹²² The Forever Pollution Project dataset available on the CNRS PFAS Data Hub (discussed further below) provides known and presumptive PFAS contaminated sites as separate data points from measured PFAS concentrations at monitoring sites, and therefore PFAS concentrations are not directly linked to the known and presumptive PFAS contaminated sites.

¹²³ Eurostat (2024): Water use by supply category and economical sector [env_wat_cat_custom_12101819]. https://ec.europa.eu/eurostat/statistics-explained/images/1/1b/Water_statistics_2024_rev1.xlsx (accessed on 07/07/2025). Data for 2020. For Germany, 2020 data was unavailable, so a value of 5.2bn m³ has been used, based on a stakeholder contribution from the German water industry association DVGW (dated 27 February 2025) for the parallel European Commission study (Analysis of treatment techniques: Removal of specific pollutants and feasibility assessment of an extended producer responsibility for PFAS).

¹²⁴ Eurostat (2024): Generation and discharge of wastewater in volume [env_ww_genv_custom_17199926]. <https://ec.europa.eu/eurostat/databrowser/bookmark/42f3b4d3-3d01-43e8-9984-79bce42a46ca?lang=en> (accessed on 19/06/2025). Data for 2020.

¹²⁵ <https://pdh.cnrs.fr/en/>

costs in Europe (Forever Pollution Project, 2025). The dataset includes “known” PFAS producing and using sites, as well as “presumptive” PFAS using sites. The exposure model (Task 3) projects the evolution of the number of sites in the different scenarios based on projected PFAS emissions. Soil remediation is assumed to occur over an uncertain time within the assessment period (27 years from 2024 to 2050), so as a simplification and to avoid the double counting of remediation costs for the same site twice, each year the number of sites is multiplied with the average annual unit cost (unit cost divided by 27 years). For comparison, Forever Pollution Project (2025)¹²⁶ assumed that remediation of the contaminated sites would take place over a period of 20 years (instead of 27 years here). Due to the uncertainty about what share of “presumptive” sites are really contaminated with PFAS, results are presented both with and without presumptive sites (in addition to known sites). While there may also be diffuse soil contamination outside of specific sites that use or produce PFAS, soil remediation generally only covers limited geographic areas around specific sites. It would not be technically or economically feasible to remediate wide-ranging diffuse contamination.

Treatment of PFAS in **landfill leachate** is an emerging area of investigation¹²⁷ and cannot easily be linked to the scenarios (from Task 3). It is therefore only included in the sensitivity analysis.

5.1.3. Step 3 Apply unit costs for soil remediation and water treatment to sites/volumes:

For the purpose of this analysis, “unit costs” means costs of remediation/treatment per relevant unit to which remediation/treatment is applied, such as a contaminated site remediated, or a volume of water treated. These unit costs will be applied to the number of sites and volumes of water that are determined in the previous steps for the different scenarios and years (based on the Task 3 exposure modelling). The unit costs are derived from key sources of previous estimates of PFAS remediation and treatment costs, notably the Forever Pollution Project (2025)¹²⁸, and a parallel European Commission study¹²⁹. The unit costs were presented in the Task 2 report and are not repeated here, except for the unit costs for drinking water and wastewater treatment which are shown in Appendix B to Annex D.

Combining steps 1-3 yields estimate remediation and treatment costs for each of the pollution scenarios from Task 3. Based on Forever Pollution Project (2025), an additional 5% are added to the core estimate for each scenario and year (0%-10% to the sensitivity estimates), to account for additional “miscellaneous” costs not included in the unit costs discussed above, such as procurement of consultants, design of remediation technology, quality assurance and PFAS monitoring. Note that since costs were only calculated for the years 2024, 2030, 2040 and 2050, costs for the years in between were estimated by linear

¹²⁶ Forever Pollution Project (2025): *Unaffordable - The absurd cost of 'PFAS as usual'.*

¹²⁷ Forever Pollution Project (2025): *Unaffordable - The absurd cost of 'PFAS as usual'.*

¹²⁸ Forever Pollution Project (2025): *Unaffordable - The absurd cost of 'PFAS as usual'.*

¹²⁹ Analysis of treatment techniques: removal of specific pollutants (PFAS, Bisphenol A, pesticides and their metabolites) and feasibility assessment of an Extended Producer Responsibility system for PFAS.

interpolation for the purpose of calculating the present value of full cost over the full period used in the comparison of scenarios (Section 5.2.6).

5.1.4. Sensitivity analysis

The following sensitivities have been considered:

- **Soil remediation:**
 - The requirements and costs for soil remediation can vary substantially depending on site-specific criteria. As discussed in the Task 2 report, the unit costs per site have been derived from Forever Pollution Project (2025) for different types of sites and they range from €6 million (“other” sites) to €40 million (PFAS manufacturing sites). In the sensitivity analysis, the full range of potential costs per site from Goldenman et al. (2019)¹³⁰ has been applied, which ranges from €300,000 to €50 million. This leads to a wider range of costs compared to the core estimates (i.e. lower costs in the low sensitivity and higher costs in the high sensitivity).
 - Moreover, there is significant uncertainty regarding the number of sites that require remediation. For the sensitivity low estimates, only 207 “known” PFAS producing and using sites identified by the Forever Pollution Project have been considered. This reduces the costs by a factor of about 50, compared to the core estimates. In the sensitivity high estimate, 11,264 additional “presumptive” PFAS using sites identified by the Forever Pollution Project have also been considered (the same number of sites as in the core estimate).
- **Water treatment:** The parallel European Commission study¹³¹ estimated a wide range of drinking water and wastewater treatment costs for PFAS depending on the technology used and the size of the treatment plant. In our core estimates, we assumed high flow¹³² and used the minimum, average and maximum cost across different technologies for our low, best and high estimates. The low and high sensitivity estimates consider the full potential range of costs including low flow to very high flow. The unit costs used for each estimate are shown in Appendix C. They range from €0.10 to €32.27 per m³ of drinking water, and from €0.76 to €14.55 per m³ of wastewater. This leads to a wider range of costs compared to the core estimates (i.e. lower costs in the low sensitivity and higher costs in the high sensitivity).
- **Landfill leachate:** Treatment of PFAS in landfill leachate is an emerging area of investigation and cannot easily be linked to the scenarios (from Task 3). It is therefore only included in the sensitivity analysis. The higher end of the range estimated by Forever Pollution Project (2025) per country is used as our sensitivity

¹³⁰ Goldenman et al. (2019). *The cost of inaction: A socioeconomic analysis of environmental and health impacts linked to exposure to PFAS*. Nordic Council of Ministers. Available at: <https://norden.diva-portal.org/smash/get/diva2:1295959/FULLTEXT01.pdf>

¹³¹ Analysis of treatment techniques: removal of specific pollutants (PFAS, Bisphenol A, pesticides and their metabolites) and feasibility assessment of an Extended Producer Responsibility system for PFAS.

¹³² 38,000 m³/day Considered most representative based on expert judgement from the project team of the parallel study.

high estimate (no landfill leachate is used in the sensitivity low estimate). Compared to the core estimate, this adds around €200 million per year for the whole EEA.

5.2. Results

5.2.1. Current costs

Based on the method, inputs and assumptions summarized above, we estimate the annual remediation cost in the EEA in 2024 to be between around €87 million (when only considering known PFAS producing/using sites) and €3.8 billion (when considering known and presumptive PFAS producing/using sites)¹³³. “Known” and “presumptive” refers to sites identified by the Forever Pollution Project as being known to manufacture or use PFAS (and thus as certain or likely to be contaminated), or as being presumed to be contaminated based on likely PFAS use or PFAS waste¹³⁴. The number of these sites was projected for the exposure scenarios in the present study, and the terminology of known and presumptive sites has been adopted from the Forever Pollution Project.

