[**The Forever Lobbying Project**](https://foreverpollution.eu/lobbying/)

**The Cost Methodology**

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#### *The online version of this document can be found on* [*this page*](https://foreverpollution.eu/lobbying/the-cost-methodology/)*.*

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#### Introduction

PFAS remediation costs were estimated for two specific scenarios: “legacy PFAS” and “emerging PFAS”. The “legacy” scenario is meant to reflect remediation of existing contamination from past activities, and related to “legacy” PFAS, namely the long-chain PFAS such as PFOS and PFOA, primarily targeted by current regulations for remediation, and for which most remediation cost data is available. Costs reflect remediation of some specific contaminated soil sites, landfill leachate, and 5% percent of drinking water facilities – the latter of which was based on expert feedback on the amount of drinking water expected to be exceeding thresholds found in the current EU drinking water directives. These costs are shown as annual costs, assumed to continue for 20 years. If we want to manage health risks from past actions and meet current regulations, the “legacy” scenario represents the absolute minimal level of investment that needs to be completed. This figure assumes PFAS emissions stop immediately and that only these legacy PFAS which received the first regulatory attention were a problem. Both of these assumptions are of course wrong, based on the current course of events and continuing emissions of much more difficult to remediate “emerging” PFAS.

Similar to Pandora’s Box and much of human folly, preventing a problem from occurring in the first place is more effective than trying to fix a problem. In the case of PFAS remediation, preventing PFAS from entering the environment will be both more cost-effective and more impactful in reducing human health repercussions than removing PFAS from the environment once it is there. Similarly, after PFAS is emitted, removing it from the site of emission as soon as possible is more cost-effective than removing it after it has spread and polluted a vast region. The best-case scenario for PFAS remediation is the execution of the “legacy” remediation scenario in tandem with concurrent implementation of PFAS manufacture and use restrictions and source control to limit additional PFAS routed to the environment.

The “emerging” scenario is meant to reflect ongoing, annual remediation costs in the case that effective restrictions and source control are not implemented, particularly for the more challenging to remediate “emerging” PFAS. “Emerging” costs reflect current and future PFAS releases and the removal of PFAS that are not yet regulated. Specifically, we consider costs to remove ultra-mobile TFA and other short and ultra-short chain PFAS from drinking water and for other media, which is technically possible but comes at a high price. However, TFA removal and destruction has not been widely studied or proven for landfill leachate or wastewater effluent – the estimated costs reflect “targeted” TFA removal, not “guaranteed” TFA removal in these media. These emerging costs are also annual costs and reflect ongoing remediation of future soil contamination, effluent and sludges from large wastewater treatment facilities, and ongoing landfill leachate treatment as well as treating drinking water from all large supply zones in Europe to remove and destroy TFA. If we are proactive in managing PFAS at the source, hopefully, the full “emerging” scenario costs are not realised as an ongoing remedial burden to society.

For each scenario, we have assumed 5% consulting and monitoring fees that would account for diverse stages of establishing the PFAS methodology: procurement of consultants, design of remediation technology, quality assurance and PFAS monitoring over the lifetime of the remediation action. Generally, the price of consulting and monitoring is proportional to the size of the remediation project, e.g. for €100k project it is expected that at least €5k would be used for consulting and analysis (one analysis of target PFAS typically costs €300, so 10 analyses can cost €3k with an additional fee for writing a report based on that data). Similarly for a €10m project, it would be prudent to budget at least €500k for consulting and modelling to ensure design optimization and large area risk assessment).

#### Acronyms

| **Acronym** | **Full term** |
| --- | --- |
| SCWO | Supercritical water oxidation |
| GAC | Granular activated carbon |
| AER | Anion exchange resin |
| RO | Reverse osmosis |
| EPA | United States Environmental Protection Agency |
| ECO | Electrochemical oxidation |
| HALT | Hydrothermal alkaline treatment |
| WWTP | Wastewater treatment plant |
| p.e. | population equivalent |
| BOD | Biochemical oxygen demand |
| COD | Chemical oxygen demand |
| TSS | Total suspended solids |
| MPCA | Minnesota Pollution Control Agency |
| MBR | Membrane bioreactor |

