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PROMISCES

Preventing **R**ecalcitrant **O**rganic **M**obile **I**ndustrial chemical**S** for **C**ircular **E**conomy in the soil-sediment-water **S**ystem

Start date of the project: **1st November 2021**

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D5.4 - Solution strategies to reach a non-toxic environment for 5 PM(T) uses from a system perspective

and how they are perceived by the different stakeholders in the system

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Executive Summary

Increasing water consumption, industrial pollution, and long dry periods – these are all water resource challenges that highlight the growing importance of the transition towards a circular economy for the soil-sediment-water system. As described by the European Commission, pollution by persistent, mobile and potentially toxic (PM(T)) substances is often a systemic problem. It is related to the ways of production, use, and emission of these chemicals and is aggravated by missing technical solutions and monitoring techniques in the soil-sediment-water system. This poses challenges for regulatory authorities to develop or enforce effective policies throughout their lifecycle. The Horizon 2020 project PROMISCES aims to increase the circularity of resources by overcoming barriers associated with the presence of PM(T)s in the soil-sediment-water system.

To reach this overall goal one objective is the development of an integrated Decision Support Framework (DSF) to assist stakeholders in the risk management of PM(T) substances in the circular economy, in connection with EU strategies, specifically the Zero pollution and Circular Economy Action plans. The DSF has three building blocks: diagnosis of potential PM(T) substances, solutions to minimize the risk posed by these substances in the soil-sediment-water system and co-created zero pollution strategies for the risk management of PM(T) substances. This report provides an overview of the design and application of the DSF block "solutions to minimize the risk posed by PM(T) substances in the soil-sediment-water system" hereinafter referred to as the DSF Solutions module, using at least one of the five different substance-use combinations to demonstrate how systematic prevention, monitoring, risk assessment and treatment solutions will be evaluated. Included solutions are based on the work in the PROMISCES project, but other solutions from our sister project ZeroPM, the European Union, the NORMAN network, The Swedish Centre for Chemical Substitution, CompTox Chemicals dashboard, PubChem and the UPWATER project are also mentioned and/or linked, where relevant.

After a general introduction, this document provides a comprehensive selection of the five PM(T) substance-use combinations (**chapter 2**). In **chapter 3,** the systems descriptions, ergo the circular economy routes that fall into the selection criteria of chapter two, are elaborated. **Chapter 4** compiles all technical solutions optimized/designed within the PROMISCES project, where relevant other solutions are also mentioned and/or linked. In addition, **chapter 4** also provides a proposal for the design and content of the Solutions module of the DSF. A guidance on how the Solutions module of the DSF can be used by the user is provided in **chapter 5**. In **chapter 6,** the boundary conditions which are needed for the implementation of the technical solutions are elaborated. This report concludes with **chapter 7** which discusses the applicability of the DSF to identify solutions for PM(T) substances in the circular economy.

To illustrate how the solutions will be evaluated in the DSF, five substance-use combinations were selected. The following criteria were used for this selection: 1) Substances are PM(T) and are used for industrial purposes; 2) The individual substances are analyzed at least once in one of the PROMISCES case studies; 3) To enable the inclusion of the perception of potential end-users, substances are measured by case studies (CSs) that are coupled to at least one PROMISCES co-creation workshop (CS#2, CS#3 and CS#4) organised as a tool to bring multiple stakeholders to participate in an innovation process that gains buy-in from all involved); 4) Substances are measured above the limit of quantification in the case studies, 5) Selection of the individual substances is diverse in terms of CE route, type of substances (industrial PM(T) or PFAS) and type of use and 6) The selection is relevant for Zero Pollution and Circular Economy Action plans meaning banned and well-

studied PM(T) substances were not selected. These criteria led to the selection of PFBS (CAS no. 375-73-5), 6:2 FTS (CAS no. 27619-97-2), PFBA (CAS no. 375-22-4), diethyl phthalate (CAS no. 84-66-2) and galaxolide (CAS no. 1222-05-5).

Three circular economy routes were selected to investigate diverse circular economy (CE) routes addressed in the project: A) Semi-closed water cycle for drinking water supply, B) Wastewater reuse for agricultural irrigation and C) Nutrient recovery from treated sludge for fertilizers. The other two CE routes of the DSF are not discussed further in this report, as they are not associated with co-creation workshops. It should be noted that the systematic solutions “Prevention”, “Monitoring” and “Risk Assessment” are the same for each circular economy (CE) route. The systematic solutions “Treatment” differentiates between the CE routes. This means that for the systematic solution type “Treatment” the DSF user will first have to choose one of the five CE routes before being directed to treatment options.

Following this distinction, an inventory of the systematic solutions for prevention, monitoring, risk assessment and treatment is given.

- **Prevention** systematic solution provides information on PM(T) assessment, substitution, and additional solutions for preventing contaminants in specific routes based on the following four questions:
    1. Is the substance persistent, mobile and/or toxic?
    2. How and where is the substance used?
    3. Are there alternatives for the substance?
    4. What are other prevention methods besides substitution?

- **Monitoring** systematic solution gives information for diagnosing the condition of a potentially chemically polluted source. This entails setting up a characterization monitoring program for the reliable assessment of water, soil and sediment quality and can be based on the following questions:
    1. Which substances are you interested in?
    2. Which models are available for complementing monitoring data in the prediction of the fate of substances of interest in the environment?
    3. Which factors are important to include in your sampling strategy for selected substances?
    4. Which analytical chemistry methods are available for analysing PM(T) substances?
    5. Which biological methods are available for analysing complex mixture effects of PM(T) substance?

- **Risk assessment** systematic solution provides guidance on the assessment of risks of PM(T) substances in environmental matrixes and circular economy routes based on the following five questions:
    1. Are there limit values available for my substance based on European legislation?
    2. What are the concentrations of my substances found in the environment?
    3. In case no legal limits or health-based guideline values are available for my substance, how can the risk be determined in a specific medium and for a specific use?
    4. How can I determine the risk to human health?
    5. How can I determine the risk of both known and unknown substances in my matrix?

This systematic solution enables users to compare known occurrences of PM(T) substances in the environment to thresholds and provides references to detailed risk assessment models for specific circular economy routes, and information on effect-based monitoring for the hazard and/or risk assessment of mixtures.

- **Treatment** systematic solution provides information for treating a chemically polluted source. This entails setting up an efficient treatment for the recovery of a chemically polluted water, soil or sediment source and can be based on the following questions:

1. What is the target media of your chemically polluted source?
2. How can different treatment technologies be compared?
3. How can knowledge gaps on substance removal, transport and fate be overcome to evaluate the effectivity of a treatment?

The inventory of the solutions feeds the design of the Solutions module of the DSF. Based on this design, an initial demonstration of the Solutions module, where relevant, is outlined in **chapter 5.** Overall, the application of the DSF Solutions module demonstrates the value of the DSF, as several starting points for solutions have been identified by using the framework. At the time of writing, the DSF Solutions module is still being implemented and will be completed once all the data, tools and deliverables from the PROMISCES project are available.

The four main systematic solutions - prevention, monitoring, risk assessment and treatment - are technological in nature. However, the availability of technical solutions alone is not sufficient to successfully manage PM(T) substances in the soil-sediment-water system, but needs to be complemented by appropriate economic, social and governance conditions. These conditions are called ‘boundary conditions’ as they are crucial for the implementation of the invented/optimized solutions and are further explained in **chapter 6**. Specific examples include clarity on standards that need to be met, division of roles and responsibilities and availability of fundings. The role that various boundary conditions play in the implementation of strategies to deal with PM(T)s within a particular circular economy route was studied in the PROMISCES project via co-creation workshops.

To conclude, a framework was developed to assess solutions for PM(T) substances in the circular economy, which is an important step towards realizing the European Zero Pollution ambition. This framework presents a way of thinking and allows users to identify solutions at four levels: prevention, monitoring, risk assessment and treatment. The framework is easy to apply at screening level and was demonstrated to be a successful starting point for scientific and technical solutions. Effectively implementing solutions for PM(T) substances in the circular economy also requires stakeholder engagement to not only define the local problem, but also to identify the barriers for social, economic, and governance conditions. Lastly, we stress that there is not a single best solution for PM(T) substances in the circular economy. A successful strategy for the safe implementation of the circular economy and the management of PM(T) substances is one that is delivered at all levels and through the cooperation of multiple stakeholders to achieve the common goal of facilitating the implementation of the Zero Pollution and Circular Economy Action Plans.

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List of Abbreviations

CE	Circular Economy
SSbD	Safe and Sustainable by Design
TWI	Tolerable weekly intake
BAT	Best Available Techniques
BREFs	BAT reference documents
CEC(s)	Contaminant(s) of emerging concern
CSs	Case studies
DSF	Decision Support Framework
ECHA	European chemicals agency
EFSA	European Food Agency
EQS	Environmental Quality Standards
HBGVs	Health-based guideline values
iPM(T)	Industrial Persistent, Mobile and potentially Toxic
Koc	Organic carbon-water partition co-efficient.
LOQ	Limit of Quantification
N/A	Not available/not applicable
NORMAN	Network of reference laboratories, research centres and related organisations for monitoring of emerging environmental substances
OECD	Organisation for Economic Co-operation and Development
PM(T)	Persistent, Mobile and potentially Toxic
PNEC	Predicted no-effect concentrations
POPs	Persistent organic pollutants
REACH	Registration, evaluation, authorisation and restriction of chemicals
RIVM	Rijksinstituut voor Volksgezondheid en Milieu
SPM	Suspended particulate matter
TRL	Technology readiness level
US EPA CPDat	United States Environmental Protection Agency Chemical and Products Database
vPvM	very Persistent very Mobile
WWTPs	Wastewater treatment plants

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1 Introduction

1.1 Background information

Increasing water consumption, industrial pollution, and long dry periods – the transition towards a circular economy for the soil-sediment-water system is becoming increasingly important to address the various water resource challenges. As described by the European Commission, pollution by persistent, mobile and potentially toxic (PM(T)) substances is often a systemic problem. It is related to the ways of production, use, and emission of these chemicals and is aggravated by missing technical solutions and monitoring techniques in the soil-sediment-water system. This poses challenges for regulatory authorities to develop or enforce effective policies throughout their lifecycle.

There are several relevant directives or regulations that govern aspects of the soil-water-sediment-system, such as the Water Framework Directive (2000/60/EC), and its daughter directives, the Groundwater Directive (2006/118/EC), the Priority Substances Directive (2013/39/EU), the Drinking Water Directive (EU/2020/2184 revision from 98/83/EC), the Urban Waste Water Treatment Directive (2022/0345(COD), revision of 91/271/2024), as well as regulations focusing on the introduction of chemicals, e.g. REACH (2006/1907/EC), Biocidal Products Regulation (528/2012/EC), and Pesticides regulations (EC 1107/2009 and 2009/128/EC). However, these regulations do not offer sufficient provisions to address persistent, mobile and potentially toxic (PM(T)s) chemicals effectively in a circular economy or to ensure the sustainable use of natural resources. Regulations related to industrial emissions, like the Industrial Emissions Directive (2010/75/EC) and the European Pollutant Release and Transfer Register (E-PRTR, 2000), the Integrated Pollution Prevention and Control (IPPC) Directive (96/61/EC, Article 15), also lack sufficient provisions to effectively manage emissions of these substances.

To overcome these challenges, the Horizon 2020 project PROMISCES aims to deliver innovative scientific and technical solutions to overcome the impacts of industrial PM(T) hereinafter referred to as industrial PM(T) substances in the soil-sediment-water system, supporting the ambitions set in the Green Deal and related regulations.

1.2 Decision Support Framework for risk management of PM(T) substances in a circular economy

The Horizon 2020 project PROMISCES aims to increase the circularity of resources by overcoming barriers associated with the presence of PM(T)s in the soil-sediment-water system. To reach this overall goal one objective is the development of an integrated Decision Support Framework (DSF) to assist stakeholders in the risk management of PM(T) substances in the circular economy, in connection with EU strategies, specifically the Zero pollution and Circular Economy Action plans. PROMISCES runs from November 2021 to April 2025. Seven case studies across Europe are the basis for research under real conditions that will feed the DSF.

The DSF has three building blocks: diagnosis of potential PM(T) substances, solutions to minimize the risk posed by these substances in the soil-sediment-water system and co-created zero pollution strategies for the risk management of PM(T) substances.

This deliverable is directly linked to PROMISCES objective of developing and assessing the "solutions to minimize the risk posed by PM(T) substances in the soil-sediment-water system" module hereinafter referred to as the DSF Solutions module. Therefore, this report provides an overview of the design and application of the Solutions module (the second building block of the DSF), using one or more of the five substance-use combinations to demonstrate how systematic prevention, monitoring, assessment, and treatment solutions will be evaluated. Included solutions are based on the work in the PROMISCES project, where relevant other solutions are also mentioned and/or linked. This includes both qualitative elements (e.g. technology readiness level (TRL), type of circularity routes benefitting from the solutions, relevant stakeholders) and quantitative elements (e.g. possible socio-economic and environmental trade-offs). In addition, this report also includes the perception of potential end-users about the viability of implementing the included systematic solutions (information gained in PROMISCES). Close consultation or collaboration with potential end-users to evaluate, optimise and implement developed solutions is needed to take on-board boundary conditions such as environmentally sustainable, cost-effective, easily implementable, and suitable for real-life challenges and as such let the proposed solutions facilitate the implementation of Zero Pollution and Circular Economy Action plans.

