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POLICY BRIEF

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"PFAS in soil – time to act together" An outcome of the international conference "PFAS in soil – forever pollution, forever concern?" held in Berlin, March 2025

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Abstract

This conference summary proposes general goals and associated actions for a collaborative effort amongst European countries to address the problem of soil contamination by perfluorinated and polyfluorinated alkyl substances (PFAS). It reflects the discussions during the international conference "PFAS in soil – forever pollution, forever concern?" taking place in Berlin/Germany on 25th and 26th of March 2025. The five general goals derived from the discussions suggest to: (i) Strictly prevent future PFAS immissions into soils, (ii) Systematically identify PFAS-contaminated sites, (iii) Provide a powerful fit-for-routine chemical analysis of PFAS in soil, (iv) Establish effective management strategies for PFAS-contaminated sites and (v) Minimize human PFAS exposure via soil (food, feed, drinking water, direct contact).

Keywords Perfluorinated and polyfluorinated alkyl substances (PFAS), Soil contamination, Exposure and hazard assessment, Management strategies, Conference summary

Introduction

Perfluorinated and polyfluorinated alkyl substances (PFAS) are a large group of chemically synthesized organic molecules that share a hydrocarbon chain as their basic structure, with the hydrogen atoms being replaced entirely (perfluorinated) or partially (polyfluorinated) by fluorine atoms. Of particular relevance to human and environmental exposure, at least with a better level of knowledge in this regard, are PFAS from the subgroups of perfluorinated carboxylic acids (PFCA) and perfluorinated sulfonic acids (PFSA). The two best-known/most thoroughly researched representatives of these subgroups are PFOA (perfluorooctanoic acid) in the PFCA subgroup and PFOS (perfluorooctane sulfonic acid) in the PFSA subgroup. PFAS have been used for decades e.g. as surfactants, coatings or for polymer-production. From these uses and respective products, the substances are continuously emitted throughout their lifecycle into the environment. One particularly worrying characteristic of PFAS, due to their stable chemical structure, is their persistence. This means that PFAS cannot be broken down naturally under environmental conditions—a characteristic that has led to PFAS being referred to as "forever chemicals". In combination with their comparatively high mobility, this property has led to PFAS now being found in all environmental media worldwide—with soils being both a major sink and source. Against this background the international conference "PFAS in soil–forever pollution, forever concern?" was organized by the German Environment Agency (UBA) and the German Environment Ministry (BMUKN) in Berlin, [1]. Around 150 participants from science, public institutions, industry and environmental organizations attended the conference and 200 joined online to discuss the hazards

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emanating from PFAS in soil, in particular for human health. The detailed conference agenda and presentation slides are available online (https://www.umweltbundesamt.de/conference-pfas-in-soil-forever-pollution-forever-0). The PFAS in soil problem was discussed in four sessions including invited talks from experts from several European countries presenting:

- several case studies illustrating the transfer of PFAS from contaminated soils via groundwater, plant and animal food towards humans,
- an overview on chemical analysis of PFAS in soil, reports from monitoring campaigns for PFAS in soil as well as an overview of the state of the development in technologies for treatment of PFAS-contaminated soil and groundwater,
- a keynote presentation on PFAS exposure through drinking water and the consequences for the health of the affected human population,
- reports from several European countries presenting their strategies for dealing with PFAS-contaminated soils.

The final session entitled "PFAS in soil–Time to act together" included reflections on the PFAS in soil problem in the broader perspective of chemicals regulation as well as a panel discussion with high-ranking representatives from the European political arena. The panelists agreed that PFAS in soil is a serious Europe-wide problem and that more cooperation is needed to tackle this problem effectively.

This paper is intended to stimulate the discussion on general goals and associated actions for a collaborative effort amongst European countries in addressing the problem of PFAS-contaminated soils. It was prepared as an outcome of the conference, reflecting the views generally shared by the presenters, panelists and participants. An initial draft of the discussion paper was prepared by the conference organizers (UBA) and all conference participants were invited for comments in an online survey. The overall feedback received to the draft was consistently positive and supportive, relevant proposals for amendment have been included in this final version.