#### List of countries

| European Union | Country name | Country code |
| --- | --- | --- |
| EU | Austria | AT |
| EU | Belgium | BE |
| EU | Bulgaria | BG |
| EU | Croatia | HR |
| EU | Cyprus | CY |
| EU | Czech Republic | CZ |
| EU | Denmark | DK |
| EU | Estonia | EE |
| EU | Finland | FI |
| EU | France | FR |
| EU | Germany | DE |
| EU | Greece | EL |
| EU | Hungary | HU |
| EU | Ireland | IE |
| EU | Italy | IT |
| EU | Latvia | LV |
| EU | Lithuania | LT |
| EU | Luxembourg | LU |
| EU | Malta | MT |
| EU | Netherlands | NL |
| EU | Poland | PL |
| EU | Portugal | PT |
| EU | Romania | RO |
| EU | Slovakia | SK |
| EU | Slovenia | SI |
| EU | Spain | ES |
| EU | Sweden | SE |
| Non-EU | Norway | NO |
| Non-EU | Iceland | IS |
| Non-EU | United Kingdom | UK |
| Non-EU | Switzerland | CH |

#### Costs Methodology By Media

##### Soils

***Sources of initial data used***

Our estimates are based on the Forever Pollution Project’s data, compiled in 2023. Now maintained by CNRS via the platform “[PFAS data hub](https://pdh.cnrs.fr/en/)”, this database provided us with a list of over 12,000 presumptive contamination sites. Our partners from national newsrooms checked and, when necessary, corrected those numbers by providing an adequate source of information. Among those sites, we shortlisted around 1,800 sites that would require priority remediation because of their typical levels of contamination and proximity to humans and vital resources. Our choice was also guided by data availability on remediation costs for these categories of sites. Namely, these are: 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. As we focused on sites for which we have data, it is very likely that there are several unknown, undisclosed sites that will require remediation in the future, in addition to the number we have shortlisted. We therefore presume the number of sites is underestimated. Full definitions of each type of site are available [in the scientific paper](https://pubs.acs.org/doi/10.1021/acs.est.3c09746) that was published on the Forever Pollution Project’s 2023 map.

***Sources of cost data used***

Given the lack of available data on costs, the best option for us was to derive a range of typical costs per category of site, based on scientific literature, available commercial figures, and a collection of costs gathered by our partners. Only countries that have already started remediation (because of better knowledge and/or higher levels of PFAS contamination in their territory) were sources of costs on soils. Specifically, we compiled costs of soil remediation projects for the Netherlands, Norway, and to a lesser extent, Germany and Belgium, and outside Europe, Australia and the USA. Data for soil remediation costs were categorised in the same land use categories described above, and the statistical distribution of soil remediation costs per type of site (e.g. airports, military base) calculated.

It is noted that most of the cost data are for the removal/management of the most polluted soil at the site. For instance, for many sites in Norway, often the soils with more than 100 µg/kg of legacy PFAS would be remediated, whereas the other more diffusely contaminated areas outside the hotspot may undergo long-term land management, which was not included in the cost of soil remediation. It is also noted that this only considered remediation of the unsaturated soil. Remediation of PFAS-contaminated groundwater, which may be a part of a soil remediation project, was not considered in the cost assessment.

***Technology assumed to be used and why***

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. The median costs per ton were similar in both approaches. Though there are several alternatives to landfilling and soil washing being developed, currently, no data are available at full scale (see [Concawe report](https://www.concawe.eu/wp-content/uploads/Rpt_24-8.pdf)), therefore, these were not considered.

For the legacy scenario, this cost estimate did not include PFAS destruction methods associated with the landfill leachate produced by landfilled soils, under the assumption this would be handled by the cost of landfill leachate cleanup. It also excludes costs of PFAS destruction for soil washing, which is an underestimate for this model and is, therefore, an overall underestimate. This is because the legacy scenario is targeted meeting thresholds for long-chain PFAS in soil-contaminated areas, such that the main remediation goal would be PFAS removal (not destruction). Currently, soil washing methods use granular activated carbon (GAC), occasionally ion-exchange resins and coagulation/flocculation, to remove PFAS from the water. In all cases, a follow-up step would be needed to destroy the PFAS, such as pyrolysis/incineration of the activated carbon, incineration or regeneration followed by destruction of the ion-exchange resins, and incineration/pyrolysis of coagulated/flocculated sludge. This type of PFAS destruction was not accounted for in the legacy scenario, as such costs are not often provided. The justification for this is that in the legacy scenario, isolated long-chain PFAS (e.g. on GAC filters, industrial sludges to hazardous waste landfills) could be managed by containment and without immediate destruction.