1.3 Objective and structure of this deliverable

This deliverable aims to provide an overview of scientific and technical solutions to minimize the risk posed by PM(T) substances in the soil-sediment-water system from use to emissions i.e. a system perspective, while also gaining the perception of key stakeholders. Therefore, this report constructs the framework of the DSF Solutions module for the inventory of systematic solutions for prevention, substitution, mitigation and remediation using a common set of criteria on their potential to help achieve a non-toxic European environment. Priority is given to solutions addressing PM(T)s identified as most critical for the safe reuse of resources. The selection is based on input/expert judgement from PROMISCES case studies and deliverables.
Note that this deliverable only focuses on the Solutions module of the DSF. The general objective, targets and specifications of the DSF including its landing page will be explained in *Deliverable 5.7 Final version of the DSF published and usage guidance for the end-users* (due in February 2025).

This document starts with a comprehensive selection of the five PM(T) substance-use combinations (chapter 2). The five selected substance-use combinations determine the course of this entire document. In chapter 3 the systems perspective ergo the circular economy routes that fall into the selection criteria of chapter two are elaborated. Chapter 4 compiles all technical solutions optimized/designed within the PROMISCES project, where relevant other solutions are also mentioned and/or linked. This chapter provides an inventory of solutions for prevention, monitoring, risk assessment and treatment. In addition, chapter 4 also provides a proposal for the design and content of the Solution module of the DSF. A guidance on how the Solution module of the DSF can be used by the user is provided in chapter 5. In chapter 6, the boundary conditions which are needed for the implementation of the technical solutions are elaborated on based on the co-creation workshops held in PROMISCES. This report concludes with chapter 7 which focusses on the most important solutions needed for each of the five selected PM(T) substance-use combination as discussed with stakeholders.

2 Selection of 5 PM(T) uses

To illustrate how the solutions will be evaluated in the DSF, five substance-use combinations have been selected. The following criteria were used for this selection:

		Nr. of substances
I.	Substances are PM(T) and are used for industrial purposes.	505
II.	The individual substances are monitored at least once in one of the PROMISCES case studies.	80
III.	To enable the inclusion of the perception of potential end-users, substances are monitored by case studies (CSs) that are coupled to at least one co-creation workshop (CS#2, CS#3 and CS#4).	73
IV.	Substances are quantified above LOQ in the represented case studies.	27
V.	Selection is diverse in terms of CE route, type of substances (industrial PM(T) or PFAS) and type of use.	16
VI.	The selection is relevant for Zero Pollution and Circular Economy Action plans.	5

Ad I. Substances are PM(T) and are used for industrial purposes

The PROMISCES project has a suspected PM(T) list that includes 505 substances (n=505). This list includes individual substances as well as mixtures. The list of substances consist of chemicals previously classified as PM(T)/vPvM by UBA (Arp et al., 2023) and the National Food Institute from the Technical University of Denmark (Holmberg et al., 2021).

Ad II. The individual substances are monitored at least once in one of the PROMISCES case studies

PROMISCES case studies are targeting 80 individual substances out of the 505 entries. Some case studies are also working on cis+trans 1,2-Dichloroetylene (sum), fatty acid-based ionic liquids, heavy metals, organophosphates & phosphonium compounds, sulfonated aliphates & benzoic acids, UV stabilizers and suspected target screening. The target compounds analysed in each case have been selected based on previous suspect screening methods, knowledge of local activities and stakeholders, and/or previously reported data. An overview of the number of individual PFAS and other industrial PM(T) substances monitored through target screening in the different case studies (CS) and their corresponding circular economy routes is presented in Figure 1. The representation of PFAS compounds is higher than that for other industrial PMTs, which apart from CS#3 are less frequently considered within PROMISCES case studies. Some substances repeat in different Circular Economy (CE) routes and case studies. From the 80 substances monitored through target screening within the project, nine substances occur in all case studies, i.e., in every circular economy route. All of these substances are PFAS and are indicated with a superscript one symbol ([1]) in Table 3. An overview of how many substances the seven PROMISCES case studies have in common/intersect is provided in Figure 2. This overview includes the amount of substances that overlap between multiple case studies or remain distinct to a specific case study.

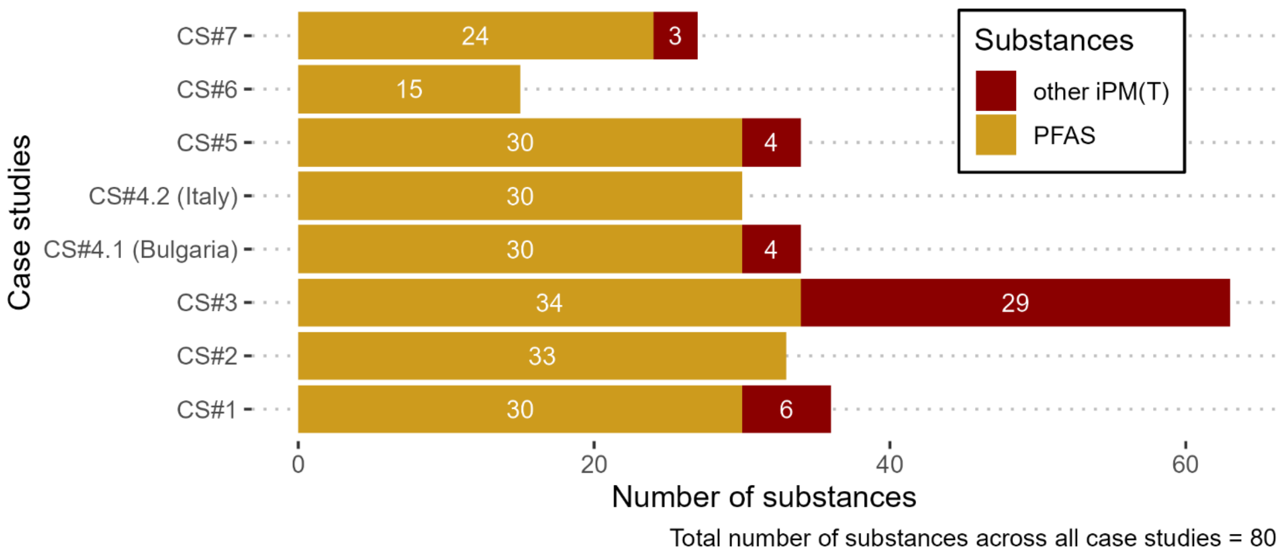


Figure 1 : Number of PFAS and other industrial PM(T) (iPM(T)) substances monitored through target screening in the different case studies (CS)

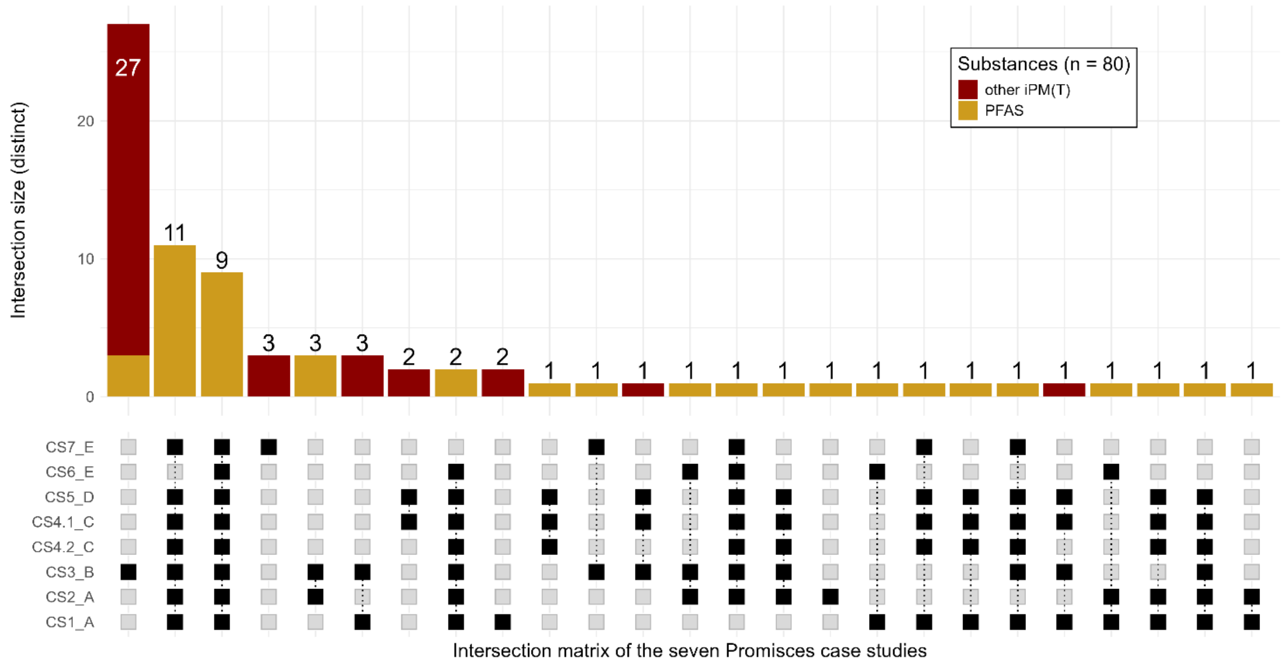


Figure 2 : Number of PFAS and other industrial PM(T) (iPM(T)) substances monitored through target screening in the different case studies (CS) and their corresponding circular economy routes. The letter after the case studies number indicates the associated CE route. CS 4.1 refers to the Bulgaria field site whereas CS 4.2 refers to the Italy field site.

Ad III. To enable the inclusion of the perception of potential end-users, substances are monitored by case studies that are coupled to at least one co-creation workshop

As part of the project, all case study (CS) leaders were asked if they could organize co-hosting one or more co-creation workshops with their stakeholders. Co-hosting a co-creation workshop not only means administratively hosting of the event, but also contacting the stakeholders, sharing data and reflecting on the results obtained from the case studies. CS#7 is not able to discuss the results of the case study with stakeholders as the information is confidential. Hence, three case studies (CS#2, CS#3 and CS#4) were selected for co-hosting and participation in co-creation workshops. An overview of the selected case studies is presented in Table 1. It should be noted that while this deliverable will cover three case studies that correspond to three circular economy (CE) routes, the DSF will include all five CE routes presented in Figure 3.

Table 1: Overview of all case studies implemented in PROMISCES and the ones that were suitable for one or more co-creation workshops.

Case Study #	**Title**	**Suitable for co-creation workshop organized (Yes/No)**
1	PFAS and PM(T) fate and remediation in the semi-closed urban water cycle – Berlin (Germany)	**N**
2	Sources, pathways, fate and transport of PFAS in the Upper Danube basin - (Austria, and Hungary)	**Y**
3	Water reuse from a wastewater treatment plant with a high share of industrial wastewater for agricultural irrigation – Barcelona Province (Catalonia)	**Y**
4	Landfill leachate treatment to safe resource recovery from wastewater treatment plants – Ancona (Italy) and Sofia (Bulgaria)	**Y**
5	Removal of PFAS from dredged sediments for material recycling – Ancona (Italy)	**N**
6	PFAS Fate and transport and remediation in soil and groundwater contaminated by AFFF – Orléans (France)	**N**
7	Remediation of groundwater contaminated in a fire-fighting training site - Barcelona Province (Catalonia)	**N**

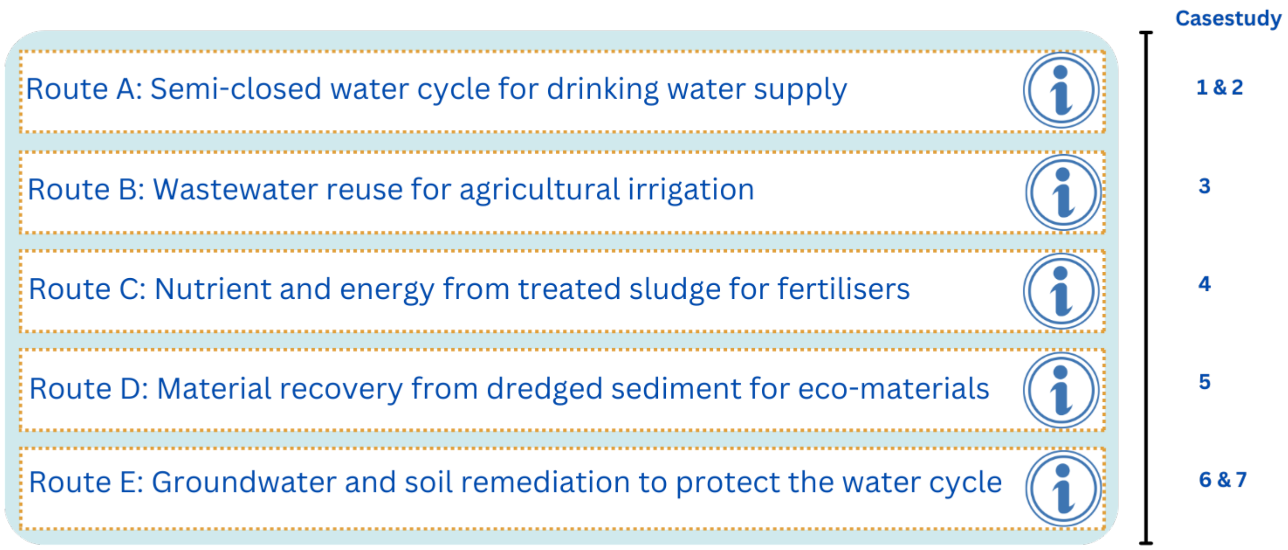


Figure 3 : The circular economy (CE) routes covered by the DSF. The information icon provides a brief description of the CE route (see chapter 3).