Five general goals and dedicated actions

Goal 1: strictly prevent future PFAS immissions into soils

Due to the persistent properties, soil contamination by PFAS and the resulting potential transfer into the food web (including groundwater/drinking water) is a long-lasting threat for soil health and soil use by future generations. Therefore, emissions of PFAS into the environment should be more strictly prevented and consequently, immissions of PFAS into soils will decline. The earlier effective preventive measures are implemented, the smaller the PFAS burden in soils for future generations will be. Recommended preventive measures considered as generally suitable include:

- Realize an ambitious restriction of the future uses and production of PFAS to minimize emissions with clearly defined minor time-limited exemptions (cf. restriction proposal under the REACH regulation).
- Accelerate research and development for non-chemical and chemical alternatives for all uses where a substitution of PFAS is not yet possible. These alternatives should be safe and sustainable for human health and the environment already by design.
- Comprehensively identify all sources for potential intended emissions/applications of PFAS on soil (e.g. agricultural pesticides, biocides, pharmaceuticals) and develop strategies to prevent them as far as possible—especially in sensitive areas (e.g. drinking water catchments).
- Avoid PFAS immissions into soil by other known technical uses or intended applications like e.g. fire-fighting foams, PFAS-containing plastic materials, etc.
- Prevent the transfer of PFAS pollution from one environmental compartment to another: Minimize (at least, or even better prevent) PFAS immissions into soils by using sewage sludge, compost, biomaterials, etc. or the reuse of treated waste water—e.g. by implementing specific chemical quality standards for these resources and materials.
- Identify all sources for potential PFAS emissions into the environment that contribute to dry and wet deposition of PFAS on soil transported from distant emission sources. This covers e.g. exhaust emissions from industrial plants and waste incineration plants (for municipal waste, hazardous waste and sewage sludge). Identification and prevention of PFAS emissions from landfills is warranted, too.
- Raise awareness about the hazards of PFAS to environment and health in the general public by information campaigns and thereby increase acceptance for preventive actions and/or stimulate consumers to ask for products/production without PFAS.

Goal 2: systematically identify PFAS-contaminated sites

Knowledge on the location of those areas where soils are highly contaminated by PFAS (hot-spots) and where PFAS soil contents are above ubiquitous anthropogenic background levels (i.e. from diffuse airborne deposition), is essential for a site-specific assessment and management of the hazards emanating from these soils

to all relevant protection goals. The following measures are recommended to improve the knowledge on PFAS-contaminated sites across Europe:

- Develop a general European guidance for the identification of potential PFAS-contaminated sites (hot-spots) and sites with PFAS soil contents above ubiquitous anthropogenic background levels. Since PFAS contamination typically is affecting both soil and groundwater, this guidance should include groundwater, too. Starting point should be indications from historical site uses/register of activities with the potential for PFAS releases into soils. A publicly available "living" catalogue of possible PFAS-sources to soil via different immission pathways (e.g. industry branches using PFAS, or materials applied to soil potentially containing PFAS) should be developed for this purpose.
- Develop a general European guidance for robust sampling protocols and for subsequent chemical analysis of PFAS in soil and groundwater at contaminated sites (hot-spots) as well as for the determination of representative ubiquitous anthropogenic background levels of PFAS in soil/groundwater—the latter being important for the discrimination of sites with elevated PFAS contents. Criteria for the identification of "significant" PFAS soil contaminations/hot-spots have to be developed and agreed on.
- It is suggested to develop such European guidance (identification of sites/sampling and site-specific PFAS analysis) in a collaborative exercise based on an exchange of good practices (i.e. experiences of pioneering European countries and regions and existing methods, e.g. the soil monitoring framework LUCAS) rather than by a classic top-down approach. This is essential to avoid time-consuming duplication of efforts.
- Report the findings transparently: Establish a shared database on PFAS soil contamination (hot-spots and ubiquitous background level) in EU Member States/European countries—in order to describe the dimension of the issue to the general public, to identify potential supra-national emission sources of PFAS and provide a knowledge base for political decision making. Results obtained and challenges experienced from on-going respective EU-funded research projects should be considered here and future data collection might ideally be coordinated by an EU-agency. The conflict between legitimate transparency requests of the public and information privacy concerns in case of contaminated sites at private properties needs to be solved.
- In order to bring this general goal and the associated suggested measures forward in Europe, PFAS might serve as a "case study" conducted jointly by EU Member States under the upcoming Soil Monitoring and Resilience Directive.
- Sufficient financial resources for the systematic identification of PFAS-contaminated sites in European countries have to be mobilized, however not only from public budgets. In line with the polluter pays principle, industries known to be responsible for PFAS emission (i.e. PFAS production, PFAS utilizing productions and processes) should be engaged to make a relevant contribution (e.g. via a fund), too.