5.2.2. Future costs Scenario 1: Business as usual

The annual remediation cost estimates for scenario 1 are shown in [Table 5-1](#). As discussed in Task 3, in scenario 1, PFAS emissions are expected to increase significantly over the assessment period, which is expected to be associated with an increase in the number of PFAS producing and PFAS using sites, and therefore PFAS contaminated sites that require soil remediation. This is reflected in an **increase in the annual soil remediation costs in the EEA from around €82 million in 2024 to around €103 million in 2050 when only considering known sites, or from around €3.6 billion in 2024 to €4.5 billion in 2050 when considering both known and presumptive sites.**

However, note that the current assessment assumes that the same site is only remediated once within the assessment period. In reality, the continuing emissions in this scenario could require some sites to be remediated again. Therefore, the estimate is likely an underestimate.

For comparison, Goldenman et al. (2019) estimated non-health costs of PFAS contamination (the majority of which was soil remediation) of €16.9 billion over 20 years (so on average €0.8 billion per year). Forever Pollution Project (2025) estimated costs of €4.3 billion/year to remediate legacy soil contamination, plus €15.9 billion/year for future soil contamination. Since Forever Pollution Project (2025) included presumptive sites, and since we assumed that each site is only remediated once within our 27-year assessment period, the most appropriate comparison would be between our best estimate with presumptive sites (€3.6 billion in 2024 to 4.5 billion in 2050) and the Forever Pollution Project’s estimate for remediating legacy sites (€4.3 billion/year),

¹³³ These totals include miscellaneous costs such as procurement of consultants, design of remediation technology, quality assurance and PFAS monitoring.

¹³⁴ For a more detailed explanation, see: <https://pdh.cnrs.fr/en/methodology/#3-pfas-contamination-sites>

which are in the same order of magnitude. The “emerging scenario” estimate of €15.9 billion/year for the remediation of future soil contamination with yet unregulated PFAS in Forever Pollution Project (2025) “assumes that ongoing contamination results in a continuous need beyond 20 years (as in the legacy scenario) as new soil sites keep emerging.” Our estimates also include new sites from continuing PFAS emissions, but our estimates are closer to Forever Pollution Project’s “legacy scenario” which covers remediation of existing sites over the next 20 years, because of our assumptions that (1) each site is only remediated once within our 27-year assessment period, and (2) only 25% of predicted future emission increases are associated with new sites, while 75% of the increased emissions come from pre-existing sites through on-site expansion and increase in production (see Task 3 report).

Note that scenario 1 reflects the regulatory situation from June 2024 and therefore does not consider the REACH restriction on PFAS in firefighting foams (i.e., it is assumed that PFAS emissions from use in firefighting foams continues). Since the majority of PFAS emissions at airports, military sites, and some other contaminated sites come from firefighting foams, it would be expected that the number of these sites would not continue to increase as a result of the firefighting foam restriction. However, existing sites would still require remediation. The exposure modelling in Task 3 projected an increase from 2,336 airports, firefighting training sites and military sites (out of a total of 11,264 presumptive sites) in 2024 to 2,893 (out of a total of 13,949 presumptive sites) in 2050. This means sites related to firefighting foam use account only for a small share of the projected increase in sites, and therefore considering the REACH restriction on PFAS in firefighting foams would only have a relatively small impact on the overall results.

As discussed in the previous section, in scenario 1, it is assumed that no significant additional drinking water or wastewater treatment cost are incurred to remove PFAS. These costs are discussed in scenarios 2 and 3 below.

Table 5-1 Prospective treatment/remediation costs per year of PFAS pollution in the EEA: Scenario 1 (business-as-usual) (€ millions, in 2024 value)

Cost category / estimate*	2024	2030	2040	2050
Soil remediation - PFAS manufacturer (known)				
Best estimate	25	25	28	31
Sensitivity high	31	31	35	39
Sensitivity low	0	0	0	0
Soil remediation – Industrial PFAS users (known)				
Best estimate	57	60	64	72
Sensitivity high	359	372	400	448
Sensitivity low	2	2	2	3
Soil remediation - Airports (presumptive)				
Best estimate	227	237	255	283
Sensitivity high	1,535	1,600	1,722	1,911
Sensitivity low	0	0	0	0
Soil remediation - Military (presumptive)				
Best estimate	634	658	711	791
Sensitivity high	861	894	967	1,074
Sensitivity low	0	0	0	0
Soil remediation – Industrial PFAS users (presumptive)				

Cost category / estimate*	2024	2030	2040	2050
Best estimate	1,595	1,656	1,782	1,975
Sensitivity high	9,969	10,348	11,137	12,343
Sensitivity low	0	0	0	0
Soil remediation - Other (presumptive)				
Best estimate	1,082	1,122	1,208	1,339
Sensitivity high	9,015	9,354	10,069	11,161
Sensitivity low	0	0	0	0
Landfill leachate treatment				
Sensitivity high	203	203	203	203
Sensitivity low	0	0	0	0
Drinking water treatment / Wastewater treatment	No significant drinking water or wastewater treatment is assumed to occur specifically to remove PFAS in this scenario.			
Miscellaneous				
Best estimate <u>without</u> presumptive sites	4	4	5	5
Best estimate <u>with</u> presumptive sites	181	188	202	225
Sensitivity high	2,197	2,280	2,453	2,718
Sensitivity low	0	0	0	0
Total				
Best estimate <u>without</u> presumptive sites	87	89	97	108
Best estimate <u>with</u> presumptive sites	3,801	3,946	4,251	4,715
Sensitivity high	24,171	25,083	26,986	29,897
Sensitivity low	2	2	3	3

*) The different estimates (best estimate, sensitivity low and sensitivity high) reflect the potential variation in the unit costs per site remediated, and assume no remediation of presumptive sites for the low sensitivity.

The categories of “known” and “presumptive” soil remediation sites are based on the categories developed by the Forever Pollution Project, “Other” sites include firefighting training sites and waste management sites.

5.2.3. Future costs Scenario 2: Drinking Water Directive (DWD)

The annual drinking water treatment cost estimates for scenario 2 are shown in [Table 5-2](#). Other cost categories in this scenario are assumed not to deviate from scenario 1 and are therefore not repeated here, but they are included in the total costs of the scenario presented in the table.

Annual treatment costs in the EEA to reach DWD thresholds are estimated to increase to around €264 million in 2030, €276 million in 2040, and €1.4 billion in 2050 (best estimates). This reflects increasing volumes of drinking water predicted by the exposure modelling from Task 3 to reach the proposed Recast Drinking Water Directive (DWD) limit of 0.1 µg/L for the sum of 20 PFAS (from 0% of drinking water in 2024, to 2.9% in 2030, 3.2% in 2040, and 18.1% in 2050). The ranges from the low to the high estimate (or the low sensitivity to high sensitivity) shown in the table reflect the potential variation in the unit costs per m³ of water treated. For comparison, Forever Pollution Project (2025) assumed that 5% of drinking water required additional treatment for legacy PFAS at a costs of €347 million/year.

Due to the significant uncertainties regarding TFA (see Task 3 report), drinking water treatment costs for TFA have been calculated separately. The inclusion of TFA would increase the drinking water treatment costs dramatically. Assuming that Member

States apply the Total PFAS threshold of 500 ng/l, additional drinking water treatment costs of around €14-15 billion would be estimated to be incurred in the EEA per year.

