PFAS usage, emissions & health effects

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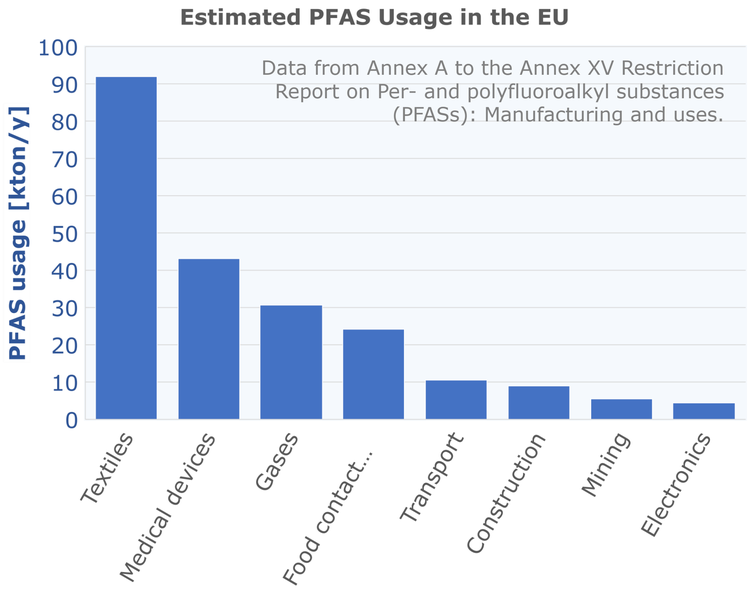
What is PFAS?

Per- and polyfluorene alkyl substances (PFAS) form a group of thousands of different persistent organic chemicals. Following the OECD definition, all chemicals with at least a $-CF_2-$ moiety in the middle of a molecule or a $-CF_3$ moiety at the end. PFAS are used because they repel oil and water, can resist harsh chemicals and high temperatures, have anti-stick properties and can be exceptionally strong. Some PFAS are known to have adverse health effects; those with the highest toxicological risks known so far (e.g PFOS, PFOA, and PFHxS) have been banned by the EU already.



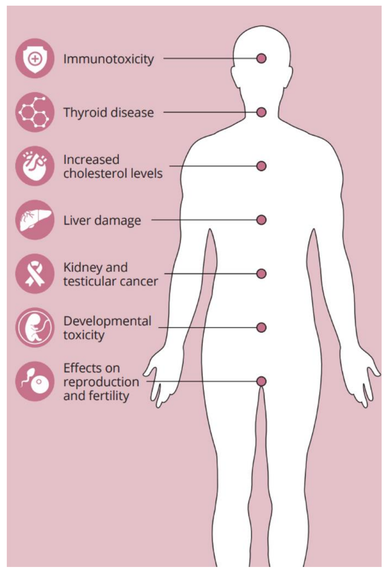
PFAS usage

The estimated **annual usage volumes** of PFAS in the EU are shown for the top 8 sectors. Data are based on the EU PFAS restriction proposal, which contains the most comprehensive dataset on this topic. The graph gives insight in the diversity of applications in which PFAS are used. No direct link exists between the estimated **usage volumes** shown here and the estimated annual emission volumes. This is in part related to the large difference in product lifetime, varying from *e.g.* single-use coatings on surgical drapes to parts of bearings that last for decades. It is important to realize that the mass balance for PFAS is far from complete – little data is available that shows the emissions from end-of-life treatments for plastics (incineration and landfilling).