As this deliverable combines the solution strategies with the perception of the stakeholders only case studies that are coupled to at least one co-creation workshop were included. This further decreased the list of individual substances from 80 to 73 individual substances monitored in the retained CS. Of the 73 individual substances 42 are classified as PFAS and 31 as other industrial PM(T).

Ad IV. Substances are quantified above LOQ in the represented case studies.

As we would like to demonstrate the systematic solutions monitoring, treatment and risk assessment with our selected substance-use combinations, it is needed that the substances are quantified above the limit of quantification (LOQ) in the represented case studies.

Preliminary data was received from case studies 2, 3 and 4 in June and July 2024. In total 32 substances were quantified above the LOQ (13 PFAS and 19 industrial PM(T)s). Of the 19 industrial PM(T)s detected above LOQ three substances were only detected in T0 of the lab-scale experiments and two were not detected consistently throughout the experiments. These five industrial PM(T)s were disregarded in this filter step. The 27 remaining substances are listed in Table 3. It is worth noting that the nine listed PFAS with a superscript one symbol ([1]) are the only substances that are quantified by all case studies, *i.e.*, in every circular economy route (Figure 2, column 3). So far only five out of these nine PFAS have been quantified above the LOQ in the represented case studies.

Ad V. Selection is diverse in terms of type of substances, CE routes and type of use.

To keep a balance in the type of substances selected for this report, we decided to choose 2 industrial PM(T)s and 3 PFAS from Table 3. PFAS only quantified in one case study were discarded in this filter step. The remaining PFAS quantified above the LOQ can be grouped into three "diverse in CE routes" combinations: quantified by all CS, only by CS#2 and CS#3 or only by CS#2 and CS#4. One substance was selected from each group. ***Perfluorobutanoic acid (PFBA)*** is the only PFAS quantified in CS#2 and CS#4 and is therefore the ***first selected substance of this report***. In the following section (Ad VI.) its relevance for EU policy is verified.

The industrial PM(T)s were only quantified in case study 3 so there is no diversity in CE routes to base the selection on. However, based on their use (retrieved from Pubchem), seven industrial PM(T)s were discarded as their use does not seem to be relevant to the three represented CE routes of this report. It should be noted that there can be multiple functional uses of a same substance, and a substance can be used in many different industries and products. We have limited Table 3 to one use case per substance.

This filter step brought the total number of individual substances to select from 27 to 9 PFAS (including PFBA) and 7 industrial PM(T)s.

Ad VI. The selection is relevant for Zero Pollution and Circular Economy Action plans.

Of the PFAS quantified above LOQ perfluorooctanoic acid (PFOA) and perfluorooctane sulfonic acid (PFOS) are the most studied. More knowledge is available about these two compounds than for the rest of the group comprising over 8,000 substances (Evich et al., 2022). The focus on these compounds has led to their ban or limitation. Both substances are globally regulated as persistent organic pollutants (POPs) under the United Nations Environment Programme (UNEP) Stockholm convention on persistent organic pollutants (Lallas, 2017). In addition, they are also subjected to restrictions according to REACH in Europe with some derogations. Based on several similar effects in animals, toxicokinetics and observed concentrations in human blood, the EFSA Panel on Contaminants in the Food Chain decided to perform a further assessment for these two legacy PFAS, with the addition of PFNA and PFHxS. These four PFAS made up half of the lower bound exposure to those PFAS with available occurrence data, the remaining contribution being primarily from PFAs with short half-lives EFSA Panel on Contaminants in the Food Chain (2020). EFSA derived a tolerable weekly intake (TWI) of 4.4 ng/kg bw per week for the sum of these four PFAS.

Due to the industrially critical applications of PFAS, manufacturers began replacing long-chain PFAS with alternative perfluorinated compounds. Short-chain (<C6) ether-PFAS and fluorotelomer sulfonates (FTSs) replaced PFOA and PFOS. Generally, replacement PFAS have shorter C−F chains and consequently have been marketed as less bio-accumulative and thus safer alternatives, but these replacement compounds are in general more mobile. Hence it is interesting to focus this report on the replacement PFAS rather than the legacy PFAS. This leads to the exclusion of the EFSA-4 bringing the total number of substances to select from to six PFAS, including PFBA. With this exclusion, the second "diverse in CE routes" group was left with one candidate substance, namely 6:2-fluorotelomersulfonic acid (6:2-FTS). 6:2-FTS is considered a very persistent very mobile (vPvM) compound and it is therefore the ***second selected substance of this report***. In the first "diverse in CE routes" group of Table 3 we chose PFBS as the ***third selected substances of this report***. PFBS is considered a substance of Very High Concern (ECHA).

Of the industrial PM(T)s substances relevant to the represented case studies one is a transformation product i.e. galaxolidone and is therefore the ***fourth selected substance of this report.*** The last selected substance was chosen from the group of plasticizers. Of this group diethyl phthalate is currently under assessment as endocrine disrupting (ECHA) and is therefore the ***fifth and last selected substance of this report***.

Table 2: Retained substances and their properties used to classify them as PM(T).

Substance	*CAS no.*	*Half-life (days)*	*Log Koc*	*T (CLP criteria)*	*PM(T) classification (conservative)***
PFBS	375-73-5	246.90	1.93	non-toxic	vPvM
6:2 FTS	27619-97-2	981.21	2.40	toxic	vPMT
PFBA	375-22-4	87.36	1.34	toxic	vPvMT
Diethyl phthalate	84-66-2	169.02	1.84	toxic	vPvMT
Galaxolidone	507442-49-1	478.18	3.81	toxic	vPT

Details on data source for the scores' calculation are provided in *Deliverable D5.1* (2024).

Table 3: Substances quantified by CS#2, CS#3 and CS#4 (above LOQ, status July 2024). Substances not monitored or only detected in T0 of the lab experiments are not included.

	Nr.	Name of substance	CAS no.	Casestudy 2 - Route A	Casestudy 3 - Route B	Casestudy 4- Route C	Diverse CE route	Relevant for EU policy (selected compouds are in green)
PFAS	1	PFHxA - perfluorohexanoic acid[1]	307-24-4	X	X	X		
	2	PFOA - perfluorooctanoic acid[1]	335-67-1	X	X	X		Legacy PFAS
	3	PFBS - perfluoro butane sulfonic acid[1]	375-73-5	X	X	X	yes, Combination CS# 2,3,4	yes, vPvM(T)
	4	PFHpA - perfluoroheptanoic acid	375-85-9	X	X	X		
	5	PFPeA - perfluoropentanoic acid	2706-90-3	X	X	X		
	6	PFHxS - perfluorohexane sulfonic acid[1]	355-46-4	X	X			Legacy PFAS
	7	6:2 FTS - 6:2-fluorotelomersulfonic acid[1]	27619-97-2	X	X		yes, Combination CS#2,3	yes, vPvM
	8	PFOS - perfluorooctane sulfonic acid[1]	1763-23-1	X	X	X**		Legacy PFAS
	9	PFBA - perfluorobutanoic acid[1]	375-22-4	X		X	yes, Combination CS#2,4	yes
	10	PFDS - perfluorodecane sulfonic acid[1]	335-77-3	X			no	
	11	PFDA - Nonadecafluorodecanoic acid[1]	335-76-2	X			no	
	12	PFPeS - perfluoropentane sulfonic acid	2706-91-4	X			no	
	13	PFNA - perfluorononanoic acid	375-95-1		X		no	

	Nr.	Name of substance (Casestudy 3 – Route B)	CAS no.	Use according to (PubChem)	Relevant to at least one CE route	Relevant for EU policy
Industrial PM(T)s	14	(4+5)-Methylbenzotriazole	29878-31-7 | 136-85-6	metal anticorrosive, ultraviolet stabilizer additives	no	
	15	1,2,3-benzotriazole	95-14-7		no	
	16	2-Aminophenol	95-55-6	bacterial metabolite used in hairdyes and an intermediate for pharmaceuticals.	no	
	17	6-Methyl-2-pyridinemethanol+ 2-Amino-4-cresol	1122-71-0 | 95-84-1	intermediate for organic chemicals and dyes	maybe	
	18	Bis(2-ethylhexyl) amine	106-20-7	antistatic; Hair conditioning	yes	
	19	Dibutyl hydrogen phosphate	107-66-4	catalyst and an antifoaming agent	yes	
	20	Dibutyl phthalate	84-74-2	plasticizer	yes	
	21	Diethyl phthalate	84-66-2		yes	Under assessment as Endocrine Disrupting
	22	Tris(2-butoxyethyl)phosphate	78-51-3		yes	
	23	Triethyl phosphate	78-40-0		yes	
	24	Galaxolidone	507442-49-1	transformation product of the commonly used synthetic musk galaxolide (HHCB, CASnr : 1222-05-5)	yes	Relevant for EU policies as it is a transformation product which are often overlooked in EU policy.
	25	Dibutyl adipate	105-99-7	solvent (The chemical has been verified to be of low con-cern)	no	
	26	Tributyl phosphate/triisobutyl phosphate	126-73-8	Mainly used as a flame retardant in aircraft hydraulic fluid	no	
	27	Caprolactam	105-60-2	manufacture of synthetic fibers (especially Nylon 6).	no	

[1] Nine substances targeted accross all seven PROMISCES case studies.

***Substance was targeted in Bulgaria, not in Italy.*

3 Description of the system, from use to emissions

In this chapter, based on the selection criteria presented in chapter 2 for the five substances to be included in this report, circular economy (CE) Routes A through C are briefly presented. The other two CE routes of the DSF are not further elaborated on in this report as they are not associated with co-creation workshops. However, as mentioned in chapter 2, the DSF will include all five CE routes presented in Figure 3. Below marked with a dotted vertical left border a proposal is presented for the information to be included in the DSF for CE routes A, B and C. This proposal is meant to feed the information icon of the CE routes (Figure 3).

3.1 CE route A : Semi-closed water cycle for drinking water supply

Drinking water is produced by treating raw water, which can be (a combination of) groundwater and surface water, in drinking water treatment plants before distribution to consumers. After using the water, the resulting wastewater is transported via the sewer system to wastewater treatment plants. There, it is treated physically, chemically and biologically. Only then the wastewater can be discharged to rivers or other surface water bodies. Finally, drinking water treatment plants can pump surface water through various soil layers – known as bank filtration – to supplement the raw water needed to produce new drinking water. Such a semi-closed water cycle not only recycles water but may also transfer chemicals, such as PFAS or industrial PM(T)s, to water consumers. Two Case studies in PROMISCES are addressing this CE route, namely case study CS#1 PFAS and PM(T) fate and remediation in the semi-closed urban water cycle, Berlin and case study CS#2: Sources, pathways, fate and transport of PFAS and PM(T)s in the Danube basin semi-closed water cycle.

Case study CS#2: Sources, pathways, fate and transport of PFAS and PM(T)s in the Danube basin semi-closed water cycle.

Along the Danube River, there are multiple locations where water is abstracted for potable use, via riverbank filtration (RBF). However, the chemical water quality of the Danube River is influenced by various discharges from wastewater treatment plants (WWTPs) and stormwater from an area with more than 80 million inhabitants throughout 14 countries. The largest contributors to river pollution are the discharges from WWTPs, which introduce a range of persistent, mobile, and toxic (PM(T)) substances like PFAS into the water, some of which are hardly removed via the RBF. Unfortunately, there is a lack of knowledge about PFAS in the river and how these chemicals impact the drinking water abstracted via bank filtration along the river.

Therefore, there is a concern that ensuring future drinking water production through RBFs may not be guaranteed without costly additional treatment at drinking water production sites, particularly if drinking water standards become more stringent. In order to reduce discharges by WWPTs, the EU Urban Wastewater Treatment Directive has been updated. The co-legislators aligned the thresholds and timelines for tertiary treatment (i.e. the removal of nitrogen and phosphorus) and quaternary treatment (that is, the removal of a broad spectrum of micropollutants). By 2039 and 2045 respectively, Member states will have to ensure the application of tertiary and quaternary treatment in larger plants of 150 000 population equivalent (p.e.) and above, with intermediate targets in 2033 and 2036 for tertiary treatment and in 2033 and 2039 for quaternary treatment (Urban wastewater: Council and Parliament reach a deal on new rules for more efficient treatment and monitoring - Consilium (Council, 2024)).