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, based on the following scenario: landfilling is sent to a site with a licence to take hotspot contaminated PFAS as it will destroy PFAS in its leachate, or a soil washing facility that destroys all PFAS in the water. For both scenarios, a ratio of 100 m3 water to 1 tonne of soil was used to remove all leachable PFAS within the landfill or by a soil-washing process. For the destruction technology, supercritical water oxidation (SCWO) as a representative future technology was considered for remediation of the leachate water, with a general estimated cost of 8 EUR/m3 for destruction, including both capital and operating costs.

***Assumptions made***

* 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.

***Calculation process***

1. 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.
2. The statistical distribution of tons of soil per site for each type of site was established for use in the calculation.
3. 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).
4. For each country, total costs for each percentile were summed across all site types.
5. 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.
6. 75th percentile costs were assumed as best-guess costs to account for contingencies not included in these cost estimates.

***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 hot spots, 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.

##### Drinking Water

***Sources of initial data used***

Unfortunately, there is no such thing as a full list of all drinking water supplies in Europe. Our best solution was to compile all the lists of “large drinking water supply zones” that were reported to the European Union under the [Drinking Water Directive](https://inspire.ec.europa.eu/metadata-codelist/PriorityDataset/LargeWaterSupplyZones-dir-1998-83). The definition of a large drinking water supply zone is a bit loose: they “provide either more than 1,000m3 drinking water per day as an average or serve more than 5,000 people”. This means that there can be more than one drinking water production facility per supply zone and that our estimates are, again, conservative. We could not access any data for Bulgaria, so this country is excluded from our drinking water estimates. When necessary, gaps or inconsistencies in national datasets were filled in with data from [Europe’s Water in Figures report](https://www.eureau.org/news/566-europe-s-water-in-figures) (2021) by EurEau.

***Technology assumed to be used and why***

Technologies currently available at scale to remove PFAS from drinking water include granular activated carbon (GAC) adsorption and reverse osmosis (RO) membrane separation. GAC with high-temperature incineration of spent media was assumed for use in the legacy scenario since it’s more cost effective, but does not remove many short-chain PFAS nor TFA in a reliable or cost-effective manner. 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). These technologies are not yet available at large scale, but hopefully will be in 20 years. If these options are not viable at the time of application for the emerging scenario, RO brine would need to be sent to existing thermal treatment options like high-temperature incineration, which would significantly increase the costs relative to this cost estimate.

***Sources of cost data used***

Two primary cost models were used for drinking water cost estimates: the [EPA PFAS treatment cost models](https://www.epa.gov/system/files/documents/2024-04/2024-pfas-tech-cost_final-508.pdf) and the [Minnesota Pollution Control Agency (MPCA) cost models](https://www.pca.state.mn.us/sites/default/files/c-pfc1-26.pdf) for removing and destroying PFAS from wastewater effluent. These models predict capital and operating costs based on the size of a facility. Capital costs were estimated from the average of these two models applied to each zone. Operating costs for GAC were taken from the EPA model, since the drinking-water-specific model will be more accurate here and include high-temperature incineration of the spent media. Operating costs for RO were taken from the EPA model, but increased by a factor of 7/4 to account for reported European RO costs being higher than those reported by the EPA. Additional operating costs were added for the emerging scenario to account for the destruction of separated PFAS, based on reports of 3 EUR/m3 operating costs for similar technologies. These costs were increased to 8 EUR/m3 to account for capital costs (typically in a similar range to operating costs over a 20-year period) and for transportation and logistics.

***Data cleaning***

The quality of the reported data varied a lot depending on the responding country. We had to harmonise those numbers by checking the ratio between the number of residents and the volume reported. If the ratio did not fall in a conventional range, we either excluded the data from our calculations or corrected volumes by an average ratio available for the rest of the drinking water zones in that country (if available) or for similar or adjacent countries (more details in the calculation process below). Additionally, some countries' flow rates seemed to be reported in volumes per year instead of volumes per day, based on volume per person ratios, so these were corrected under that assumption.

***Assumptions made***

* 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 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](https://energie-wasser-praxis.de/wp-content/uploads/2023/05/ewp_0922_64-71_Borchers.pdf), 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.