These much higher costs (compared to PFAAs) reflect that TFA concentrations are already widely observed to exceed the proposed threshold, as well as the assumption that more costly technologies are required to remove TFA (reverse osmosis, as was also assumed by Forever Pollution Project (2025)). For comparison, Forever Pollution Project (2025) estimated that around €18 billion per year would be required to treat all drinking water in the EU for TFA, which is the same order of magnitude as our estimates. The differences between our estimates and those of Forever Pollution Project (2025) are due to a different approach and different unit costs. We used volumes of water treated and multiplied with a unit cost per volume from a parallel Commission study¹³⁵. Forever Pollution Project (2025) estimated numbers of treatment plants and multiplied with unit costs per plant from the US EPA and the [Minnesota Pollution Control Agency](#).

Note that TFA drinking water treatment costs are not additive to PFAAs drinking water treatment costs, because the additional water treatment to remove TFA would also remove PFAAs. The table below shows a total for remediation and treatment costs without TFA treatment, and another total “with TFA treatment”, where both TFA and PFAA would be removed.

Table 5-2 Prospective treatment/remediation costs of PFAS pollution per year in the EEA: Scenario 2 (Drinking Water Directive) (€ millions in 2024 value)

Cost category / estimate*	2024	2030	2040	2050
Soil remediation		Same as scenario 1		
Landfill leachate treatment		Same as scenario 1		
Drinking water treatment - PFAAs				
Best estimate	0	264	276	1,446
High estimate	0	537	562	2,943
Low estimate	0	109	114	599
Sensitivity high	0	20,508	21,448	112,318
Sensitivity low	0	63	66	345
Wastewater treatment	No significant wastewater treatment is assumed to occur specifically to remove PFAS in this scenario.			
Miscellaneous				
Best estimate	181	201	216	297
High estimate	181	215	231	372
Low estimate	4	10	10	35
Sensitivity high	2,197	4,331	4,598	13,950
Sensitivity low	0	0	0	0
Total (without TFA treatment)				
Best estimate	3,801	4,223	4,541	6,233
High estimate	3,801	4,510	4,841	7,805
Low estimate	87	204	217	737
Sensitivity high	24,171	47,642	50,579	153,447
Sensitivity low	2	65	69	348
Drinking water treatment – TFA and PFAAs				

¹³⁵ Analysis of treatment techniques: removal of specific pollutants (PFAS, Bisphenol A, pesticides and their metabolites) and feasibility assessment of an Extended Producer Responsibility system for PFAS.

Cost category / estimate*	2024	2030	2040	2050
Best estimate	15,416	15,140	14,692	14,258
High estimate	18,893	18,555	18,006	17,474
Low estimate	11,473	11,268	10,934	10,611
Sensitivity high	721,061	708,175	687,230	666,904
Sensitivity low	2,216	2,176	2,112	2,050
Total (with TFA treatment)				
Best estimate	19,988	19,843	19,678	19,685
High estimate	23,639	23,429	23,158	23,062
Low estimate	12,133	11,920	11,578	11,249
Sensitivity high	817,338	804,076	782,939	763,491
Sensitivity low	2,218	2,179	2,115	2,053

*) The different estimates (best, low, high sensitivity low and sensitivity high) reflect the potential variation in the unit costs per m³ of water treated. For total costs, the best, high and sensitivity high estimates include soil remediation of known and presumptive sites, whereas the low and sensitivity low estimates only include known sites.

5.2.4. Future costs Scenario 3: Environmental Quality Standards (EQS)

Scenario 3 assumes that all proposed EQS for water are fulfilled in 2030. We assume here that, to achieve such a hypothetical outcome, all wastewater needs to be treated (however, it is very likely that in addition to this, emissions would also need to be drastically reduced in order to be able to achieve EQS, but here we focus on wastewater treatment only). The annual wastewater treatment cost estimates for scenario 3 are shown in [Table 5-3](#). Additional **treatment costs in the EEA to remove PFAS from wastewater are estimated to decrease slowly from around €73 billion in 2024 to around €71 billion in 2030, €69 billion in 2040, and €67 billion in 2050 (best estimates)**. The decrease reflects a decline in the EEA population, which is assumed to lead to an equivalent decline in the amount of wastewater generated. The ranges from the low to the high estimate (or the low sensitivity to high sensitivity) shown in the table reflect the potential variation in the unit costs per m³ of water treated. **For comparison, Forever Pollution Project (2025) estimated costs of €67 billion/year to treat short chain PFAS in all large wastewater treatment plants in the EU as well as the associated sludge, so in the same order of magnitude.**

Other cost categories in this scenario are assumed not to deviate from scenario 1 and are therefore not repeated here, but they are included in the total costs of the scenario presented in [Table 5-3](#). However, note that in reality, it is likely that wastewater treatment alone would not be sufficient to ensure compliance with the proposed EQS. A reduction of PFAS production, use and emissions may also be required, which would reduce other costs (notably new soil remediation costs).

Table 5-3 Prospective treatment/remediation costs per year of PFAS pollution in the EEA: Scenario 3 (Environmental Quality Standards) (€ millions in 2024 value)

Cost category / estimate*	2024	2030	2040	2050
Soil remediation	Same as scenario 1			
Landfill leachate treatment	Same as scenario 1			
Drinking water treatment	Same as scenario 1			
Wastewater treatment				
Best estimate	72,785	71,485	69,369	67,316
High estimate	118,433	116,317	112,874	109,533
Low estimate	32,549	31,967	31,021	30,103

Cost category / estimate*	2024	2030	2040	2050
Sensitivity high	626,142	614,956	596,754	579,091
Sensitivity low	21,557	21,172	20,545	19,937
Miscellaneous				
Best estimate	3,820	3,762	3,671	3,820
High estimate	6,103	6,004	5,846	6,103
Low estimate	1,632	1,603	1,556	1,632
Sensitivity high	64,812	63,776	62,129	64,812
Sensitivity low	0	0	0	0
Total				
Best estimate	80,226	79,005	77,089	80,226
High estimate	128,156	126,079	122,769	128,156
Low estimate	34,263	33,654	32,669	34,263
Sensitivity high	712,927	701,535	683,416	712,927
Sensitivity low	21,559	21,174	20,548	21,559

*) The different estimates (best, low, high sensitivity low and sensitivity high) reflect the potential variation in the unit costs per m³ of water treated. For total costs, the best, high and sensitivity high estimates include soil remediation of known and presumptive sites, whereas the low and sensitivity low estimates only include known sites.

5.2.5. Future costs Scenario 4: Total stop of production and uses of PFAS

The annual remediation cost estimates for scenario 4 are shown in [Table 5-4](#). As discussed in Task 3, in scenario 1, PFAS emissions are expected to fall significantly over the assessment period. However, the Task 3 report also discussed that due to the persistence of PFAS in soil, it is assumed that the number of contaminated sites remains constant at its peak level (i.e., the emissions cease but the sites remain contaminated). This is reflected in **constant annual soil remediation costs in the EEA of around €83 million when only considering known sites, or around €3.7 billion when considering both known and presumptive sites.**

It is assumed that no significant drinking water or wastewater treatment is occurring specifically to remove PFAS in scenario 4.