It is essential to consider not only treating PM(T) substances during drinking water production but also exploring upstream solutions. This includes examining emission points into the river such as WWTPs and industrial sources, and even further upstream. Specifically, the necessity of using certain chemicals should be assessed, including whether alternatives are available, and if these substitutes have better PM(T) characteristics. Another important consideration is the legacy contamination within the system. Legacy contamination can have lasting effects on PM(T) concentrations within the Danube, even if emissions from WWTPs and industries along the river are greatly reduced or eliminated. It remains unclear whether the impact of this legacy contamination on the river is significant compared to the load of PM(T) substances discharged into the river. Further details on case study 2 are provided on the PROMISCES webpage circular economy routes (PROMISCES, 2024).

3.2 CE route B : Wastewater use for agricultural irrigation

In areas where surface water or groundwater quantities are lacking, treated municipal or industrial wastewater can be reused to irrigate farmland. Treated wastewater is currently discharged into surface waters, but it can also undergo additional treatment and be directly used for irrigation. PROMISCES will investigate combined electrochemical and wetlands treatment for the removal of PFAS and industrial PM(T)s. Knowledge gained on the water-to-crop transfer of compounds will provide vital information on potential human health risks associated with direct or indirect (e.g. animal fodder) crop consumption and inform agricultural best practices for farmers. One case study in PROMISCES is addressing this CE route, namely case study CS#3: Water reuse from a wastewater treatment plant with a high share of industrial wastewater in Barcelona Province.

Case study CS#3: Water reuse from a wastewater treatment plant with a high share of industrial wastewater, Barcelona Province

The Catalan Water Agency (ACA: Agència Catalana de l'Aigua) seeks to promote water reuse in the Besòs River Basin to mitigate water restrictions put in place due to recent periods of severe droughts, to combat the growing water scarcity. To this end, 64 municipalities working together in the Consorci Besòs Tordera (CBT) initiated the Reclaimed Water Master Plan (RWMP). This plan involves the construction of a number of Reuse Water Plants (RWPs) and transportation infrastructure to meet urban, agricultural, industrial and environmental water demands.

However, when looking at the reuse of wastewater for agricultural purposes, micro-contaminants, like specific chemical substances or medicine residues, coming from both industrial and household sources have to be removed. Specifically, over the past decades, concerns have been growing about chemicals which do not degrade (persistent substances; P), can easily spread throughout the environment (mobile substances; M) and are suspected to harm organisms (toxic substances: T). In the current design of the RWPs, removing PM(T) substances is not considered. However, this might be needed if the water is to be used for agricultural purposes (irrigation) to prevent that the PM(T) concentrations found in crops exceed human and environmental safety levels. Moreover, expected future regulations may demand that (some of the) PM(T) substances be removed from reclaimed water for agricultural and other uses. Further details on case study 2 are provided on the PROMISCES webpage circular economy routes (PROMISCES, 2024).

3.3 CE route C: Nutrient and energy recovery from treated sludge for fertilizers

Reusing what was once considered waste is an integral part of a circular economy. To enable safe resource reuse of sewage sludge in the form of fertilizers, PROMISCES will study the efficiency of PFAS and industrial PM(T) removal during landfill leachate treatment. Testing new treatment technologies and combinations will bring us closer to the goal of near-zero pollution discharge from landfill leachate treatment plants. Certain innovative treatments will also allow energy recovery (e.g. gas). Ultimately, this will lead to better prevention of PFAS transfer into fertilizer products. This is critical because as soon as the fertilizer is applied, its constituents end up in the crops, soil and groundwater. One case study in PROMISCES is addressing this CE route namely case study CS#4: Innovative landfill leachate treatment to enable resource recovery from wastewater treatment plants, Ancona & Sofia.

Case study CS#4: Innovative landfill leachate treatment to enable resource recovery from wastewater treatment plants, Ancona & Sofia

In Italy and Bulgaria currently, conventional leachate treatment plants are not designed to remove emerging organic micropollutants, such as perfluoroalkyl substances (PFAS), which are persistent, mobile and toxic (PM(T)) for the environment. Generally, in Italy landfill leachate treatment plants discharge treated landfill leachate in municipal wastewater treatment plants (WWTPs). Hence, landfill leachate may be a major source of municipal wastewater contamination by PFAS and other PM(T) substances. Untreated landfill leachate and thus PM(T)-rich leachate result in the following issues for the general management of a municipal WWTP:

Incompliance with new limits for organic micropollutants that may be defined by the upcoming Urban Wastewater Treatment Directive

Limitation on the reuse of municipal wastewater and municipal sewage sludge due to presence of PM(T) substances, including PFAS, heavy metals and other PM(T)s related to the discharge of landfill leachate

In Bulgaria, the existing landfills either treat leachate locally and discharge it to a water body or dry gully; or recirculate it back onto the landfill.

In both cases, PFAS and other PM(T) substances remain untreated in the environment with all potential negative impacts. To overcome these issues, advanced treatments need to be installed at the landfill leachate treatment plants, such as reverse osmosis or nanofiltration, to remove PM(T) substances. However, the treatment of landfill leachate produces biological sludge waste which introduces environmental issues during its disposal. In addition, concentrate is produced during operation of RO or NF filtration technologies. Those wastes of landfill leachate treatment are currently disposed in landfills or incinerated. Within PROMISCES projects, innovative and more sustainable technologies have been tested to treat sludge and concentrate coming from landfill leachate treatments, which are pyrolysis and plasma. Further details on case study 2 are provided on the PROMISCES webpage circular economy routes (PROMISCES, 2024).

4 Design of the solution assessment module of the DSF

When choosing the solution assessment module of the DSF (PROMISCES, 2025f), the user will first be presented with an image of the four main solution types and an introduction text of this module (Figure 4). Below is a proposal for the information to be included in the DSF as an introduction of the Solutions module. The proposal is marked with a dotted vertical left border. For the purpose of this report the figure was placed above the introduction text. In the DSF the introduction text will be available on the right side while the image will be presented on the left.

Figure 4 : Interactive plot of the DSF - Systematic solutions interconnected in multiple ways.

Hale et al. (2022) defined ways to manage PM(T) substances based on the toxic free hierarchy presented in the "Chemicals Strategy for Sustainability Towards a Toxic Free Environment". Whenever possible, PM(T) substances should be prevented from entering the soil-sediment-water system. Refraining from using PM(T) substances in production processes and products is the most efficient way of preventing environmental and human health risks due to these substances. Even though prevention is preferable, it is not always possible and solutions for the identification through monitoring, risk assessment and treatment of PM(T) substances in the soil-sediment-water system are still required, especially in light of the PM(T) substances currently being used and already present in the environment. Based on this publication, we distinguish four systematic solutions in the DSF, namely prevention, monitoring, risk assessment and treatment.

The systematic solution prevention provides different measures that can be implemented to prevent the release of persistent, mobile and potentially toxic substances into the environment. The systematic solution monitoring gives information for diagnosing the condition of a potentially chemically polluted source. The systematic solution risk assessment can be applied when a potentially contaminated source has been confirmed to determine risk to humans and the environment. In addition it can also be used to evaluate the effectiveness of a treatment process or a prevention measure. Prevention measures are rarely 100% efficient. The systematic solution treatment provides remediation options for a confirmed polluted source.

Each solution type is clickable. The halo surrounding the four main solutions represents the boundary conditions for the implementation of these solutions related to governance, financial support and/or social perspectives. ***This halo is also clickable*** and redirects to the "co-created zero pollution strategies for the risk management of PM(T) substances" module (PROMISCES, 2025a) of the DSF. It should be noted that the systematic solutions "Prevention", "Monitoring" and "Risk Assessment" are the same for each circular economy (CE) route. The systematic solution "Treatment" differentiates between the CE routes. This means that for the systematic solution "Treatment", it is necessary to first choose one of the five CE routes before being directed to treatment options.

4.1 Prevention

Below is a proposal for the information to be included in the DSF for this solution type.

Prevention

This page offers different measures that can be implemented to prevent the release of persistent, mobile and potentially toxic (PM(T)) substances into the environment. It provides information on PM(T) identification, substitution, and additional scientific and technical solutions for preventing contaminants in specific routes based on the following four questions: 1) Is the substance persistent, mobile and/or toxic? 2) How and where is the substance used? 3) Are there alternatives for the substance? 4) What are other prevention methods besides substitution?

➢ **Question 1: Is the substance persistent, mobile and/or toxic?**

The diagnosis of potential PM(T) substances module can be used to support the identification of persistent, mobile, and toxic substances. It includes an (eco)toxicity-score based on the CLP criteria (EC, 2023). It also includes an emissions score, which can be useful for regulators or environmental managers by helping them to prioritize substances not only based on their P, M and T properties, but also on the expected volume of emissions. This may help to identify substances for which exposure is (expected to be) highest. Substances that occur as by-products should also be considered. The benchmark values used for the P, M and T score are explained in Deliverable D5.1 - Mapping of PM(T) concerns in EU (2024).

The results of the PM(T) identifier tool provide a prediction of potential PM(T)/vPvM properties. It should be noted that a low or high score is only a first indication that the substance is of potential low or high concern. Predicted scores should be used as a first screening step, which need to be followed by further investigation of these properties.

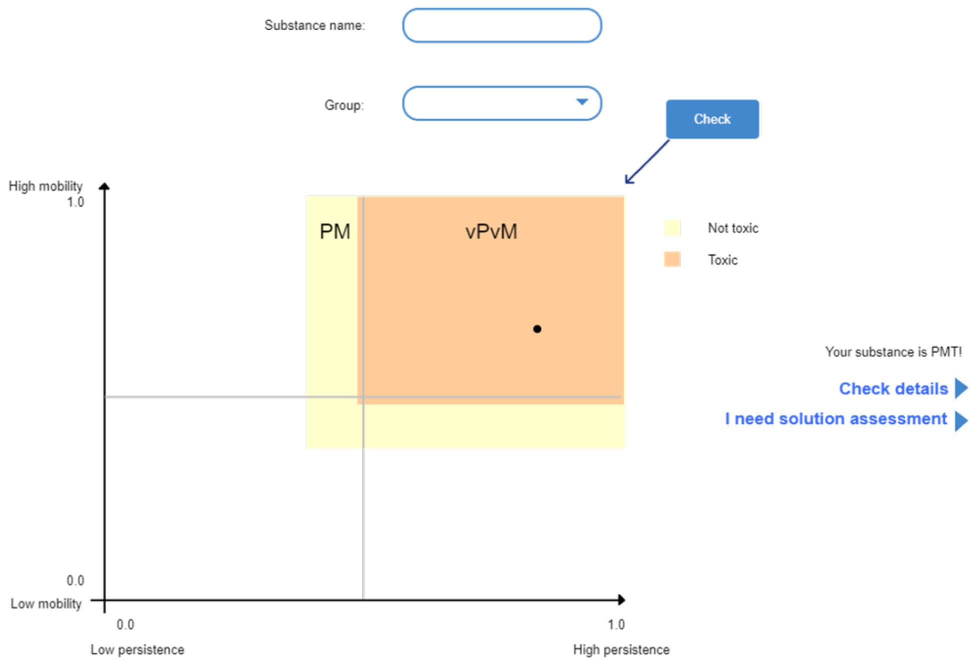


Figure 5 : Interactive plot of the DSF: PROMISCES PM(T) identifier tool.

If a substance is labelled as potential PM(T)/vPvM, the SimpleBox Aquatic Persistence Dashboard can be used to evaluate the time that a substance remains in the water phase and hence its tendency to flow downstream and eventually reach the ocean. The SimpleBox Aquatic Persistence Dashboard enables the user (exposure/risk assessor or policy maker) to screen the combined PM(T) properties of a substance as it directly indicates the timescale over which a chemical is anticipated to remain in surface water bodies. The tool is available in the zenodo repository (2024).

- **Question 2: How and where is the substance used?**

The DSF includes information on product categories in which substances are used (e.g. coatings and paints, or adhesives and sealants) and their sectors of uses (e.g. health services, or building and construction work) based on data registered in REACH.

The NORMAN Suspect List Exchange (2024b) and the Environmental Protection Agency Chemical and Products database (EPA CPDat) can provide information on the known or predicted use of the substance of interest. The NORMAN Suspect list provides information on the products in which the substance may be used. CPDat provides information on the functional use of the substance and is available through the CompTox Chemicals dashboard (2024). Inversely, the ChemSec PFAS guide (2023) can be used to identify whether sectors or products are likely to contain PFAS. Lastly, PubChem collects chemical information from multiple sources, including the NORMAN Suspect List and CPDat.

Most industrialised countries have inherited a long industrial past during which environmental concerns and constraints were not the same as they are today. At the time, there was little or no awareness of the consequences of product spills and pollution in the water, air and/or soil. This pollution, due to former waste deposits or the infiltration of polluting substances, is likely to cause a nuisance or a risk for people or the ecosystems on these sites. For groundwater and soil pollution, it may also be relevant to know where and when a substance was used in the past. Databases on soil and groundwater contamination and their relationship with past industrial activities may be available at national level.