***Calculation process***

1. 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).
2. Estimate flow treated for each, in m3/day.
	1. In some cases, this was provided. Some countries (IT and NL) seemed to be reporting in m3/year not m3/day based on scale, so flow rates were adjusted accordingly.
	2. 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).
3. Apply treatment costs summarised above to estimate capital and annual O&M costs for each large drinking water zone.
	1. 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).
	2. Emerging scenario – RO with emerging liquid destruction technology for brine management for all large drinking water zones.
4. Estimate 20-year present value cost for each large drinking water zone.
5. For each country, sum up 20-year present value costs for each scenario and divide by 20 for annualised costs.

***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).

##### Wastewater Effluent

***Sources of initial data used***

The EU [Urban Waste Water Treatment Directive](https://environment.ec.europa.eu/topics/water/urban-wastewater_en) requires Member States to report information on its implementation. This reporting includes listing urban wastewater treatment plants and wastewater treatment from certain industrial sectors and their associated flows. We used the [public version of the data published in January 2023](https://www.eea.europa.eu/en/datahub/datahubitem-view/6244937d-1c2c-47f5-bdf1-33ca01ff1715?activeAccordion=1084682%2C1084679), about the 2021 data call.

To factor in the available level of equipment linked to each plant – the more advanced the treatment already in place, the lower the capital costs – we cross checked the treatment level (primary, secondary, tertiary, advanced) reported in this dataset with the “[European-wide spatial analysis of sewage treatment plants and the possible benefits to nature of advanced treatment to reduce pharmaceutical emissions](https://data.mendeley.com/datasets/zsrv92557p/2)” study by Van Dijk et al. (2023).

Some data, especially for non-EU countries, were pulled from local sources or shared by consortium partners.

***Data cleaning***

We checked the reported volume per population equivalent (p.e.) from all reported WWTPs to ensure the accuracy of the data. In other cases, flow rates were missing and estimated from country-specific data provided (SE), from reported m3/p.e./day usage in those countries from other parts of the same country (FR, DE), or assuming a value of 0.3 m3/p.e./day (PT, IS, NO, UK, CH), which was close to typical values from countries reporting both p.e. served and flow rates.

***Technology assumed to be used and why***

Because treatment of PFAS in wastewater sludges is only included in the emerging scenario, only technologies that result in near-full PFAS destruction were considered. 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.

***Sources of cost data used***

Costs for wastewater effluent were based on [cost models developed for the Minnesota Pollution Control Agency (MPCA) (2023)](https://www.pca.state.mn.us/sites/default/files/c-pfc1-26.pdf) for removing and destroying PFAS from wastewater effluent. This included capital and O&M costs for RO, with brine treated by both GAC adsorption and AER and capital costs for MBR pretreatment. Operating costs from the MPCA cost curves were multiplied by 2x to account for the treatment of short-chain PFAS like PFBA and PFBS instead of just 8-carbon PFAS like PFOA.

***Assumptions made***

* Assuming that provided data for "uwwWasteWater 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-pfc1-26.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 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.

***Calculation process***

1. Estimate flow treated for each wastewater plant, in m3/day.
	1. In some cases, this was provided.
	2. 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).
2. Filter to only include WWTPs greater than 4 000 m3/day. This is meant to reflect only large WWTPs with mechanical treatment.
3. Apply treatment costs summarised above to estimate capital and annual O&M costs for each large WWTP.
	1. 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.
4. Estimate 20-year present value cost for each large WWTP.
5. For each country, sum up 20-year present value costs for each scenario and divide by 20 for annualised costs.

***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. 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).

##### Wastewater Biosolids

***Sources of initial data used***

The best source we could find was the “[Sewage sludge production and disposal](https://ec.europa.eu/eurostat/databrowser/product/page/env_ww_spd)” from Eurostat. It provides total sludge disposal per country, in thousands of tonnes of dry substance, for “urban” wastewater treatment plants and “other” wastewater treatment plants. Countries also provide a breakdown of how this sludge is managed: via incineration, compost, agriculture, landfilling, or “other” treatment. Whenever possible, we used 2022 data. In case such data was unavailable, we looked for a compromise between the most recent and the most complete data available.

***Technology assumed to be used and why***

Because treatment of PFAS in wastewater sludges is only included in the emerging scenario, only technologies that result in near-full PFAS destruction were considered. The most established method currently used is pyrolysis of sludge with thermal oxidation of produced syngas to facilitate PFAS destruction.