Table 5-4 Prospective treatment/remediation costs per year of PFAS pollution in the EEA: Scenario 4 (Total stop of production and uses of PFAS) (€ millions in 2024 value)

Cost category / estimate*	2024	2030	2040	2050
Soil remediation - PFAS manufacturer (known)				
Best estimate	25	25	25	25
Sensitivity high	31	31	31	31
Sensitivity low	0	0	0	0
Soil remediation - Industrial PFAS user (known)				
Best estimate	57	58	58	58
Sensitivity high	359	361	361	361
Sensitivity low	2	2	2	2
Soil remediation - Airports (presumptive)				
Best estimate	227	230	230	230
Sensitivity high	1,535	1,556	1,556	1,556
Sensitivity low	0	0	0	0

Cost category / estimate*	2024	2030	2040	2050
Soil remediation - Military (presumptive)				
Best estimate	634	642	642	642
Sensitivity high	861	872	872	872
Sensitivity low	0	0	0	0
Soil remediation – Industrial PFAS user (presumptive)				
Best estimate	1,595	1,612	1,612	1,612
Sensitivity high	9,969	10,078	10,078	10,078
Sensitivity low	0	0	0	0
Soil remediation - Other (presumptive)				
Best estimate	1,082	1,094	1,094	1,094
Sensitivity high	9,015	9,119	9,119	9,119
Sensitivity low	0	0	0	0
Landfill leachate treatment		Same as scenario 1		
Drinking water treatment / Wastewater treatment		Same as scenario 1		
Miscellaneous				
Best estimate <u>without</u> presumptive sites	4	4	4	4
Best estimate <u>with</u> presumptive sites	181	183	183	183
Sensitivity high	2,197	2,222	2,222	2,222
Sensitivity low	0	0	0	0
Total				
Best estimate <u>without</u> presumptive sites	87	87	87	87
Best estimate <u>with</u> presumptive sites	3,801	3,845	3,845	3,845
Sensitivity high	24,171	24,442	24,442	24,442
Sensitivity low	2	2	2	2

*) The different estimates (best estimate, sensitivity low and sensitivity high) reflect the potential variation in the unit costs per site remediated, and assume no remediation of presumptive sites for the low sensitivity.

The categories of “known” and “presumptive” soil remediation sites are based on the categories developed by the Forever Pollution Project, “Other” sites include firefighting training sites and waste management sites. “Other” sites include firefighting training sites and waste management sites.

5.2.6. Comparison of scenarios

Table 5-5 shows the total EEA present value (PV) of the treatment and remediation costs of each scenario across the assessment period (2024-2050), as well as the equivalent annual costs (EAC).

The present value of treatment/remediation costs over the whole period is around €78 billion in **scenario 1 (business as usual)**. Around €1.8 billion of these costs are associated with the remediation of known PFAS producing/using sites, while the rest is associated with sites where PFAS use and contamination is presumed by the Forever Pollution Project.

The present value of treatment/remediation costs over the period is around €86 billion in **scenario 2**, which is about €8 billion higher than scenario 1 due to additional drinking water treatment costs to remove PFAAs. When considering drinking water treatment costs for

removing TFA (as well as PFAAs), the present value over the period is even higher at around €376 billion (about €298 billion higher than scenario 1).

Scenario 3 is associated with the highest total treatment/remediation costs by far, with a present value of costs over the whole period estimated at €1.5 trillion. This is about €1.4 trillion higher than scenario 1. This is because **wastewater treatment** costs could be much higher than the other cost categories (notably drinking water treatment costs and soil remediation costs), which is consistent with the findings of Forever Pollution Project (2025)¹³⁶.

The **stop of production and use of PFAS in scenario 4** reduces the present value of water treatment and soil remediation costs over the period by about €5 billion compared to scenario 1, to around €73 billion. As discussed in Section 5.2.5, the reduction compared to scenario 1 is only modest because it is assumed that the number of contaminated sites remains constant at its peak level (i.e., the emissions cease but the sites remain contaminated) to reflect the persistence of PFAS in soil. This is reinforced by the assumption that sites are only remediated once within the assessment period, even in scenario 1 where emissions continue.

Table 5-5 Prospective treatment/remediation costs of PFAS pollution in the EEA: Total present value over the period 2024-2050 and equivalent annual costs (€ billions, in 2024 value)

Scenario	Absolute value		Relative to Scenario 1	
	Total present value (PV)	Equivalent annual cost (EAC)	Total present value (PV)	Equivalent annual cost (EAC)
Scenario 1	78.3	4.3	-	-
Scenario 2 (without TFA treatment)	85.8	4.7	7.5	0.4
Scenario 2 (with TFA treatment)	375.7	20.5	297.5	16.2
Scenario 3	1,482.8	80.9	1,404.5	76.6
Scenario 4	72.8	4.0	-5.4	-0.3

6. Conclusions

6.1. Human health and environmental costs of PFAS pollution

Three main types of societal costs have been identified and assessed in this study: costs associated with the human health impacts of PFAS pollution, costs associated with the remediation and treatment of soil and water to remove PFAS pollution, and potential pathways for costs associated with the losses of ecosystem services due to PFAS pollution (simply referred to as 'ecosystem service costs' in the following). An overview of the results

¹³⁶ Forever Pollution Project (2025): *Unaffordable - The absurd cost of 'PFAS as usual'*.

across all three cost types for each scenario is shown in Table 6-1, which presents undiscounted annual costs in 2024, 2030, 2040 and 2050, as well as the present value over the whole assessment period. The ecosystem service costs could not be quantified or monetised, but the case studies in this report have shown that PFAS may affect ecosystem services contributing billions of Euros to the EEA economy, and [Table 6-1](#) summarises the likely relative trend of ecosystem service costs across scenarios qualitatively.

Key conclusions are outlined below for each scenario.

6.1.1. Scenario 1 (Business as usual)

Health costs dominate the quantified costs in this scenario. The exposure modelling in Task 3 predicted an increase in emissions of PFAS overall, while PFOA, PFOS and PFHxS emissions will decline under this scenario. Human health costs from PFOA, PFOS, PFHxS and PFNA pollution are estimated at €39.5 [0.005-600.5] billion/year in 2024, reaching €29.5 [0.004-426.0] billion in 2050¹³⁷, due to the estimated decline in blood serum concentrations of legacy PFAS (PFOA, PFOS, PFHxS). However, the increasing blood serum levels of 'other PFAS' types that are not yet sufficiently studied in the scientific literature and could not be quantified, could result in an increase in the combined disease burden from all PFAS pollution between 2025-2050. In more detail:

- Relatively high proportions of disease burden are attributable to PFOA, PFOS, PFHxS and PFNA exposure impacts through osteoporosis, high blood pressure, and CKD.
- Non-market disease burden accounts for the majority of the estimated human health costs, followed by productivity costs and healthcare costs.
- The 'background' cohort and/or the population group 'adults (20+ years) general population' accounts for the majority of human health costs from PFOA, PFOS, PFHxS and PFNA exposure.
- Human health costs per person, from PFOA, PFOS, PFHxS and PFNA exposure, are especially high for 'newborns (0 years)', 'children (1-4 years)', 'people (15+ years) residing near contaminated sites', and 'exposed workers'.

Remediation costs and miscellaneous costs of PFAS pollution add another €3.8[0.002-24.2] billion/year in 2024. The exposure modelling in Task 3 predicted an increase in the number of contaminated sites that require remediation, leading to an increase in the estimated remediation costs to €4.7 [0.003-29.9] billion/year in 2050. It is assumed that no significant drinking water or wastewater treatment is occurring specifically to remove PFAS in scenario 1.

Ecosystem service costs could not be quantified, but they could be significant and would be expected to increase in this scenario, at least partially offsetting the decrease in health costs.

¹³⁷ As a reminder: Square brackets indicate the potential range of values, taking into account the estimates from the sensitivity analysis. For example, "€39.5 [0.005-600.5] billion" indicates a medium estimate of €39.5 billion, a low sensitivity estimate of €0.005 billion, and a high sensitivity estimate of €600.5 billion.

The total present value of quantifiable costs over the assessment period is estimated at around €440 billion in scenario 1 (with human health costs limited to PFOA, PFOS, PFHxS and PFNA only).