For example, the French Ministry of the Environment has been listing polluted or potentially polluted sites and soils since the early 1990s. The data is available on the Georisques portal (2024).

- **Question 3: Are there substitutes for the substance?**

The PM(T) identifier tool enables smart decision-making by helping to compare alternatives and select substances for production processes and products that are safe-by-design. Substances that are considered PM(T) should be substituted if alternatives are available. Substitutions do not have to be chemical, but can also be an alternative product, technology or service. There are multiple platforms that can be used to find substitutes for substances. These can be distinguished into platforms that are searchable databases for specific substances, products and/or functional uses, and platforms that gather general information and case study reports on substitution.

Examples of databases on substitution:

- marketplace.chemsec.org (2024),
- ZeroPM Alternative Assessment Database - ZeroPM (2024).

Both these tools should serve as a starting point for deeper analysis. An effective substitution requires to assess whether the alternatives can be relevant in terms of performances and economically viable. Therefore, the specific goals and context of uses have to be known. The involvement of stakeholders with a detailed knowledge of the technical and economic criteria to be validated is therefore expected in order to carry out a more in-depth study[1].

When substituting one chemical with another, great care should be taken that this does not lead to regrettable substitution; e.g. the replacement with substances that have different or unknown hazards. The PM(T) assessment tool can be used to compare whether substances are (expected to be) less persistent, mobile, and toxic than the substance to substitute. This should be applied as a screening tool to select substances that are likely to be safer. For more detailed information and guidance on identifying safer alternatives for substances and examples of successful case studies, we recommend the following resources:

- INERIS substitution portal (2024),
- subsportplus.eu (2024),
- The Swedish Centre for Chemical Substitution | RISE (2024),
- OECD series on Risk Management of Chemicals (2024b).

- **Question 4: What are other prevention methods besides substitution?**
  - *Minimize release to the environment using Best Available Techniques*

If no suitable alternatives are available and the use of substances with PM(T) properties cannot be prevented, great care should be taken to avoid any emissions of the substance. Responsible use of PM(T) substances might be possible within closed-loop systems without any risk of emissions. Best Available Techniques (BAT) should be used to minimize risk of emissions. For some industrial sectors,

[1] *The economic viability of an alternative can be assessed from the point of view of a manufacturer who, for example, has to incur investment costs. But it can also be studied from the point of view of society, by integrating, for example, the positive externalities linked to the substitution of a dangerous substance. Interested readers may, for instance, refer to the dedicated page on the ECHA website or on the OECD website.*
ECHA. (2024). *Socio-economic analysis in REACH*. Retrieved 1-11-2024 from https://echa.europa.eu/support/socio-economic-analysis-in-reach.
OECD. (2024a). *The costs and benefits of regulating chemicals*. Retrieved 01-12-2024 from https://www.oecd.org/en/topics/sub-issues/risk-management-risk-reduction-and-sustainable-chemistry/the-costs-and-benefits-of-regulating-chemicals.html.

BAT reference documents (BREFs) have been established. These reference documents are available at BAT reference documents* (2024a) disclaimer, as of publication, PM(T) substances are not explicitly addressed in BATs.

- *Develop new substances using Safe and sustainable by design principles*

A framework has been developed to help the development of safer and more sustainable chemicals; called the Safe and Sustainable by Design (SSbD) framework. A methodological guidance (2024) is available on the website of the Publications Office of the European Union. In addition, a toolbox (2024) is available that collects tools and models for the purpose of SSbD.

Other tools and models that could be used for Safe and Sustainable by Design:

- A science-based innovative dashboard to operationalise Safe & Sustainable-by-Design (2024).
- *[Room for reference to relevant models in PROMISCES model ToolBox]*

- *Consider if the functional use or even product itself is essential*

Discussions on the exact definition of essential use, and how to best implement it, are still ongoing. However, if a safe or safer alternative for the PM(T) substance cannot be identified, it is worth considering as a user or producer of a PM(T) substance or product whether it is truly essential to use it. If the level of performance required or could it be relaxed? Does the functional use of the PM(T) substance significantly impact the performance of the product? And if so, to what extent is the product required for human health or the functioning of society?

So far, no EU legislation contains a definition of essential uses of substances. Nonetheless, the European Commission published a Communication in 2024 in order to elaborate on the concept and relevant criteria, and to guide its possible use. The communication is available in the web of the publication office of the European union[2](2024b).

According to the Communication, a use of a "most harmful substance" i.e. a PM(T) and/or a vPvM substance is essential for society if the following two criteria are met:

1) that use is necessary for health or safety or is critical for the functioning of society, and

2) there are no acceptable alternatives.

The communication provides examples of what can be considered as "necessary for health or safety" (e.g. if the use and the technical function of the substance is necessary to manage health crises and emergencies), as "critical for the functioning of society" (e.g. to provide services that must remain in service for society to function like ensuring the supply of energy), and as an "acceptable alternative". Nonetheless, this will be subject to further assessment.

[2] https://op.europa.eu/en/publication-detail/-/publication/90926c62-0365-11ef-a251-01aa75ed71a1/language-en

4.2 Monitoring

The monitoring solution type entails a database that includes both the monitoring data of the PROMISCES case studies as well as data from NORMAN EMPODAT Database - Chemical Occurrence Data (2024a). Data collection templates in excel that were developed by NORMAN are used for importing the PROMISCES case studies data into EMPODAT. These data collection templates (DCTs) can be downloaded at https://www.norman-network.com/nds/empodat/downloadDCT.php. EMPODAT is a database of geo-referenced monitoring and bio-monitoring data on emerging substances in the following matrices: water, sediments, biota, suspended particulate matter (SPM), soil, sewage sludge and air. Table 4 gives an overview of the matrices that are relevant to the CE routes represented within the PROMISCES project. Data from EMPODAT with the matrices presented in Table 4 are automatically downloaded to a local server, processed and then uploaded into the DSF monitoring module via an API. Most PROMISCES monitoring data are also included on the Zenodo platform.

Table 4: Matrices of the EMPODAT database that are relevant for the circular economy (CE) routes of the PROMISCES project.

	Circular economy route				
Matrices	A	B	C	D	E
Surface water	✓	✓	✓	✓	✓
Groundwater	✓	✓	✓	✓	✓
Waste water	-	✓	-	-	-
Sediments	-	-	-	✓	-
Sewage sludge	-	-	✓	-	-
Soil	✓	✓	✓	✓	✓
Biota	-	-	-	-	-
SPM	-	-	-	-	-
Air	-	-	-	-	-

Below marked with a dotted vertical left border a proposal for the information to be included in the DSF for this solution type is shown. In this proposal we also refer to different deliverables that are still under construction.

Disclaimers:

- The content of question 1 has been seen and approved by WP5. This includes the decision of incorporating the NORMAN database through an API.
- The content of question 2 has been seen and approved by the first-authors of Deliverable 2.3 “Toolbox Fate & Transport modelling” and D2.4 “Guidance Document on Emission Fate and Transport”.
- The content of question 3 has been seen and approved by case study leaders 2,3 and 4 as *Deliverable 1.7* (2025c) is still under development.
- The content of question 4 and 5 is based on their respective deliverable.

Monitoring

The information supplied on monitoring in this section complies with relevant EU directives, strategies and action plans at the time of writing (December 2024). An overview of the current regulatory context, challenges and identified needs is available in *Deliverable 5.8 Modular recommendations for evaluation and implementation of relevant EU directives, strategies and action plans* (2025).

This page provides information for diagnosing the condition of a potentially chemically polluted source. This entails setting up a characterisation monitoring program for the reliable assessment of water, soil and sediment quality and can be based on the following questions: 1) Which substances are you interested in?, 2) Which models are available for complementing monitoring data in the prediction of the fate of substances of interest in the environment?, 3) Which factors are important to include in your sampling strategy for selected substances? 4) Which analytical chemistry methods exist for analysing PM(T) substances? and 5) Which biological methods exist for analysing complex mixture effects of PM(T) substance?

- **Question 1: Which substances are you interested in?**

This section gives an overview of the most frequently monitored substances, their average concentration levels in different matrices and detection frequency, which can be helpful when it is not clear which substances to include in a monitoring program. This section can also help to benchmark data to what is already available in the EMPODAT database. The occurrence data can be assessed in connection to the sector in which a substance is used [Link to Question 2 of the Prevention Module]. Nevertheless, if available, local information on how a substance is used should always be prioritized.

Below, a visual overview of target chemical monitoring data from the NORMAN EMPODAT Database (2024a), - Chemical Occurrence Data (norman-network.com) is provided. The concentration plot shows the substances with highest median concentration across the monitored matrices. A maximum of 20 substances is shown. The substances shown in the concentration plot are also visualized in the frequency plot. The full dataset behind the visualisation (not only the 20 highest) can be downloaded. On the concentration plot a single substance and/or a single matrix can be selected to zoom in. This zoomed-in effect is directly displayed in the frequency plot and in the database below. For a specific sample, it is possible to click on the sample ID and all the background information will be displayed.

- *Target chemical monitoring data*

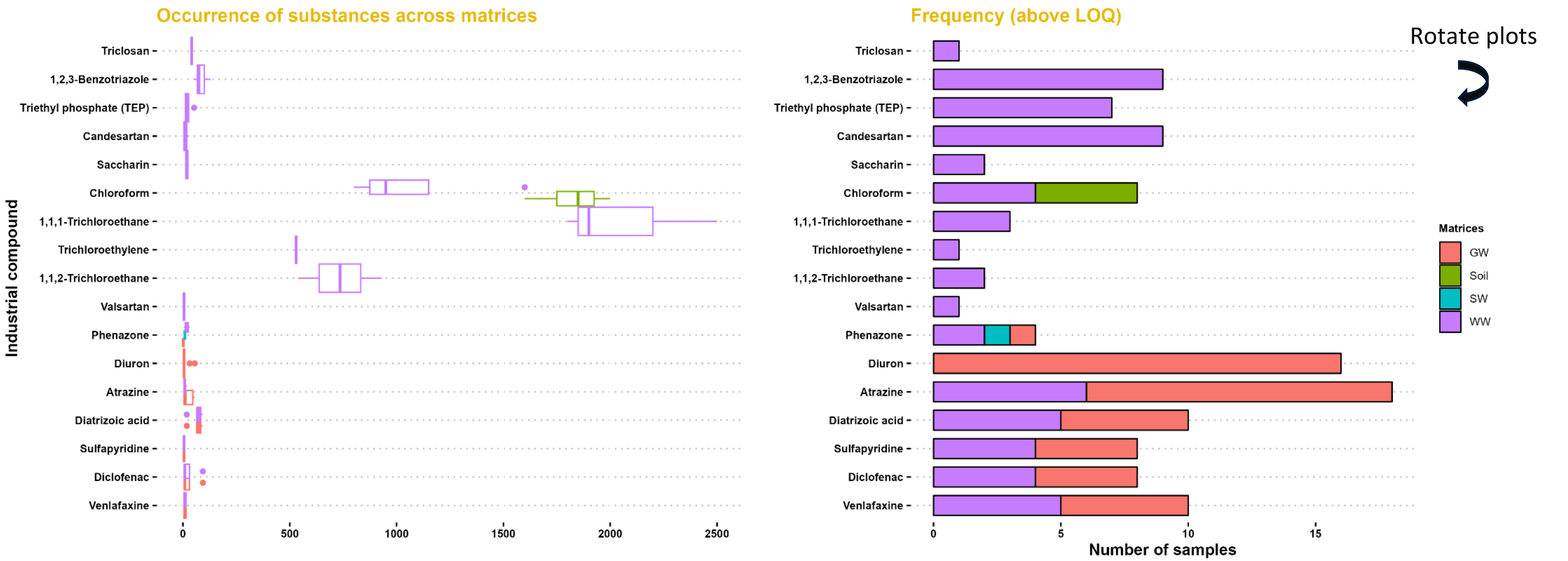


Figure 6 : Example of interactive DSF plot: Monitored concentrations in the Norman Empodat database (left) and detection frequency above LOQ. Data from Norman was downloaded on the 12th of June for the selected matrices

Remark: *You can click the boxplots in the concentration plot (on the left) to zoom into an individual substance of interest or on the different matrices presented in the legend. The corresponding frequency information for your selection will be shown in the Frequency plot (on the right). You can also change the rotation of this figures. The information shown below in the database is directly connected to the selection that you made in the concentration plot. For example if you click on the highest boxplot in the concentration plot you will zoom into information regarding the concentration (left plot) and frequency (right plot) of 1,1,1-Trichloroethane across several matrices. If you're interested in one matrix you can select it in the legend on the right side.*

The database can be used to visualize a selection using the three filters indicated with a symbol ( ): individual compound, CAS and sample matrix.