***Sources of cost data used***

Costs for wastewater biosolids were based on [sludge pyrolysis cost models developed for the Minnesota Pollution Control Agency (MPCA)](https://www.pca.state.mn.us/sites/default/files/c-pfc1-26.pdf) for removing and destroying PFAS from wastewater biosolids. Reported total 20-year net present value costs were divided by the mass of biosolids treated over that time to yield a range of 1,160 to 3,380 EU per dry tonne of sludge treated. 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.

***Assumptions made***

* 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.

***Calculation process***

1. 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”.
2. Multiply by the range of costs stated above for pyrolysis for high end and low end costs.
3. 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.

***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.

##### Landfill Leachate

***Sources of initial data used***

Data on landfills was the toughest one to gather. The best we could do was to use European aggregates available via Eurostat, called “[number and capacity of recovery and disposal facilities](https://ec.europa.eu/eurostat/databrowser/product/page/env_wasfac)”.

For each country, when available, we kept the total rest capacity provided for landfilling of hazardous waste and non-hazardous waste from 2020. We excluded inert waste from our scope.

***Data cleaning***

Once again, we checked whether the landfill capacity reported per inhabitant fell into conventional ranges. To handle data gaps or outliers for certain countries, we looked for data from previous years (2018, 2016 or, at worst, 2014). If nothing was available within expected ranges, we preferred to use an average landfill capacity/person from other countries with a similar profile (geographically close, known to have comparable ways of handling waste) and to apply those to the country’s population.

***Technology assumed to be used and why***

Treatment of PFAS in landfill leachate is an emerging area. Because leachate has a lot of extra solids, nutrients, and organics, it typically cannot be sent straight to RO, GAC, or ion exchange but requires pretreatment first. Foam fractionation is one technology that can effectively separate long-chain PFAS from leachate without pretreatment. The legacy scenario uses foam fractionation for the treatment of landfill leachate, with the destruction of foamate liquid using high-temperature incineration. This would probably not remove TFA, and probably not remove all C4 PFAS like PFBA or PFBS, pending significant technology advances.

The emerging scenario assumes use of RO with SCWO or other destruction of brine. These costs include some pretreatment to reduce iron, solids, and organics prior to the use of RO – this step makes the RO work better and able to achieve a higher degree of concentration, which means less final brine to dispose of. RO recovery after pretreatment is assumed to be 65%, meaning that 35% of initial leachate is routed to brine for destruction. Similar to the drinking water scenario, liquid destruction would be routed to SCWO or a similar emerging destruction technology.

***Sources of cost data used***

Limited cost data is available for treating PFAS in landfill leachate. One paper from academia and industry cited a list of 1.5 EUR/m3 operating costs, while conversations with an operator currently piloting full-scale treatment said it’s difficult to do for less than 24 EUR/m3. This reflects the range used for the foam fractionation with offsite disposal technology assumed for the legacy costs.

For the emerging scenario, costs from the MPCA study per m3 ranged from about 2 to 63 EUR/m3 for the RO scenario with pretreatment, depending on the size of the facility (larger facilities are cheaper per volume treated due to economies of scale). Adding SCWO treatment at 8 EUR/m3 of 0.35 m3 brine/m3 leachate brings these numbers up to 5 to 65 EUR/m3 of leachate. These values were applied to estimated leachate production values for the emerging scenario.

***Assumptions made***

* 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](https://nam02.safelinks.protection.outlook.com/?url=https%3A%2F%2Fwww.sciencedirect.com%2Fscience%2Farticle%2Fpii%2FS2352340923000793&data=05%7C02%7Caling%40stthomas.edu%7C35bf562622284aff3dc808dcf363ab3a%7Ca081ff79318c45ec95f338ebc2801472%7C0%7C0%7C638652856959580586%7CUnknown%7CTWFpbGZsb3d8eyJWIjoiMC4wLjAwMDAiLCJQIjoiV2luMzIiLCJBTiI6Ik1haWwiLCJXVCI6Mn0%3D%7C0%7C%7C%7C&sdata=PtSbI488%2B1WdU%2BieMcGL7Kd1L6agK5oP5JJOnMl4%2BBA%3D&reserved=0)).
* 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.

***Calculation process***

1. Estimate total landfill capacity per country.
	1. In some cases, this was provided.
	2. 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).
2. Apply assumption for percent of capacity in use (70%) to estimate used landfill volume per country.
3. 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.
4. 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.
5. 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).
6. The best guess cost was assumed to be half of the high end cost estimated here.

***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).