Goal 3: provide a powerful fit-for-routine chemical analysis of PFAS in soil

The availability of a powerful fit-for-routine chemical analysis of PFAS in soil is essential for the generation of robust and comparable monitoring data. This applies for the assessment of sites with elevated or high PFAS contamination (hot-spots) as well as for the determination of ubiquitous PFAS background levels. It is acknowledged that the development of standard methods for chemical target analysis of PFAS in soil (as well as in other solid matrices and water) is already underway at European (CEN, European Committee for Standardization) and/or international institutions (ISO, International Organization for Standardization). These activities should be supported, critically accompanied from a regulatory perspective and/or amended considering relevant progress in science and technology. Due to the broader scope of this paper only some general reasonings on standardization, harmonization as well as research needs are mentioned:

- Attention should be paid to establish "European standard operation procedures" for target analysis of PFAS in soil that fit to a PFAS compound listing considered relevant for monitoring—being either agreed by scientific-regulatory negotiations and/or legally required. The spectrum of PFAS compounds included in such monitoring listing might differ regarding the purpose, e.g. initial screening versus more comprehensive analysis or determination of ubiquitous PFAS background levels versus PFAS hot-spots; the selection of compounds considered as relevant for any monitoring should be communicated in a transparent way.
- Methods for PFAS target analysis should be adapted to cover a wide range of PFAS levels in soil, i.e. especially enable for robust low quantification and detection limits to determine background levels. Such sen-

sitive methods for PFAS target analysis in soil water (or leachates) and groundwater are required, too.
- A general strategy should be the rather broad selection of PFAS (as well as precursor compounds) for monitoring and thereby possibly including compounds for which yet no decision criteria/threshold values exist. If these will be developed at a later stage monitoring campaigns/chemical analysis must thus not start again.
- On-going research and development followed by standardization on PFAS sum parameters (e.g. EOF, AOF, TOP-Assay) suitable for soil/solid materials, soil water (leachate) and groundwater should be supported to broaden the monitoring scope beyond PFAS target analysis (suitable for soil/solid materials, soil water/leachate and groundwater). These activities should comprise the development of guidance on the interpretation of the results in (regulatory) decision making, too.
- A further important area of research is the identification of "rarely addressed" PFAS in soil/solid materials, soil water/leachate and groundwater by suspect-screening, non-target-screening and/or other innovative methods (e.g. receptor- or cell-based systems in combination with chemical methods).

Goal 4: establish effective management strategies for PFAS-contaminated sites

At identified PFAS-contaminated sites, efforts are warranted to minimize the spreading of PFAS in the surrounding environment. This is pivotal in order to spatially restrict the environmental damage and hazards to potentially affected protection goals via relevant exposure routes. Simply because PFAS-contaminated soils do not stop from spreading PFAS to water bodies or aquifers and thus threatening water resources/aquatic ecosystems and leading to further far-reaching problems. The following actions are recommended to establish effective management strategies:

- Develop general European guidelines on management strategies for PFAS-contaminated sites. These should include guidance on how to define/derive decision criteria such as trigger values for (remediation) action and target values for remediation measures. The same applies to the definition of criteria for handling excavated soil (i.e. threshold values for re-using, landfilling or depositing excavated soil) to avoid the transfer of PFAS-contamination to other sites. However, since to date no legal basis for a harmonization of respective decision criteria does exists in Europe, such an activity would aim to foster cooperation and exchange on basic principles for their derivation. The development in a collaborative exercise based on an exchange of good practices (i.e. experiences of pioneering European countries and regions) is again highly favored.
- An important aspect to be considered in the development of such general guidelines is a prioritization framework helping authorities to decide which sites are prioritized for management/remediation. The framework should address multiple criteria for a balanced decision making, e.g. level of pollution, actual and potential future site use, expected remediation efficiency, consequences of remediation measures for relevant soil properties etc. Remediation costs are a notably important criterion, however costs and benefits should be integrated in such a framework, as well as recommendations on how remediation measures should be evaluated for effectiveness.
- A multi-actor platform/network for the exchange of knowledge on PFAS management and remediation technologies as well as on related national and EU-funded research programs would stimulate cooperation and complementary activities across European countries.
- Accelerate research (via EU and national research programs), development and application of ready-to-use technologies for the stabilization/remediation of PFAS in soil and for the treatment of PFAS-contaminated groundwater.
- Sufficient financial resources for the management/remediation of PFAS-contaminated sites have to be mobilized while basically, the polluter pays principle applies. If a polluter cannot be made accountable, financial support should be made available for communities affected by PFAS-contaminated sites. As already mentioned under goal 2 and in line with the polluter pays principle, industries known to be responsible for PFAS emission (i.e. PFAS production, PFAS utilizing productions and processes) should be engaged to make a relevant contribution to a dedicated fund that must be organized in a long-term and reliable manner.