6.1.2. Scenario 2 (Drinking Water Directive)

Estimated health costs are comparable to Scenario 1, despite the reduction in PFAS concentrations in drinking water. This is because drinking water only accounts for a small fraction of human exposure, and therefore the exposure modelling from Task 3 predicts virtually identical blood serum concentrations of PFAS in scenarios 1 and 2. Human health costs from PFOA, PFOS, PFHxS and PFNA pollution are estimated to decline from €39.5 [0.005-600.5] billion/year in 2024 to €29.5 [0.004-426.0] billion in 2050, due to the estimated decline in blood serum concentrations of legacy PFAS (PFOA, PFOS, PFHxS). Similar to Scenario 1, the increasing blood serum levels of 'other PFAS' types that are not yet sufficiently studied in the scientific literature and could not be quantified, could result in an increase in the combined disease burden from all PFAS pollution between 2025-2050.

Costs for soil remediation and removal of PFAAs from drinking water are expected to be relatively small compared to the health costs, contributing €3.8 [0.002-24.2] billion/year in 2024 and €6.2 [0.3-153.4] billion/year in 2050. This is based on the predictions from the Task 3 exposure modelling that the number of contaminated sites requiring soil remediation increase (equivalent to scenario 1), and that the volumes of drinking water requiring additional treatment due to DWD threshold exceedances increase.

Costs to remove TFA from drinking water have been calculated separately (due to more severe uncertainties associated with TFA). The inclusion of TFA would increase the drinking water treatment costs dramatically. Assuming that Member States apply the Total PFAS threshold of 500 ng/l, additional drinking water treatment costs of around €14-15 billion would be estimated to be incurred in the EEA per year. These much higher costs (compared to PFAAs) reflect that TFA concentrations are already widely observed to exceed the proposed threshold, as well as the assumption that more costly technologies are required to remove TFA.

Ecosystem service costs would be expected to be comparable to scenario 1, since drinking water treatment does not significantly affect PFAS pollution in the environment.

The present value of quantifiable costs over the assessment period is estimated at around €450 billion in scenario 2 (with human health costs limited to PFOA, PFOS, PFHxS and PFNA only), which is slightly higher than in scenario 1. When considering drinking water treatment to remove TFA, the present value of scenario 2 could even be over €200 billion higher than in scenario 1.

6.1.3. Scenario 3 (Environmental Quality Standards)

Under this scenario, estimated remediation/treatment costs dominate the total quantifiable costs of PFAS pollution. This is largely because of the assumption that additional treatment to remove PFAS will be required for all wastewater in the EEA to achieve compliance with the EQS. Costs for soil remediation and wastewater treatment are estimated to decrease slowly from around €80.2 [21.6-712.9] billion/year in 2024 to €75.4 [19.9-666.9] billion/year in 2050. The decrease reflects a decline in the EEA population, which is assumed to lead to an equivalent decline in the amount of wastewater generated.

The estimated reductions in PFAS concentrations in the environment (and therefore also food and drinking water) also lead to sharp reductions in blood serum concentrations of PFAS (overall, and specifically for PFOA, PFOS, PFHxS and PFNA which account for the quantifiable health costs as discussed above) over time, according to Task 3 exposure modelling.

As a result, quantifiable human health costs from PFOA, PFOS, PFHxS and PFNA pollution are estimated to decline from €39.5 [0.005-600.5] billion/year in 2024 to €12.0 [0.001-373.5] billion in 2030. Subsequently, zero health costs are estimated in the medium and low-sensitivity scenarios for 2040 and 2050 given the negligible levels of PFAS in human blood serum, although some health impacts are estimated in the high-sensitivity scenario with equivalent monetary costs of €3.5 billion in 2040 and €3 billion in 2050. In addition, **the blood serum levels of 'other PFAS' types that are not yet sufficiently studied in the scientific literature and could not be quantified could result in additional disease burden between 2025-2050.** In more detail:

- Relatively high proportions of disease burden are attributable to PFOA, PFOS, PFHxS and PFNA exposure impacts through osteoporosis, high blood pressure, and adult obesity. In 2040 and 2050, these endpoints/health risks account for the entirety of the costs to human health in the high-sensitivity scenario.
- The 'background' cohort and/or the population group 'adults (20+ years) general population' accounts for the majority of human health costs from PFOA, PFOS, PFHxS and PFNA exposure.
- In 2030, human health costs per person from PFOA, PFOS, PFHxS and PFNA exposure are especially high for 'newborns (0 years)', 'children (1-4 years)', 'people (15+ years) residing near contaminated sites', and 'exposed workers'. However, from 2040 onwards, the costs are borne entirely by adults in the general population, people (15+ years) residing near contaminated sites, and exposed workers as these groups are affected by osteoporosis, high blood pressure and adult obesity.

The present value of quantifiable costs over the assessment period is estimated at around €1.7 trillion (with human health costs limited to PFOA, PFOS, PFHxS and PFNA only), which is about €1.3 trillion higher than estimates under scenarios 1 and 2, due to the dominant wastewater treatment costs. However, ecosystem service costs, which could not be quantified, would be expected to gradually decrease in this scenario and to be lower than in scenarios 1 and 2, at least partly offsetting the wastewater treatment costs.

6.1.4. Scenario 4 (Total stop of production and uses of PFAS)

Health costs dominate the quantified costs of PFAS pollution in this scenario. Costs from human exposure to PFOA, PFOS, PFHxS and PFNA are estimated to fall sharply from €39.5 [0.005-600.5] billion/year in 2024 to €0.5 [0-21.5] billion/year in 2040. This is a less steep decline than estimated under scenario 3 due to the assumption in the Task 3 exposure modelling that stockpiles of articles in consumer uses would continue to be used until they reach their end of life, leading to a slightly slower decline in predicted blood serum concentrations. In 2050, zero pollution and steep decline in exposure towards zero levels of PFAS in human blood translates to no monetary costs. **However, the blood serum levels of 'other PFAS' types that are not yet sufficiently studied in the scientific literature (and**

thus not quantified) could result in additional disease burden between 2025-2040. In more detail:

- Relatively high proportions of disease burden are attributable to PFOA, PFOS, PFHxS and PFNA exposure impacts through high blood pressure, osteoporosis, female infertility, and adult obesity. In 2040, disease burden is attributable to osteoporosis in the medium-sensitivity scenario, or chronic kidney disease, high blood pressure, high LDL cholesterol, osteoporosis and female infertility in the high-sensitivity scenario.
- The 'background' cohort and/or the population group 'adults (20+ years) general population' accounts for the majority of human health costs from PFOA, PFOS, PFHxS and PFNA exposure.
- In 2030, human health costs per person from PFOA, PFOS, PFHxS and PFNA exposure are especially high for 'newborns (0 years)', 'children (1-4 years)', 'people (15+ years) residing near contaminated sites', and 'exposed workers'. However, from 2040 onwards, the costs are borne entirely by adults in the general population, people (15+ years) residing near contaminated sites, and exposed workers as these groups are affected by CKD, high blood pressure, high LDL cholesterol, osteoporosis, and other relevant endpoints or impact pathways.

Similarly to scenario 1, the remediation costs would still be relatively small compared to the health costs (around €3.8 [0.002-24.2] billion/year throughout the assessment period) and no significant drinking water or wastewater treatment specifically to remove PFAS has been assumed.

Similarly to scenario 3, ecosystem service costs, would be expected to gradually decrease in this scenario and to be lower than in scenarios 1 and 2.

In conclusion, out of the four assessed scenarios, scenario 4 would be expected to be the scenario associated with the lowest societal costs of PFAS pollution by far. **The present value of quantifiable costs over the assessment period is estimated at around €330 billion in scenario 4** (with human health costs limited to PFOA, PFOS, PFHxS and PFNA only), which is about €110 billion lower than the present value for scenario 1.

6.1.5. Scenario Comparison

The table below presents a high-level comparison of the estimated costs of PFAS pollution.