Effects on health

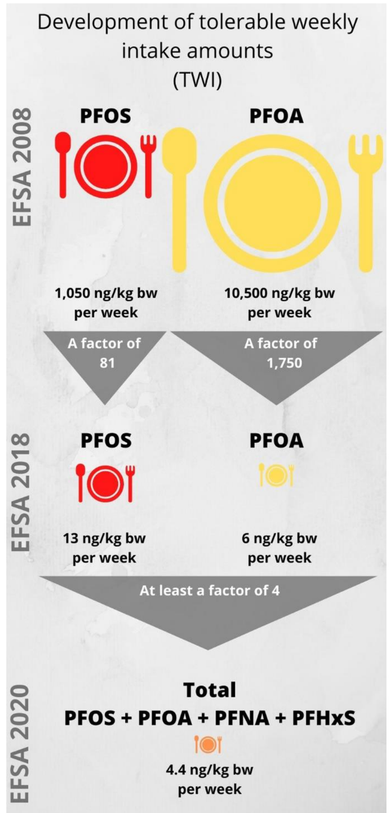
All PFAS molecules are **persistent:** they don't or barely degrade in the environment. Many are **mobile** and **bioaccumulative**, some are **toxic**. Not all PFAS have been proven to cause adverse health effects, in part related to the existence of thousands of different molecules that are a PFAS.

Even if a PFAS is not harmful, manufacturing and end-of-life processing of that material could lead to emissions of other PFAS with a worse toxicological profile.



Reused from the HBM4EU project. https://www.hbm4eu.eu/wp-content/uploads/2022/06/HBM4EU_Policy-Brief-PFAS.pdf

The **precautionary principle** is a rationale for a cautious approach when introducing new chemicals. The figure indicates its relevance to PFAS. In just a few years, the tolerable intake was reduced enormously. For 'novel' PFAS compounds, the knowledge on toxicological effects is still limited, but for humans and for other species. It could therefore be expected that these guidelines will continue to change.



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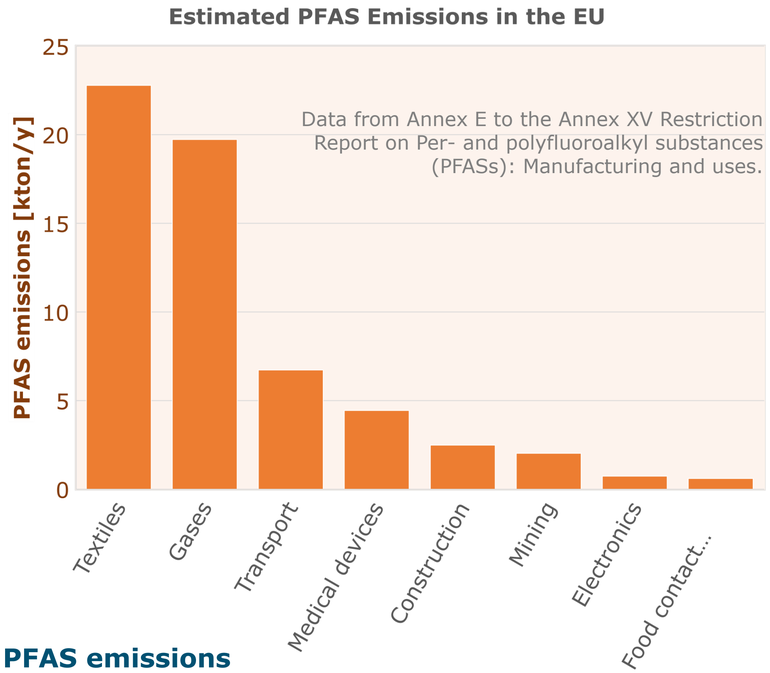

PFAS emissions

PFAS emissions mainly occur into water and air, this happens during different stages of the product lifecycle. Some PFAS (mostly fluoropolymers such as PTFE) generally don't cause emissions when present in end products, their usage is currently considered safe. Yet, during production and end-of-life, emissions cannot be completely avoided with the currently installed technology. Some treatments during use (heating, contact with chemicals) may also cause emissions.

Measures to reduce PFAS emissions during **production** have proven to be effective. However, for example PFAS used as a manufacturing aid during fluoropolymer **production** cannot be recycled or recovered completely and may be emitted through flue gas or wastewater. Gaseous byproducts are also known to be emitted, as they are reported in the E-PRTR database.

Incineration processes can degrade PFAS if the process is suitable. Most importantly, the temperature needs to be sufficiently high: almost all PFAS mineralize completely at >1200 °C. Municipal waste is usually incinerated at 850-950 °C, causing partial degradation and formation of potentially toxic, smaller PFAS molecules. Hazardous waste incinerators and cement kilns typically operate using conditions suited for PFAS mineralization.