Goal 5: minimize human PFAS exposure via soil (food, feed, drinking water, direct contact)

In the vicinity of PFAS-contaminated sites a targeted minimization of human PFAS exposure from contaminated soil via groundwater, plant and animal food is mandatory to protect the health of local human populations as effectively as possible. As learned from prominent PFAS hot-spots around the globe (e.g. Ronneby/Sweden; Veneto Region/Italy; Korsør/Denmark), inaction in this

respect might potentially result in severe adverse health effects. Besides technical measures aiming to minimize the further spreading of PFAS in the environment (cf. goal 4), effective hazard management strategies preventing as far as possible the entry of PFAS from contaminated soil into (aquatic and terrestrial) food-chains for human consumption are essential. The following actions are recommended:

- Extend and refine the scientific knowledge on soil-borne PFAS exposure pathways to groundwater/drinking water for human consumption as well as to food and feed crops, farm animals and game animals used for human consumption. Thus, more targeted research especially at PFAS-contaminated sites and surrounding areas and transect studies with increasing PFAS soil contents is required. Monitoring studies are needed that integrate PFAS analysis of soil and groundwater with PFAS analysis in biota samples (i.e. biomonitoring including e.g. plants, soil organism, above-ground terrestrial organism) and human biomonitoring/epidemiology studies.
- Develop scientifically robust approaches for the hazard assessment of PFAS-contaminated soils (protection goal: human health). Respective soil guidance/trigger/screening values for PFAS should enable the decision making at contaminated sites regarding the need for site specific assessment and/or management. (Note: Today there is no harmonized nomenclature across EU Member States for such "regulatory action limits" for contaminant levels in soil. Further, existing national "regulatory action limits" are not easy to compare due to differences in regulatory scope, site use scenarios, input data and calculation methods.) Again, the development of at least a sufficiently EU-harmonized general regulatory-scientific base for the derivation of soil guidance/trigger/screening values for PFAS could serve as a "case study" conducted jointly by EU Member States under the upcoming Soil Monitoring and Resilience Directive. For regulatory coherence, such an exercise should consider already existing legally binding PFAS thresholds for human health protection, e.g. for drinking water.
- Develop a catalogue of effective and appropriate hazard management measures minimizing human exposure from PFAS-contaminated soils covering all potential routes of exposure. Such a catalogue should include measures that have already proven their efficacy under real world conditions as well as measures suggested at PFAS-contaminated sites for precautionary action (sometimes called "no-regret measures").
- Provide general guidance/recommendations for a hazard/risk communication strategy specific for PFAS-contaminated soils/sites–comprising all relevant steps in the process (planning, implementation, and finalization); relevant target audiences include the local residents, community institutions, public press, etc. Such guidance could reflect the experiences already made at well-known PFAS-contaminated sites across European countries.

Outlook—on how to proceed

As already highlighted, this paper is intended to stimulate a discussion on the general goals and associated actions for a collaborative effort amongst European countries in addressing the shared problem of PFAS-contaminated soils. A more in-depth discussion on detailed realistic options for an implementation of the here recommended actions is needed. Important points to be further discussed include ideas and potential commitments on (shared) responsibilities, starting points for cooperative actions, financing, infrastructure (e.g. network, web-platform, and database) and ideas for research on the topic.

Abbreviations

AOF	Adsorbable organic fluorine
BMUKN	Federal Ministry for the Environment, Climate Action, Nature Conservation and Nuclear Safety (Germany)
CEN	European Committee for Standardization
EOF	Extractable organic fluorine
EU	European Union
ISO	International Organization for Standardization
LUCAS	Land Use/Land Cover Area Frame Survey
PFAS	Perfluorinated and polyfluorinated alkyl substances
PFCA	Perfluorinated carboxylic acids
PFOA	Perfluorooctanoic acid
PFOS	Perfluorooctane sulfonic acid
PFSA	Perfluorinated sulfonic acids
REACH	Registration, Evaluation, Authorization and Restriction of Chemicals
TOP	Total Oxidizable Precursor (Assay)
UBA	Umweltbundesamt (German Environment Agency)

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Author contributions

TF, ABE, LV and CS jointly wrote the initial draft. Comments received from the online survey among conference participants were integrated into a revised draft by TF with LV and ABE proofreading. TF prepared the final manuscript for submission as well as the revised manuscript incorporating peer review feedback. All authors read and approved the final manuscript.

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