Table 6-1 Comparison of estimated health costs, remediation/treatment costs and ecosystem service costs of PFAS pollution in the EEA by scenario, undiscounted costs per year and present values over the whole assessment period (medium estimate and [low-high] sensitivities, in 2024 euros)

Scenario	Health costs from human exposure to PFOA, PFOS, PFHxS and PFNA	Soil remediation / water treatment costs	Potential costs associated with the losses of ecosystem services
Scenario 1: Business as usual	Undiscounted annual values: 2024: €39.5 [0.005-600.5] bn 2030: €29.5 [0.005-529.5] bn 2040: €27.0 [0.004-456.5] bn 2050: €29.5 [0.004-426.0] bn Present value over assessment period: €360 [0.052-5,750] bn	Undiscounted annual values: 2024: €3.8 [0.002-24.2] bn 2030: €3.9 [0.002-25.1] bn 2040: €4.3 [0.003-27.0] bn 2050: €4.7 [0.003-29.9] bn Present value over assessment period: €78.3 bn	↗ Potentially significant and increasing impact (not quantifiable) on ecosystem services that contribute € billions to the EEA economy.
Scenario 2: Drinking Water Directive (DWD)	Undiscounted annual values: 2024: €39.5 [0.005-600.5] bn 2030: €29.5 [0.005-529.5] bn 2040: €27.0 [0.004-456.5] bn 2050: €29.5 [0.004-426.0] bn Present value over assessment period: €360 [0.051-5,750] bn (Comparable to Scenario 1, since drinking water only accounts for a small fraction of human exposure)	Undiscounted annual values: 2024: €3.8 [0.002-24.2] bn (€20.0 [2.2-817.3] bn with TFA) 2030: €4.2 [0.07-47.6] bn (€19.8 [2.2-804.1] bn with TFA) 2040: €4.5 [0.07-50.6] bn (€19.7 [2.1-782.9] bn with TFA) 2050: €6.2 [0.3-153.4] bn (€19.7 [2.1-763.5] bn with TFA) Present value over assessment period: €85.8 bn (€297.5 bn with TFA)	↗ Comparable to scenario 1.
Scenario 3: Environmental Quality Standards (EQS)	Undiscounted annual values: 2024: €39.5 [0.005-600.5] bn 2030: €12.0 [0.001-373.5] bn 2040: €0.0 [0.0-3.5] bn 2050: €0.0 [0.0-3.2] bn Present value over assessment period: €240 [0.03-4,350] bn	Undiscounted annual values: 2024: €80.2 [21.6-712.9] bn 2030: €79.0 [21.2-701.5] bn 2040: €77.1 [20.5-683.4] bn 2050: €75.4 [19.9-666.9] bn Present value over assessment period: €1,480 bn	↘ Potentially significant impact (not quantifiable) on ecosystem services will continue for some time due to persistence, bioaccumulation and biomagnification of PFAS. Gradual decrease of impacts (not quantifiable) in the long term due to eventual degradation, dispersion to lower

Scenario	Health costs from human exposure to PFOA, PFOS, PFHxS and PFNA	Soil remediation / water treatment costs	Potential costs associated with the losses of ecosystem services concentrations, and remediation/treatment.
Scenario 4: Total stop of production and uses of PFAS	Undiscounted annual values: 2024: €39.5 [0.005-600.5] bn 2030: €17.0 [0.002-412.5] bn 2040: €0.5 [0.0-21.5] bn 2050: €0.0 bn Present value over assessment period: €260 [0.033-4,500] bn	Undiscounted annual values: 2024: €3.8 [0.002-24.2] bn 2030: €3.8 [0.002-24.4] bn 2040: €3.8 [0.002-24.4] bn 2050: €3.8 [0.002-24.4] bn Present value over assessment period: €72.8 bn	↘ Comparable to scenario 3.

Note. The sensitivities for human health costs and remediation/treatment costs are based on the sensitivity scenarios defined in Sections 3.1.7 and 5.1. For example, not all endpoints are included in the low and medium estimates for health costs. Please refer to Section 3.1.7 for the endpoints which are included in the medium, low and high sensitivities.

In summary, scenario 4 is expected to have the lowest societal costs of PFAS pollution, out of the four assessed scenarios. This is primarily because, under this scenario, soil remediation costs would no longer increase either (assumed to remain constant over the assessment period due to the persistence of PFAS in soil) and no additional water treatment costs are expected. Ecosystem service costs (not quantified) would also fall gradually in Scenario 4. In addition, the stop of production and use of PFAS would reduce emissions, leading to a gradual decline in health costs (with a lag due to the persistence of PFAS in human blood serum), even when assessing the health costs of only 4 PFAS.

In the medium-sensitivity scenario, the highest quantifiable costs are estimated for scenario 3 due very high wastewater treatment costs that are expected to be required to comply with EQS thresholds. However, the scenario does lead to gradually declining human health costs (with a lag due to the persistence of PFAS in human blood serum), and gradually declining ecosystem service costs (not quantified).

Scenarios 1 and 2 are expected to lead to relatively similar societal costs, in between scenarios 4 and 3. In both scenarios 1 and 2, costs for remediation/treatment and ecosystem service losses are expected to increase over the assessment period due to increasing PFAS emissions, while human health costs are estimated to fall slightly between 2024 and 2050 due to the estimated decline in blood serum concentrations of legacy PFAS (PFOA, PFOS, PFHxS).

Note that these conclusions should be interpreted with care, considering the uncertainties and limitations noted throughout this report, and summarised in Section 6.2.

6.2. Gaps and limitations

There are a range of gaps, limitations and assumptions that were required to conduct this analysis, which we document below.

It should also be noted that the present study uses June 2024 as the regulatory position for the business-as-usual scenario and does not consider the REACH restrictions on PFHxA and on all PFAS used in fire-fighting foams. The assessment is also based on projected emissions taken from the universal PFAS restriction Background Document published in 2023. The updated version of the Background Document published in August 2025 contained lower absolute values of projected PFAS emissions, but with a sharper increase over time. The combination of these two limitations (emissions without latest restrictions and data from 2023 version of the universal PFAS restriction proposal Background Document) could to some extent mitigate each other and are considered anyhow within the acceptable range of uncertainty of the study.

6.2.1. Concerning the human health cost assessment

The main gaps in evidence include:

- Lack of detailed evidence on the size of more or less exposed population groups. There is a lack of confirmation on the number of people potentially exposed across population groups, especially concerning workers and people living near polluted sites in the EEA (these are primarily estimates at present).
- Lack of exposure evidence and future projections. Evidence of PFAS levels in blood serum for specific populations and additional substances, noting that evidence of

exposure has been found for 17 substances when there might be around 10,000 PFAS that humans could be exposed to in Europe. Studies projecting PFAS levels in blood serum into the future have not been found.

- Limited studies into risk associations, limited confidence and lack of studies characterising exposure-risk relationships. There remain limitations in the number and weight of scientific studies into the links between PFAS exposure and health risks. For some specific endpoints identified, there is currently insufficient evidence. It is also likely there are other relevant endpoints that remain unexplored. In addition, strengthening the coverage of substances particularly concerning the study of quantitative exposure-risk relationships. ERFs with sufficient evidence were identified for 13 endpoints concerning human exposure to four PFAS substances only (of the 17 for which there is exposure evidence).
- Limited to no understanding of mixture/cumulative effects of exposure. There is a very limited to no understanding of any potential mixture or cumulative effects of PFAS exposure on health outcomes identified in the literature. The ERFs identified in the literature examine the attribution of health risks to the levels of specific PFAS in blood, in isolation.
- Lack of readily accessible studies into the burden of disease, care pathways, medical costs, and sickness absence associated with each endpoint. There is a wide range of scientific and grey literature exploring these themes or areas of research. However, there does not appear to be a consensus on the burden of disease, care, costs and sickness that might be associated with a typical case of ill health, for the endpoints in scope.