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PFAS in the **Black Sea** and its drainage basin

Image adapted from the 'Forever Pollution Project', Le Monde 2024. Red dots indicate confirmed contamination, blue dots presumed contamination, and purple dots are known industrial PFAS users. The blue line indicates the course of the Danube.

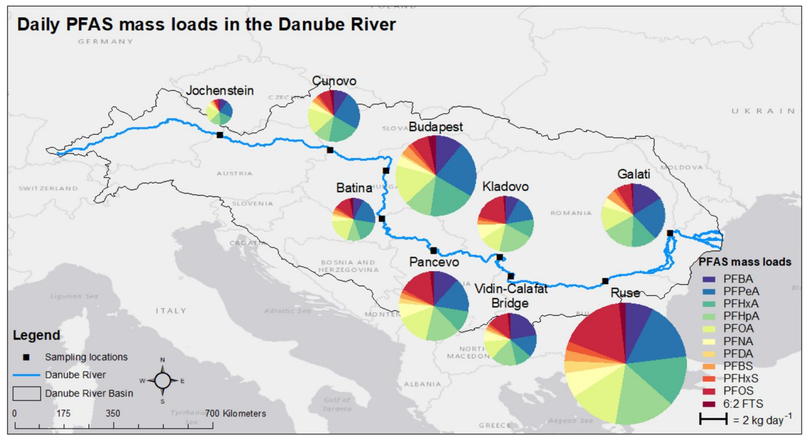

Image reused from Beggs *et al.*, 2022. Estimation of per- and poly-fluoroalkyl substances mass loads in the Danube River using passive sampling. https://doi.org/10.1016/j.scitotenv.2023.164458

Measured concentrations

Various efforts have been undertaken to measure concentrations of PFAS in areas relevant for the Black Sea basin. Older studies typically focus on a few well-known and phased-out PFAS compounds, results are summarized by the Forever Pollution project (top left image). More recent studies typically analyse a larger variety of PFAS molecules and sometimes consider temporal variations related to flow rates. The bottom left image makes clear that:

- The largest PFAS input into the Danube is not related to PFAS manufacturing (this takes place in Germany only in the Danube basin).
- Mass loads do not necessarily increase when progressing downstream. The highest mass loads are found close to large urban areas and industrial sites. Mixing effects may play a role on measurement results, as well as PFAS partitioning to sediment and groundwater.

The important role of diffuse emissions

Diffuse PFAS emissions relate to industrial use of PFAS or precursors thereof, as well as usage of end products in both industrial and consumer context. Volumes of diffuse emissions (74 ± 18 kton/y in EU) are estimated to be significantly higher than volumes of point source emissions relating to PFAS manufacturing (0.5-3.8 kton/y). Meanwhile, they are difficult for governments to monitor and register due to a large variety in chemicals and usages throughout product chains. A large share of diffuse PFAS emissions is expected to occur into wastewater. Wastewater treatment plants (WWTPs) are usually ineffective in removing PFAS from water. Moreover, PFAS bound to activated sludge is in the EU often used as fertilizer, thereby increasing local PFAS concentrations.