WHAT IS SELECTED IN THE PLOTS IS SHOWN IN THE TABLE BELOW

Individual compound	Cas No.	Sample Matrix	Sample matrix type	Concentration [ng/L]	Sampling date dd-mm-yy	Limit of detection	Limit of quantification	T [Celsius]	pH	Station name and codes	Data source

- *<u>Suspect and/or non-target chemical monitoring data</u>*

Currently the DSF focuses only on target chemical monitoring data. However, it is possible to include suspect and even non-target screening data in the monitoring dataset (after downloading the target chemical monitoring data selected in the previous section onto the local computer). Suspect and non-target screening is increasingly used in addition to target monitoring to improve the identification of contaminants of concern, particularly less-investigated substances, restricted, or compounds for which the standards are not commercially available or too expensive. For each detected suspect compound, the data can be provided as semi-quantified concentrations with a level of confidence of identification of the substance, from 1 (confirmed with analytical standard) to 5 (mass of the compound matches) as described in Schymanski et al. (2014). With the addition of this information, the target and suspect screening monitoring data can be exploited in an integrated, complementary assessment workflow as described in Dulio et al. (2024). Purchase or synthesis of standards for full confirmation can be decided subsequently based on the relevance of the identification, e.g., frequency of detection (above LOQ), peak intensity and/or potential ecological or toxic effect. In this way, it is possible to obtain a comprehensive overview of the chemical profile beyond target analysis.

➢ **Question 2: Which models are available for complementing monitoring data in the prediction of the fate of substances of interest in the environment?**

It is often practically impossible or simply too costly to monitor the exposure of all substances of interest in the environment at all times, and/or all exposure pathways and routes always and everywhere. This section provides with fate and transport models that can be used to complement monitoring data, refine monitoring schemas and assess potential future developments. The outcomes of these models can also help designing a sampling strategy in terms of selection of critical locations, sampling frequency, time points and sampling matrix.

Within the PROMISCES project four types of fate and transport models where developed/optimized to calculate contaminant concentrations in the environment at a given location and at a given point in time i.e.:

- Screening level models for assessment of regional exposure of groundwater from soil pollution and for assessment of general exposure of air, soil and water on a local, regional or global scale,
- Spatial and temporal explicit models for the identification of pollution plumes from contaminated soil in groundwater.
- Emission-models on urban to catchment scale to identify sources and pathways of chemicals and relate them to instream concentrations.
- In context of model trains these emission models have been connected to ground water models identifying the transport and fate of contaminants during bank filtration form rivers to water abstraction for supply.

A toolbox for these four types of fate and transport models of persistent, mobile and potentially toxic substances (PM(T)) in the environment is provided by the PROMISCES-project in *Deliverable 2.3 Toolbox Fate & Transport modeling* (in preparation). A guidance for applications of these four types of models is available A guidance for applications of these four types of models is available in *Deliverable 2.4 Guidance Document on Emission Fate and Transport* (in preparation). This guidance document explains the basic concepts of specific model and how these models can best be used in model trains in a tiered way. This means, explanations of applications of a combination of standalone models to cover complex situation including several environmental spheres such as atmosphere, lithosphere, hydrosphere, biosphere, and anthroposphere and their interfaces.

➢ **Question 3: Which factors are important to include in your sampling strategy?**

In this section different types of methodologies and lessons learned from PROMISCES when it comes to sampling strategies are highlighted based on *Deliverable 1.7 Implementing of monitoring strategies including new approaches and feedbacks* (in preparation). It includes information on:

- Selection of sampling locations
- Designing sampling strategy keeping in mind the representativeness of the sample and heterogeneity. This includes sample size and sampling frequency and the selection of the sample matrix of interest. For statistical analysis ideally both field and laboratory studies should include at least three replicates and should also include field and laboratory blanks.
- Execution of sampling event in such a way that any contamination from any material (e.g. Tubing Sealing, O-rings) is avoided.
- Transportation of field samples to the laboratory.
- Storing of samples until analysis.

➢ **Question 4: Which analytical methods are available for analysing PM(T) substances?**

Several different approaches are required to cover PM(T) analysis in various sample matrices such as drinking water and groundwater. Due to potential direct exposure to humans, the methods for these matrices may be most relevant for monitoring by authorities. Within the PROMISCES project in total sixteen analytical methods have been developed/adapted for the detection of PM(T) substances, respectively four for industrial PM(T)s, ten for PFAS and two for global organic fluorinated content.

The reported methods respond to the needs observed in PROMISCES case studies (*https://PROMISCES.eu/Project/Case+Studies.html*). The target compounds analysed in each case have been selected based on previous suspect screening methods, knowledge of local activities and stakeholders, and/or previously reported data.

Their design and experimental conditions are marked by the physical-chemical properties of the targeted compounds, the instrumentation available, the matrix under study and the required analytical performance, primarily in terms of limits of quantification (LOQs) that should be ideally lower than the corresponding predicted no-effect concentrations (PNEC).

This paragraph is intended to help select appropriate analytical methods for industrial PM(T), global organic fluorinated content and PFAS analysis. Note that the proposed methods can give an indication of the relevant methods depending on the substance/matrix of interest.

- *Four analytical methods for (i)PM(T)*

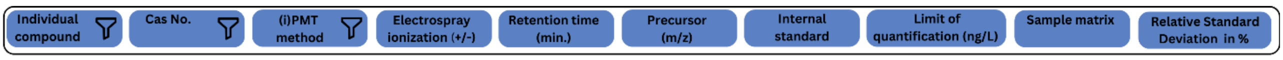
The four methods detailed in this section cover 84 different (i)PM(T)s and four different types of matrices. Below a comparative summary of the four (i)PM(T) methods is presented.

Table 5: Interactive table of the DSF: Comparative summary of all industrial PM(T) methods.

	BAFG	**BWB**	**CSIC 1**	**CSIC 2**
Matrix	Surface water	Drinking, ground, surface water, wastewater	WWTP effluent	Groundwater
Separation	UPLC	UPLC	UPLC	GC$^{\alpha}$
Analyser	Triple quadrupole	Orbitrap (HRMS)	Q-TOF (HRMS)	Single quadrupole MS
Sample preparation	Direct injection	Online-SPE	On-line SPE	PT
# PMTs analytes	26	21	42	59
# Internal standards	16	8	22	3
LOQ (ng/L)	1-200	12 – 369	0.02 - 321	8.4-6400

$^{\alpha}$used particularly for chlorinated solvents and other volatile organic compounds (VOCs) in groundwater samples.

Search for individual compounds will be possible using the three filters indicated with a symbol (): individual compound, CAS and ESI.



Further details for each method are available in *Deliverable 1.2 Targeted methods for industrial PM(T)* (2023).

- *Ten analytical methods for PFAS*

The ten methods detailed in this section cover 57 different PFAS and 12 different types of matrices. Below a comparative summary of the ten PFAS methods is presented.

Table 6: Interactive table of the DSF: Comparative summary of the ten PFAS methods.

	ACEA_1	ACEA_2	BRGM_IPGP_1	BRGM_IPGP_2	BWB_1	BWB_2	CSIC_1	CSIC_2	TU Wien_1	TU Wien_2
Matrix	Sediment, sludge	Leachate, concentrate, liquid waste	Drinking water, Ground water, WWTP effluent, process water	Sediment, soil, sludge	Drinking water, ground water	Surface water, wastewater	Drinking water, ground water, WWTP in- & effluent, process water	Sediment, soil, sludge, lettuce	Aqueous matrices	Sludge, sediment
Separation	UPLC	UPLC	UPLC	UPLC	UPLC	UPLC	UPLC	UPLC	HPLC	HPLC
Analyser	Triple quadrupole	Triple quadrupole	Triple quadrupole	Triple quadrupole	Triple quadrupole	Orbitrap (HRMS)	Orbitrap (HRMS)	Orbitrap (HRMS)	Triple quadrupole	Triple quadrupole
Sample preparation	Ultrasonic extraction w/ MeOH Sediment: concentrate	Dilution w/ H_2O+MeOH Washing water, permeate: DI	(DI)	(DI)	1:1 MeOH dilution Optional auto-SPE	Online-SPE	SLE	SPE	Solid: Online-SPE (Aqueous: DI)	Sludge: Ultrasonic extraction
# PFAS analytes	30	30	56	56	30	27	29	29	34	34
# extracted internal standards	1					19	20	20	24	24
# non-extracted internal calibration standards	19	19	22	22	19		2	2	7	7
Limit of quantification in ng/L		15 - 75 (washing water, leachate) 1000 - 10000 (liquid waste)	15 - 100 (process water, WWTP effluent) 2 - 15 (groundwater, surface water)		1 - 5 (0.01 - 0.05 w/ automated SPE)	25 - 100	0.13 - 5.44 (surface water) 0.15 - 12.40 (effluent water) 0.69 - 49.60 (influent water)		1 - 10	
Limit of quantification in µg/kg	10 - 50 (sludge) 0.050 - 0.250 (sediment)			0.040 - 0.300 (soil) 160 - 1200 (sludge)				0.13 - 4.96 (sediment) 0.04 - 9.92 (lettuce)		0.1 - 0.5 (soil) 1 - 20 (sludge)

It will be possible to search for individual compounds using the three filters indicated with a symbol ( ): individual compound, CAS and ESI.

Further analytical details of the ten PFAS methods above are available in [*Deliverable D1.1 - Methods for PFAS in waters and complex matrices*] (2024).

- *Two analytical methods for global organic fluorinated content*

Two analytical approaches for assessment of global organic fluorinated content for relevant matrices include Total Oxidizable Precursor (TOP) assay and Combustion Ion Chromatographic (CIC) approaches. In the table below, a comparative summary of these two methods presented.

Table 7: Interactive table of the DSF: Two prominent analytical approaches for assessment of global organic fluorinated content.

	TOP assay		CIC approaches	
Matrices	TUW	BRGM	BRGM	BWB
Waters (surface and groundwaters)	x	x	x	x
Waste water Effluent	x	x	x	
Waste water Influent	x			
Landfill leachates			x	
Sludge		x	x	

Analytical details including the validation of the methods and their limitation are available in *Deliverable 1.3 Methods for global organic fluorinated content (TOP, TOF/AOF/EOF) for relevant matrices* (2024).

- **Question 5 : Which biological methods are available for analysing complex mixture effects of PM(T) substances?**

Currently, chemical hazards are typically assessed by targeted chemical analysis. However, this approach fails to account for the complex mixture effects of the many chemicals potentially present in water supplies and omits the possible effects of non-targeted chemicals. In this paragraph the methodology of effect-based monitoring using existing and improved in vitro CALUX bioassay testing combined with in silico toxicology is proposed. It is worth noting that this tool is a toxic-free way of testing for safer and sustainable PFAS alternatives for a green environment. This tool is complementary to targeted and non-targeted chemical analysis and covers a large variety of different key events in toxicology in a time- and cost-efficient way. Briefly, the in vitro bioassay groups addressed 40 PFAS compounds (e.g. including all regulated 20 PFAS) and industrial standards (e.g., ADONA, GenX) with a combination of a wide range of CALUX bioassay endpoints and additional general toxicity in vitro bioassays. Additional up to 22 industrial PM(T) chemicals have been tested with a combination of a wide range of CALUX bioassays and additional general toxicity in vitro. This combined approach resulted in potency factors of a handful of PFAS/ industrial PM(T) for several vitro bioassays by two bioassay laboratories involved in the PROMISCES project and can be applied to other PFAS/industrial PM(T) substances. Further details regarding the methodology and its validation are available in *Deliverable 1.5 Set of novel QSAR models/grouping/read-across and in vitro bioassay approaches predicting relevant toxicological endpoints for PFAS/PM(T) chemicals* (2024).

4.3 Risk assessment

The systematic solution risk assessment provides information on risk assessment of environmental matrices for specific circular economy routes, as studied within the PROMISCES project. This means that after a general introduction of the systematic solution risk assessment the user will first have to choose one of the five CE routes. The systematic solution risk assessment is coupled to the database of the systematic solution type monitoring. Thus, it also includes both the monitoring data of the PROMISCES case studies as well as data from NORMAN EMPODAT Database - Chemical Occurrence Data (norman-network.com).

Risk assessment

This section aims to provide guidance on the assessment of risks of PM(T) substances in environmental matrixes and circular economy routes based on the following four questions: 1) Are limit values available for my substance based on European legislation? 2) What are the concentrations found in the environment for my substance?,) 3) What if no legal limits or HBGVs are available for my substance?, 4) How could I determine the risk for human health of a specific circular economy route?, 3and 5) How can I determine the risk of a mixture of known and unknown substances?

When using the information below it is important to acknowledge the difference between health-based guideline values (HBGVs) on the one hand and legal limits for substances in specific matrices on the other. The former is the chemical concentration that is not expected to result in any significant risk to human health, whereas in the derivation of legal limits other considerations are also taken into account such as technical and economic feasibility. Therefore, compliance with legal limits does not necessarily mean zero risk. Furthermore, especially when it comes to PFAS, legal limits differ between countries, matrices and context and might change in the near future. Also, different HBGVs have been derived for PFAS based on differences in toxicological information used as well as different mixture risk assessment approaches.

In relation to the protection of the chemical status of water bodies, and thus human and environmental health, this section includes information on Environmental Quality Standards (EQS) from Directive 2000/60/EC (the Water Framework Directive). EQS are tools used for assessing the chemical status of waterbodies. See for more information also the technical guidance on deriving EQS (2017). Finally, it should be noted that, while this section provides guidance on the risk assessment of environmental concentrations of substances, the evolution of these concentrations and thus the potential associated risk very much depends on the physical-chemical properties of that substance. Therefore, it is strongly suggested, when using the information provided in this section, one should not forget about these intrinsic properties of the chemical. For example, it's persistence in the environment. See also Cousins et al. (2019) for further reading on why persistence alone might be a major cause for concern.