The main assumptions draw on the available evidence, literature precedent and good practices to address these gaps where that is reasonable and proportionate. Assumptions have been developed for:

- The size of the population across groups, especially concerning those such as exposed workers and people living near polluted sites; as well as their potential evolution into the future (CAGR) under prospective scenarios (based on Eurostat and World Bank data and outputs of Task 3 of this study).
- PFAS in blood serum in the future, under prospective scenarios (based on output of Task 3 of this study).
- The confidence or strength of evidence of health risk associations and ERFs, based on an assessment of the available literature, and their applicability to EEA-wide population groups.
- Typical burden of disease for a case of ill health by endpoint, in terms of Disability-Adjusted Life Years (based on Global Burden of Disease evidence available at the Institute for Health Metrics and Evaluation, IHME); the care pathways for these endpoints; and the typical sick leave taken by workers affected by a typical case.
- Unit values for VOLY, VSL (based on ECHA's latest reference values) and the resulting monetary values for the non-market disease burden by endpoint, and typical medical costs in the EEA for each typical care pathway by endpoint (monitoring, consultations, admissions, procedures, drugs, etc), and the economic

costs associated with values in terms of lost output resulting from sickness absence (proposed to be proxied by average salaries and wages) and additional costs incurred by employers in sick pay.

The main limitations of the study are the lack of coverage of PFAS types and health risks due to limitations in the availability and/or weight of evidence (i.e., the lack of substances studied, lack of endpoints examined in depth, limited to no understanding of cumulative exposure impacts, etc).

The methods specified exclude the analysis of substances for which there is no exposure evidence, which is considered reasonable. Substances for which there are no ERFs with sufficient weight of evidence and/or a lack of evidence that does not allow for the reasonable quantification of impacts are also excluded. The literature was also uncertain on whether the impacts represented by the ERFs captured the isolated effects of a substance, despite other PFAS being present in human blood. Therefore, the methodology has considered the results for each endpoint or health risk to correspond to the maximum estimated health impact for one single PFAS out of all PFAS associated with that endpoint or health risk instead of aggregating the estimated impacts across all associated PFAS. This means that **the assessment is focussed on the exposure and the maximum impacts per endpoint associated with four already regulated PFAS substances**. In addition, 13 exposure-risk relationships (of the under 30 identified in the literature) are considered sufficiently evidenced and/or have ERFs established and thus can be assessed quantitatively.

This means **there could be thousands of substances and more than 10 health-risk associations that are not captured in this assessment**. The Table below considers the effects of the main limitations of this study in estimating human health costs of PFAS exposure.

Table 6-2 Effects of the main limitations on the estimates of human health costs from PFAS exposure contained in this study

Main limitations	What this means for the estimates of human health costs from PFAS exposure
Lack of detailed evidence on the size of more or less exposed population groups	Unlikely to have any substantial effect
Lack of PFAS captured in the assessment due to limitations in the available evidence linking and/or characterising ERFs for thousands of PFAS (except for PFOA, PFOS, PFHxS and PFNA).	Under-estimate: this suggests that the estimates produced in this study might only be a proportion, potentially small, of the total human health costs of all PFAS pollution.
Lack of health risks covered in the assessment. Whilst under 30 human health risks are linked to PFAS exposure, the evidence is limited and, in more than half of these cases, the literature does not provide ERFs	Under-estimate: this also suggests that the estimates produced in this study might only be a proportion, potentially small, of the total human health costs of all PFAS pollution.
Limited to no understanding of the mixture/cumulative effects of exposure to multiple PFAS in the literature found for this study.	Under-estimate: this also suggests that the estimates produced in this study might only be a proportion, potentially small, of the total human health costs of all PFAS pollution.
Lack of readily accessible studies into the burden of disease, care pathways, medical costs, and sickness absence associated with each endpoint.	Unlikely to have any substantial effect

In summary, these main limitations of this **study suggest that the estimates of human health costs from PFOA, PFOS, PFHxS and PFNA exposure reported in this report represent a lower bound for the total human health damage and costs that all PFAS pollution may cause in the EEA**, even though the study is more comprehensive than the available precedent.

There are other limitations with quantification of health impacts, as well as their valuation (e.g., uncertainties in ERFs, monetary unit values, etc.). However, the evidence review conducted for this study suggests these limitations are dwarfed by the issues presented by the lack of coverage and evidence concerning thousands of substances and potential health risks associated with PFAS exposure.

6.2.2. Concerning the ecosystem service cost assessment

The ecosystem service assessment is constrained by substantial evidence gaps that currently prevent the development of a meaningful monetised cost estimate. For this reason, a qualitative / case study approach has been adopted.

The gaps/limitations include:

- Lack of data on ecosystem impacts of PFAS: There is very limited information on how PFAS (and many other chemicals) affect species at population and ecosystem levels. Such effects are difficult and resource-intensive to monitor, typically requiring long-term field studies. The assessment in this report therefore relies primarily on laboratory data.
- Barriers to extrapolating laboratory data to real-world impacts: Laboratory studies show that some PFAS can elicit adverse biological effects, indicating potential harm to ecosystems. However, most studies assess specific effects of individual PFAS in a single species, under short-term and controlled exposure conditions. Concentration thresholds derived from these studies indicate hazard potential, but they cannot be directly extrapolated to infer whether ecosystem-level impacts occur at higher or lower environmental concentrations, due to the complexity of real-world conditions. In addition, some PFAS are highly persistent and bioaccumulative, which may lead to higher internal (tissue) concentrations relative to external environmental levels (e.g. in water). PFAS are also present in the environment in mixtures/cocktails. Substances with similar chemical structures may act additively or synergistically, meaning that combined effects could be greater than those predicted from individual substances.
- Data gaps across PFAS substances and species: Toxicity varies widely between PFAS substances, and different biological organisms have different levels of sensitivity. Existing data covers a relatively small number of PFAS and biological species.
- Ecosystem service assessment: Costs to ecosystem services can only be estimated if impacts on ecosystem function are understood. For example, for case study 1 on algae and climate change, there is a need to better understand the extent to which PFAS inhibit the carbon sequestering capacity of algae. This requires advanced/

emerging risk assessment studies.¹³⁸ There is also a need to understand the extent to which each species supports the ecosystem service. For example, there are large discrepancies between the identified estimates for the carbon capturing potential of algae.

Despite these limitations, there is a clear and scientifically plausible **chain of logic that PFAS contamination is likely to cause losses of ecosystem function and services**. While the magnitude of these costs cannot currently be quantified, they should not be overlooked or assumed to be insignificant.