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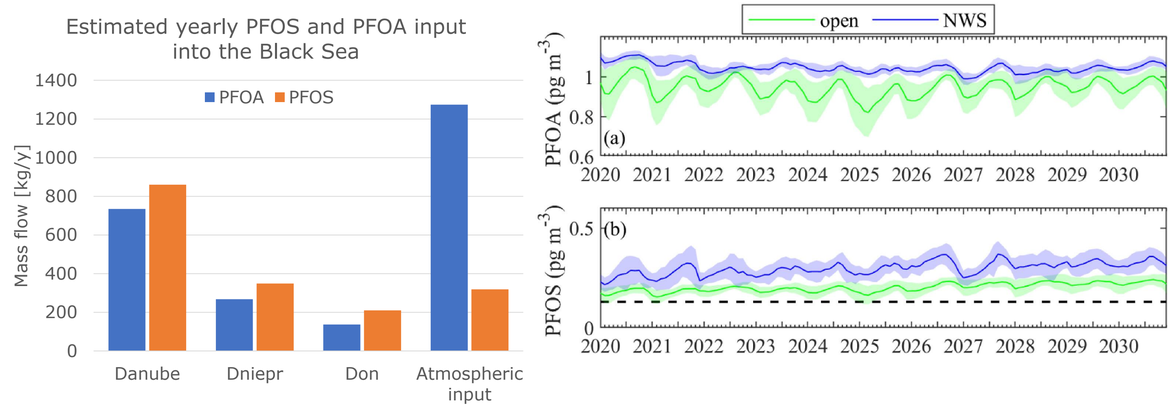
Modelled data

A few studies estimated the input of two legacy PFAS compounds (PFOS and PFOA) into the Black Sea and the distribution within the sea. Such estimations need many assumptions; much care needs to be taken when interpreting the figures. Lindim *et al.* estimated the PFOA and PFOS input (result in graph below) based on many factors, including the catchment basin size, population size, economic factors, wastewater treatment effectiveness, and physical parameters related to the specific chemical.



Left image made with data from Lindim *et al.*, 2016, https://doi.org/10.1016/j.watres.2016.07.024. Right image reused from Miladinova *et al.*: estimated monthly surface concentrations of (top) PFOA (µg m^{-3}) and (bottom) PFOS (µg m^{-3}).

Predictions of PFAS concentrations in the Black Sea

Measuring concentrations of chemicals in the environment is important to have a reliable view on the current status, while modelling can be used to predict future concentrations. Miladinova *et al.* modelled the concentrations of PFOS and PFOA in the Black Sea. The northwestern shelf area has the highest concentrations of PFOS and PFOA in the Black Sea, mostly due to riverine input. Although PFOA and PFOS have been banned in the EU, concentrations of these chemicals in the surface layer of the Black Sea (upper 10 m) are not expected to decrease significantly in the predicted period (until 2030, see the right graph above). Concentrations are above the environmental quality standard (EQS) set by the EU in 2006 and are therefore of concern. Input is expected to decrease in most scenarios, but due to very limited vertical mixing, most PFAS remains at the surface.

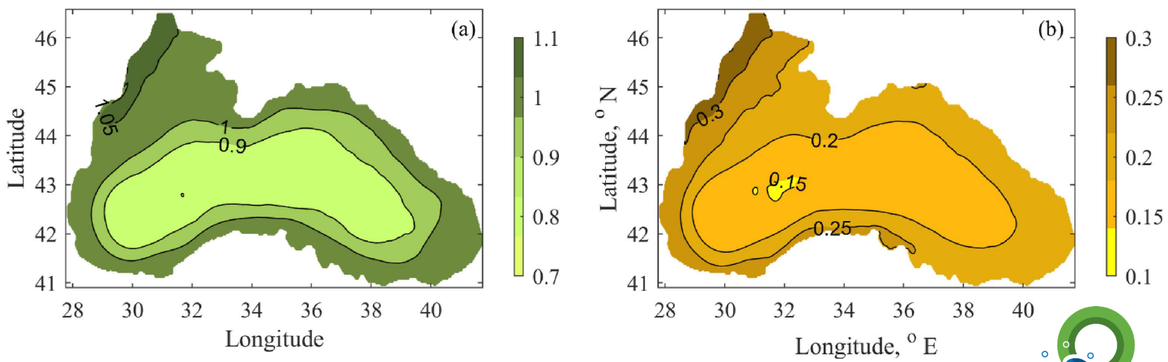


Image reused from Miladinova *et al.*, 2024. https://doi.org/10.1016/j.envres.2024.118100. Figure shows the average concentrations in the surface layer over 2020–2030 for the scenario in which concentrations of PFOA and PFOS in rivers and atmosphere remain equal to those in 2019. (a) PFOA (µg m^{-3}) (b) PFOS (µg m^{-3}).

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