- **Question 1: Are there limit values available for my substance based on European legislation?**

The appropriate limit value may depend on the specific circular economy route, product, and or application. Furthermore, a specific country might have implemented a stricter limit then required based on European legislation. This is for example the case for the limit for PFAS in drinking water in Denmark. Directive (EU) 2020/2184 for the quality of water intended for human consumption requires Member States to implement one of the following two limit values in national legislation: 100 ng/L for 20 PFAS or 500 ng/L for the sum of PFAS. In June 2021, Denmark implemented, following a recommendation from the European Food Agency (EFSA) a stricter limit for PFAS in drinking water, namely 2 ng/L for the sum of PFOA, PFOS, PFNA and PFHxS. The DSF does not provide an exhaustive overview of limit values on the national level. Limit values from European legislation will be used as default, but the user may overwrite this default value with the appropriate national limit value.

For an overview of current (proposed) limit values for PFAS in food, surface water, groundwater and drinking water in Europe, we refer to Table 1 of Reinikainen et al. 2024. For other industrial PM(T) substances consult the:

- Directive - 2000/60 - EN - Water Framework Directive - EUR-Lex
- Directive - 2006/118 - EN - Groundwater Directive - EUR-Lex
- Directive - 2013/39 - EN - Priority Substances - EUR-Lex
- Directive - 2020/2184 - EN - Drinking Water - EUR-Lex
- EUR-Lex - 52022PC0541 - EN - Urban Waste Water Treatment Directive - EUR-Lex
- Directive (EU) 2024/3019 of the European Parliament and of the Council of 27 November 2024 concerning urban wastewater treatment (recast)
- Regulation - 2020/741 - on minimum requirements for water reuse- EN - EUR-Lex

➢ **Question 2 What are the concentrations of my substance found in the environment?**

The tool below can be used to screen whether any information is available in the NORMAN EMPODAT Database on the occurrence of a specific substance in a specific compartment of interest, and how it compares to a regulatory limit value. It is possible to enter the regulatory limit values included under question 1 or provide the limit values applicable to a specific context.

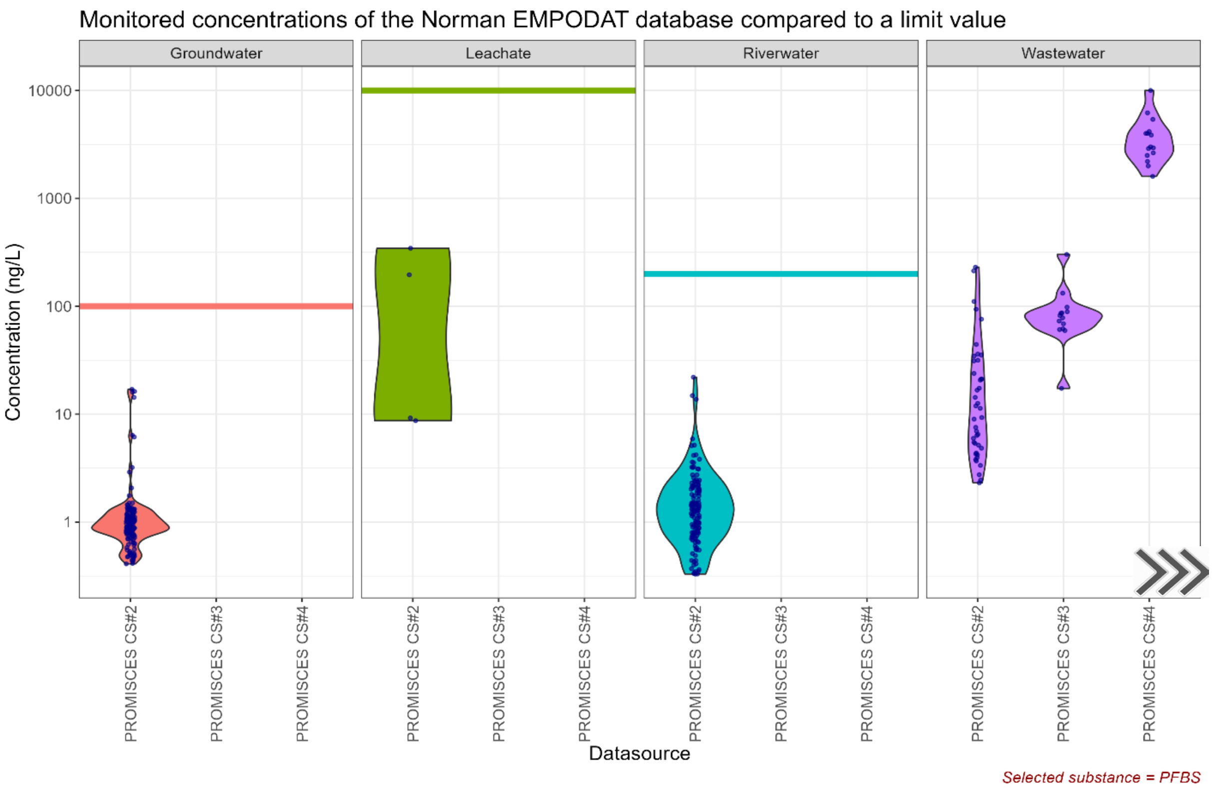


Figure 7 : Example of interactive DSF plot: Monitored concentrations of PFBS compared to a limit value.

- **Question 3: In case no regulatory limit values or HBGVs are available for my substance how can the risk be determined in a specific medium and for a specific use?**

For screening purposes, the NORMAN ecotoxicology database provides information on the lowest Predicted No Effect Concentrations (PNECs) of over 90.000 substances. These are indicative for the impact on the ecosystem, and are available for freshwater, marine water, sediments, freshwater biota (fish), marine biota (fish), freshwater biota (molluscs), and marine biota (molluscs). For screening purposes, the "Lowest PNECs (2024a)" from the NORMAN ecotoxicology database can be used as a preliminary threshold in the figure under question 2. Also, within PROMISCES, an artificial intelligence/machine learning-based model to predict the aquatic toxicity of organic compounds in general was developed and validated. The quantitative machine learning model is able to predict the aquatic toxicity of PFAS compounds for different species. The developed model predicts PFAS better after transfer learning, especially when equally weighting PFAS and non-PFAS to get better predictions for PFAS. Further details pertaining the model are available in *Deliverable 2.1*.

- **Question 4 : How can I determine the risk to human health?**

The PROMISCES project has developed a risk-based human health exposure assessment (HHEA) model to enables users to estimate the concentration of a particular substance along a process chain. The model is probabilistic, which allows users to estimate exposure even when exact removal rates in a process are uncertain or unknown. The output is a distribution of predicted concentrations in the end product, which is compared to a HBGV. The thresholds are supplied by the model. An overview of the reference values used in the HHEA model is available in zenodo repository (2024).

The HHEA model covers the CE routes A, B, C and E. Thereby excluding CE route D titled "Material recovery from dredged sediment for eco-materials".

A. Nutrient and energy recovery from treated sludge for fertilizers

B. Wastewater reuse for agricultural irrigation

C. Semi-closed water cycle for drinking water supply

E. Groundwater and soil remediation to protect the water cycle

- **Question 5: How can I determine the risk of both, known and unknown substances in my matrix?**

Matrixes contain a combination of multiple known and unknown substances. When the composition of the mixture is unknown, effect-based methods can be applied to determine the risk of a mixture of substances. Effect-based methods rely on the application of specific bioassays to determine the whole-mixture potency of a sample. This can be utilized to determine the relative potency of a sample, e.g. to compare to a reference, between locations, or compare potency before and after treatment. To determine the risk with effect-based methods, a bioassay specific effect-based threshold (EBT) should be defined and used. An overview of existing assays, EBT, and guidance how to derive EBTs is provided in the Technical Proposal for Effect-Based Monitoring and Assessment under the Water Framework Directive of the EU Working Group Chemicals (2021).

To be most informative, bioassays with relevant toxicological endpoints should be chosen for which the substances of interest are both sensitive and specific. If unknown, QSAR modelling can be applied to predict relevant toxicological endpoints based on substance structure. For PFAS substances monitored within the PROMISCES project the TTR-TR CALUX bioassay has proved to be the most suitable. The TTR-TR CALUX is an assay for the disruption potential of thyroid hormone transport. For more information, see PROMISCES *Deliverable 1.5 Set of novel QSAR models/grouping/read-across and in vitro bioassay approaches predicting relevant toxicological endpoints for PFAS/PM(T) chemicals*.

4.4 Treatment

The information for the solution type "treatment" will be different per CE route. This means that after a general introduction of the systematic solution the user will first have to choose one of the five CE routes before being directed to treatment options.

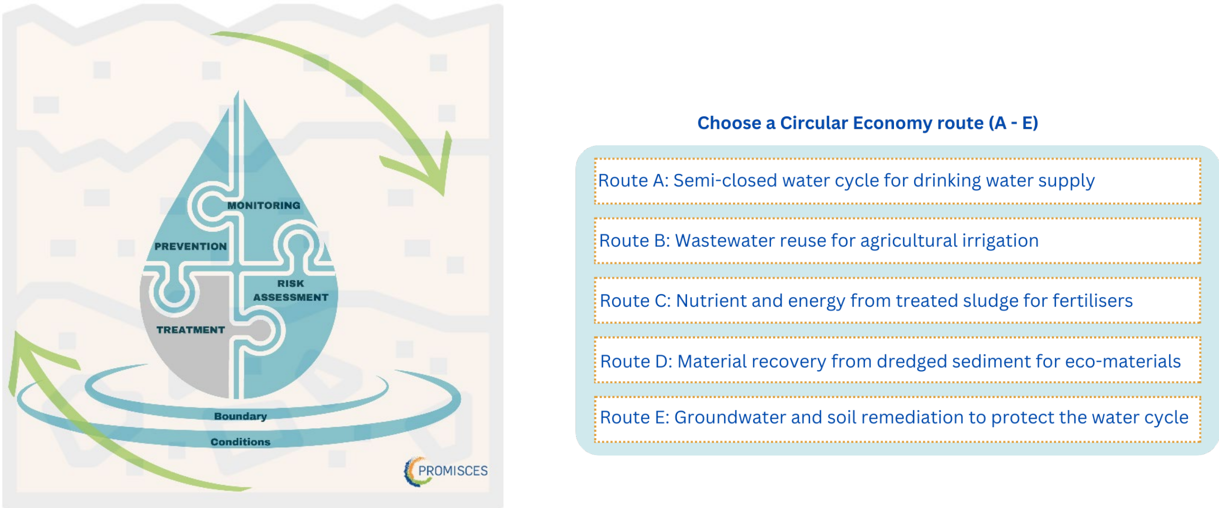


Figure 8 : Interactive plot of the DSF: Selection of a CE route before being directed to treatment options.

It is still under discussion whether a database is needed for this solution type. At this moment, we believe that the information provided will be plain text, with links to relevant data sources (e.g. the GitHub where the Human Health Exposure Assessment Model, or HHEA model, designed by KWB is stored, which is related to D2.5 and zenodo where the factsheets will be stored individually). Information on the evaluation of the developed treatment solutions will be on technical aspects as well socio-economic details.

The following information will be shown for the relevant CE route:

- Under question 2:
  - Information on the evaluation of remediation technologies developed in PROMISCES (WP3-4) and a comparison of these developed technologies with existing ones by presenting their advantages and disadvantages (from a technical, economic and environmental point of view).
  - Information on how bioassays can be used to assess the effectivity of a treatment (based on information provided by BDS).
- Under question 3: Information on the efficacy of the developed treatment, based on the HHEA model in zenodo repository (2024).

Below, marked with a dotted vertical left border an example of the information to be included in the DSF for this solution type is shown.

Treatment

This page provides information for treating a chemically polluted source. This entails setting up an efficient treatment for the recovery of a chemically polluted water, soil or sediment source and can be based on the following questions: 1) What is the target media of your chemically polluted source?, 2) How can different treatment technologies be compared?, and 3) How can knowledge gaps on substance removal, transport and fate be overcome to evaluate the effectivity of a treatment?

➢ **Question 1: Which treatment technology is available for your target media?**

In the table below, it is possible to select the target media of interest for this CE route. Once the target media has been selected, all the available technologies are displayed. Details about each technology can be downloaded from the zenodo repository by clicking the download icon in the last column named "Factsheet".

Table 8: Interactive table of the DSF: Available technologies for the selected CE route.