6.2.3. Concerning the remediation/treatment cost assessment

The main gaps, limitations and assumptions in the methodology include:

- **Extrapolation:** In the absence of detailed site-specific assessments, there is significant uncertainty about the number of sites and extent of remediation/treatment that would be required on a national or international level, so any extrapolation to national or international totals is highly challenging.
- **Wider pollution:** Remediation/treatment can only cover part of the PFAS pollution but does not cover PFAS pollution distributed over larger areas at lower concentrations.
- **Thresholds and sites:** There are limitations in the identification of remediation/treatment sites, which are discussed in detail in Forever Pollution Project (2025)¹³⁹. Furthermore, it is uncertain how well our assumptions¹⁴⁰ on how identified concentration thresholds trigger remediation/treatment at specific sites reflect reality. These assumptions may not accurately reflect the real-world distribution and concentration of PFAS and requirements for additional treatment/remediation at individual sites.
- **Unit costs:** Remediation/treatment costs can vary significantly on a case-by-case basis. Unit costs for remediation and treatment per site have been identified for different types of sites, but these may not represent the actual costs for all sites.
- **Landfill leachate treatment:** Data on the treatment of PFAS in landfill leachate is weak, and this area is still emerging. The cost estimates for landfill leachate treatment are only applied in the sensitivity analysis, indicating a lack of robust data.
- **Overlap with other costs:** Remediation and treatment costs are interrelated with other health and environmental cost categories. They are separate costs in their

¹³⁸ For example, Faber et al. (2021). Identifying ecological production functions for use in ecosystem services-based environmental risk assessment of chemicals. Available at: <https://www.sciencedirect.com/science/article/pii/S0048969721014777>

¹³⁹ Forever Pollution Project (2025): *Unaffordable - The absurd cost of 'PFAS as usual'*

¹⁴⁰ For example, regulatory thresholds for PFAS vary across countries and have only been defined for a small proportion of PFAS species. This variability can trigger different risk management measures, complicating the estimation of remediation and treatment costs. The present study has not assessed threshold exceedances at specific sites, but in scenario 2, the Proposed Recast Drinking Water Directive (DWD) limits of 0.1 µg/L for the sum of 20 PFAAs and 0.5 µg/L for total PFAS were assumed to trigger additional treatment of all drinking water in a cohort when the exposure model predicts the average drinking water concentrations to exceed these thresholds without intervention (in scenario 1). In scenario 3, it has been assumed as a simplification that all wastewater treatment plants require additional treatment to achieve compliance with proposed EQSD limits. In all scenarios, for soil remediation, it has been assumed as a simplification that known PFAS manufacturing and using sites require remediation on average once every 27 years.

own right and can be incurred by the same and/or different stakeholders in the EEA. However, they can also overlap with other health and environmental cost categories and can be used to approximate these other health and environmental cost categories (avoided damage cost approach). The degree of these overlaps cannot be quantified.

The table below provides an overview of how the main limitations listed above are expected to affect the remediation/treatment cost estimates.

Table 6-3 Effects of the main limitations on the estimates of PFAS remediation/treatment costs contained in this study

Main limitations	What this means for the remediation/treatment cost estimates
Uncertainty about the number of sites and extent/ costs of remediation/ treatment required	Under-estimate/ Overestimate: This could lead to an over or underestimate. The sensitivity analysis explores lower and higher unit costs per site remediated or per litre treated, as well as the exclusion of “presumptive” sites where the need for remediation is less certain.
Remediation/treatment cannot cover PFAS pollution distributed over larger areas at lower concentrations	Under-estimate: the estimates in this study are meant to reflect costs of remediation of specific sites, and treatment of water when regulatory thresholds are exceeded. However, this would be an underestimate for the cost of achieving a clean environment, which would require additional clean-up that is likely not feasible in reality.
Landfill leachate treatment	Under-estimate: the exclusion of landfill leachate treatment in the core estimate due to weak data likely leads to an underestimate. The potential costs of landfill leachate treatment are explored in the sensitivity analysis, which shows that the impact on the overall quantified costs is relatively minor.
Overlap with other costs	Overestimate: Since the potential overlap could not be quantified, this could lead to an overestimate.

Appendices to Annex D

A. Illustrating the estimation of attributable health impacts of PFAS exposure with an example (PFOS exposure through low (and very low) birth weight)

Around 7% of newborns in the EEA suffer from low birth weight (< 2.5 kg) at present.¹⁴¹ Evidence suggests that some of these cases might be attributable to PFOS exposure. These cases are estimated below, as well as estimating the disability-adjusted life years that are associated with said health risk and estimated attributable 'statistical' deaths.

Pathway	Unit	Central estimate	Formula/ Source
Affected population	Newborns	3,726,318	Eurostat (see Step 1)
Exposure	µg/L PFOS	10.54	HMB4EU (see Step 2)
Baseline incidence rate	Percentage	7.0%	IHME Database. In addition, it has been assumed 1.0% births below 1.5kg, 6% births between 1.5-2.5kg, 92% births between 2.5-4.5kg and 1% above 4.5kg, based on the available evidence from Euro-Peristat.
Baseline numbers	Number of new cases	261,519	= 7% × 3,726,318
ERF	Decrease in birth weight (g) per doubling of PFOS (µg/L)	-45.2 g	Step 3
Attributable health impact of PFAS exposure			$= -45.2 \text{ g} * \log_2 \left(\frac{10.54}{5.25} \right)$ The 10th percentile (= 5.25 µg/L PFOS) is chosen as the reference exposure level below which no health effects are observed or attributable to PFAS exposure. $\log_2 \left(\frac{10.54}{5.25} \right)$ calculates the number of doublings of PFOS at current exposure (10.54 µg/L) compared to the reference exposure level.
	Decrease in birth weight at current exposure	-45.4g	
	Attributable statistical cases of low birth weight (birth weight <2.5kg)	9,531	PFOS exposure is attributable to lower weight at birth compared to the alternative. Evidence of the distribution of births across different birth weight brackets has been explored to estimate attributable statistical cases due to PFOS exposure. Around 6% of newborns weigh between 1.5-2.5 kg at birth. The ERF and associated evidence suggest that a proportion of newborns closer to 2.5 kg find themselves in this weight bracket due to 'losing' around 45 g from PFOS exposure. This means that, under a uniform

¹⁴¹European Perinatal Health Report: Core indicators of the health and care of pregnant women and babies in Europe from 2015 to 2019. Available at: https://www.europeristat.com/wp-content/uploads/2022/11/Euro-Peristat_Fact_sheets_2022_for_upload.pdf

Pathway	Unit	Central estimate	Formula/ Source
			distribution of births in the weight bracket 1.5-2.5 kg, around 9,531 newborns could have had low birth weight due to an attributable loss of 45 g from PFOS exposure.
	Disease burden (DALYs)	31,834	$= 3.34 \text{ DALY/case} \times 31,834 \text{ cases}$
	Preventable statistical deaths	196	At present, the average estimated life expectancy at birth in the EEA is 81.6 years (Eurostat). $= \frac{31,834 \text{ (DALY)} \times 50.3\% \text{ (YLL per DALY)}}{81.6 \text{ (YLL per statistical death)}}$
Monetary value of human health costs	€ billion/year (in 2024€)	6.3	$= 9,531 \text{ cases} \times 657,000 \text{ €/case}$

**Please note any differences with results presented in the body are entirely due to rounding.*

The estimated burden of disease from low (and very low) birth weight attributable to PFOS exposure in the EEA at present is estimated to be around 9,531 cases, 31,834 DALYs and 196 preventable statistical deaths; and the human health cost from low (and very low) birth weight attributable to PFOA exposure is estimated to surpass €6.3 billion/year (9,531 cases*657,000 €/case).

Please note that burden was also estimated from exposure to PFOA, following the same methods. However, the main results presented in this study correspond to the maximum of the estimated burden from all PFAS for which ERFs were identified in Step 3 (which in this case is for PFOS).

B. Water treatment unit costs

Unit cost in € per m3 of water treated	Drinking water treatment – PFAAs	Drinking water treatment – TFA	Wastewater treatment
Low estimate	0.17	0.51	0.76
Best estimate	0.42	0.69	1.69
High estimate	0.85	0.85	2.75
Sensitivity - Low	0.10	0.10	0.50
Sensitivity - High	32.27	32.27	14.55

Source: Parallel European Commission study "Analysis of treatment techniques: removal of specific pollutants (PFAS, Bisphenol A, pesticides and their metabolites) and feasibility assessment of an Extended Producer Responsibility system for PFAS".

Notes: Low, best and high estimate are based on the minimum, average and maximum cost across different potential treatment technologies, assuming high flow water treatment plants. The low and high sensitivity consider the full potential range of costs including low flow to very high flow treatment plants. For TFA drinking water treatment, only technologies involving reverse osmosis have been considered effective.

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