TARGET MEDIA	TARGET POLLUTANTS	TECHNOLOGY ID-NUMBER	TECHNOLOGY	TRL	CATEGORY	FACTSHEET
SOIL	PFAS	1	In situ non-newtonian fluid flushing / removal for soil contaminated by aqueous firefighting foam	*tbd*	Separation – physical Destruction – biological Concentration - physical	
SEDIMENT	PFAS	2	Mobilization – sediment washing – ultrasonic cavitation of sediment washing solution	*tbd*	Separation – physical Destruction - chemical	
LANDFILL LEACHATE, WATER	PFAS, other iPMTs	3	Membrane filtration (nanofiltration, reverse osmosis)	*9*	Separation – physical Concentration - physical	
LANDFILL LEACHATE	PFAS	4	Plasma	*tbd*	Destruction - chemical	
LANDFILL LEACHATE CONCENTRATE, SEWAGE SLUDGE	PFAS	5	Co-pyrolysis of membrane concentrates and sewage sludge		Destruction – physical, chemical	
WATER	PFAS	6	Foam fractionation	*tbd*	Separation – physical	
WATER	PFAS, other iPMTs	7	Plant uptake (wetlands)	*6*	Separation – physical Destruction – biological	
WATER	PFAS, other iPMTs	8	Adsorption to media (carbon (granular and powdered), anion exchange, surface modified clay)	*tbd*	Separation – physical	
WATER	PFAS	9	Ultrasonic cavitation	*tbd*	Destruction - chemical	
WATER	PFAS	10	Cold atmospheric plasma	*tbd*	Destruction - chemical	
WATER	PFAS	11	Activated persulfate with ferrate	*tbd*	Destruction - chemical	
WATER	PFAS, other iPMTs	12	E-peroxone based electrochemical advanced oxidation process (EAOP)	*6*	Destruction - chemical	
WATER	PFAS	13	DMSO and sodium hydroxide on concentrate	*tbd*	Destruction - chemical	
WATER	PFAS, other iPMTs	14	Ozonation	*tbd*	Destruction - chemical	
WATER	PFAS, other iPMTs	15	Fungi	*tbd*	Destruction – biological	
WATER	PFAS, other iPMTs	16	Bacteria	*tbd*	Destruction – biological	

➢ **Question 2: How can different treatment technologies be compared?**

Selecting one or multiple treatment technologies to apply should depend on both the effectiveness and sustainability (e.g. environmental impact, social aspects). Ideally, the decision for a specific technology should be based on detailed exposure and risk assessments (see systematic solution Risk Assessment) and a comparison of lifecycle assessments (LCA). However, these are often not available, especially at an early technology readiness level (TRL). Four critical aspects are identified within the PROMISCES project as key factors for assessing the effectivity of a treatment, namely remediation yield, energy consumption, cost and environmental evaluation. These factors are often available at lower TRL levels, and can be applied to compare technologies at a screening level. Because these factors can change during the development of a technology, we advise comparing technologies of a similar TRL. The statistics surrounding these four factors are displayed below for this CE route. More details of the technologies are available in the factsheets (under question 1 of this systematic solution).

The UPWATER project developed a generic framework to compare treatment technologies from an economic, ecological and technical perspective as part of a multi-criteria decision. The evaluation methods are outlined in [DELIVERABLE D5.1 UPWATER Assessment Framework (2023)].

------interactive plots here ----------- (as an example for this report CE route C: Nutrient and energy recovery from treated sludge for fertilizers was chosen).

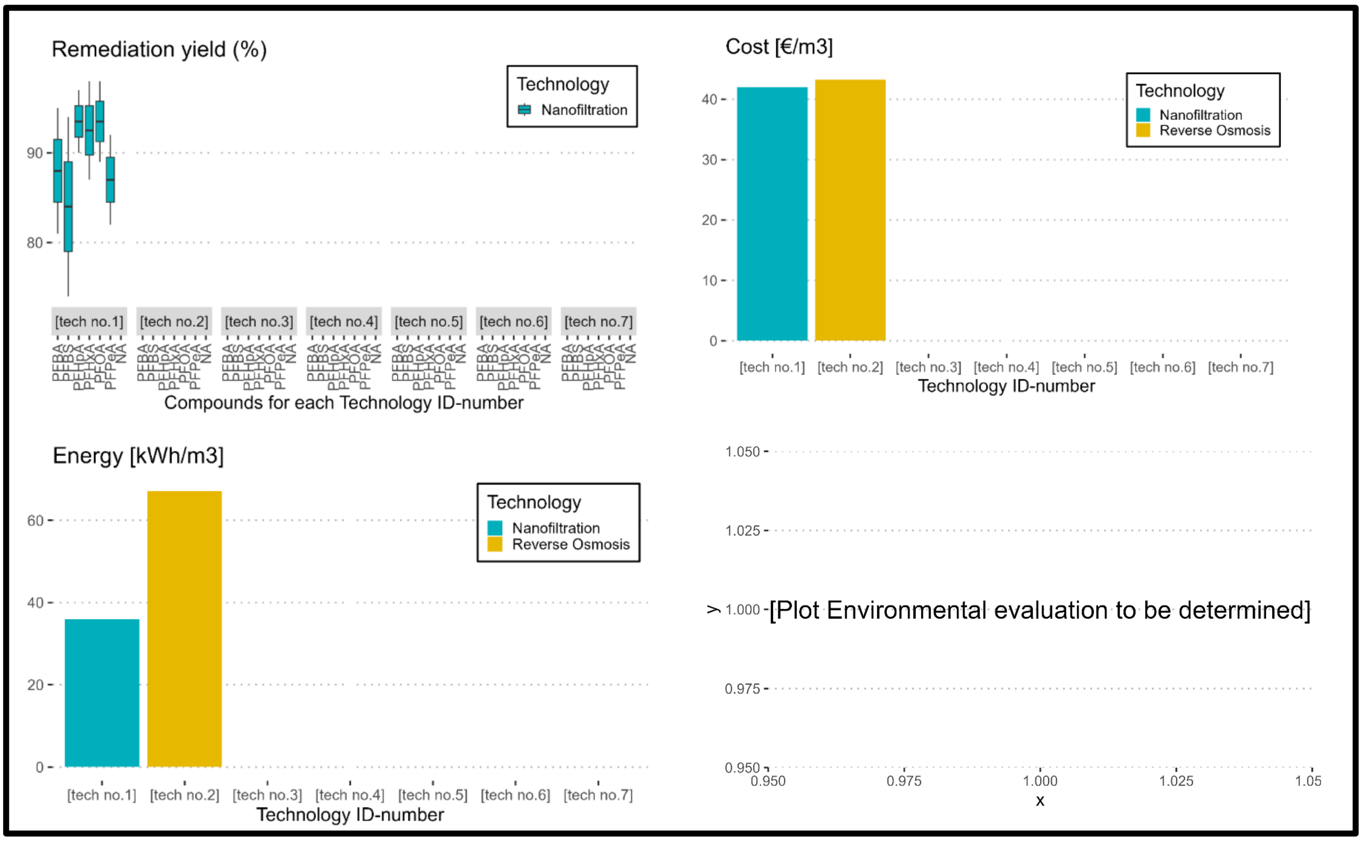


Figure 9 : Interactive plot of the DSF: Key factors for assessing the effectivity of a treatment, namely remediation yield, energy consumption, cost and environmental evaluation.

- **Question 3: How can knowledge gaps on substance removal, transport and fate be overcome to evaluate the effectiveness of a treatment?**

Assessments of entire exposure routes are hard to conduct, due to missing information on substance removal, transport and fate. To overcome these knowledge gaps and identify the most effective treatment for a chemically polluted source, the PROMISCES project has developed a risk-based human health exposure assessment (HHEA) model for the risk assessment of specific circular economy (CE) routes. The model enables users to estimate the concentration of a particular substance along a process chain. The model is probabilistic, which allows users to estimate exposure and risk even when exact removal rates in a process are uncertain or unknown. An overview of the HHEA model is available in zenodo repository (2024).

Disclaimer: The HHEA model covers the CE routes A, B, C and E. Thereby excluding CE route D titled "Material recovery from dredged sediment for eco-materials".

5 Application of the solution assessment module of the DSF

In this chapter, where relevant, we provide examples of how the Solution module can be applied to find solutions for the five preselected substance-use combinations presented in chapter 2. The purpose of the examples is to guide users in using the Solution module.

5.1 Application of the systematic solution prevention

As mentioned in chapter 4, solution type "Prevention" is the same for each circular economy (CE) route. Hence, the examples given in this section are independent of a PROMISCES CE route. The examples are not fictional, but should not be seen as an endorsement of any mentioned alternative.

The PM(T) assessment tool is included in the web-version of the DSF. It will be possible to use the tool online. The five selected substances-uses of this report will be shown by default. Ideally the user can select more than one substance at the same time and receive the PM(T) scores in an overview table as Table 9 and/or visually with multiple points.

Table 9: Overview of PM(T) and emissions scores of the 5 selected substances and Galaxolide (precursor of Galaxolidone). The PMT scores were retrieved on the 28th of November 2024 from the DSF.

Name	CAS no.	PM(T) classification (conservative)**	P-score (conservative-average-robust)	M-score (conservative-average-robust)	T-classification based on CLP criteria
PFBS	375-73-5	vPvM	0.93-0.51-NA	0.51-0.45-NA	Non-toxic
6:2 FTS	27619-97-2	vPM(T)	0.93-0.34-NA	0.34-NA-NA	Toxic
PFBA	375-22-4	vPvM(T)	0.93-0.51-NA	0.51-NA-NA	Toxic
Diethyl phthalate	84-66-2	nPvM(T)	0.23-0.53-NA	0.53-0.50-0.53	Toxic
Galaxolide	1222-05-5	vPnM(T)	0.68-0.43-NA	0.12-NA-NA	Toxic
Galaxolidone	507442-49-1	vPnM(T)	0.64-0.22-NA	0.22-NA-NA	Toxic

** P = persistent, M = mobile, T = toxic, v = very, n = not.

To illustrate the application of the Prevention module the selected example substances above are limited to one use case per substance.

5.1.1 PFBS

➢ **Question 1: Is the substance persistent, mobile and/or toxic?**

According to the PM(T)-identifier tool, PFBS is very persistent and very mobile, but non-toxic. The conservative P-score is 0.93 and the conservative M-score is 0.51. Due to its very persistent and very mobile properties, use and emission of PFBS should be avoided as much as possible.

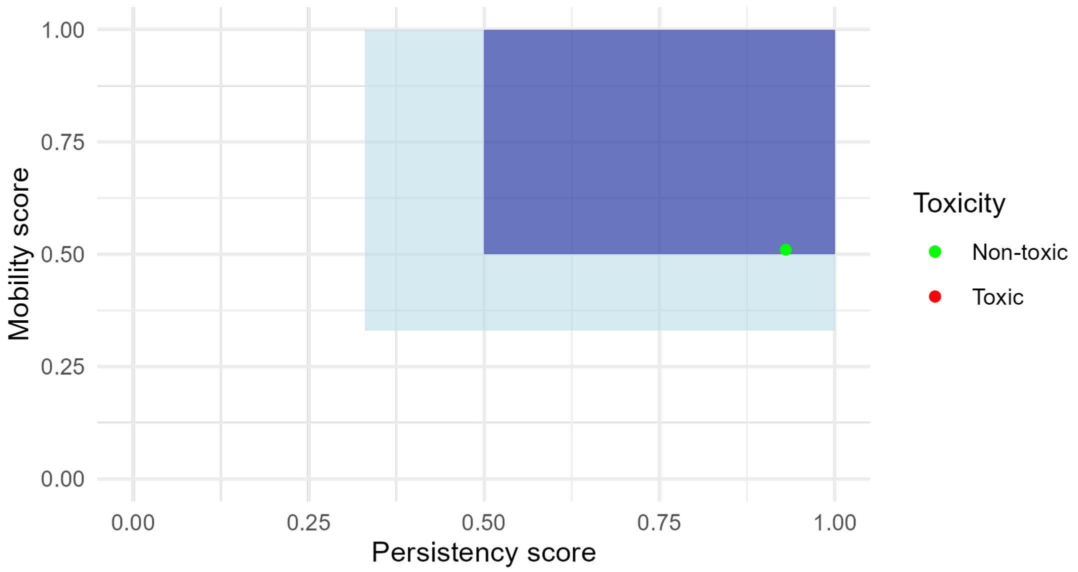


Figure 10 : PM(T) score for PFBS according to the PROMISCES PM(T) identifier tool.

➢ **Question 2: How and where is the substance used?**

There is no reported functional use based on US EPA CPDat, but based on the chemical structure of the substance it is predicted to have the functional use of flame retardant, emulsion stabilizer, and skin conditioner (Table 10).

Table 10: Functional use of PFBS according to the United States Environmental Protection Agency Chemical and Products Database (US EPA CPDat).

Functional use	Type (reported or predicted)	Predicted Probability of Associated Functional Use
Flame retardant	predicted	0.897
Emulsion stabilizer	predicted	0.805
Skin conditioner	predicted	0.579

According to NORMAN Suspect List Exchange, PFBS is associated with 15 industries and products. Some examples are aqueous film-forming foams (AFFF), floor polish, and apparel. For a complete overview of industries and products associated with PFBS through the NORMAN Suspect List Exchange, The “Use and Manufacturing” chapter on the PubChem Substance page of PFBS provides the most accessible and concise overview.

➢ **Question 3: Are there substitutes for the substance?**

PFBS is used in a wide variety of industries and products, with 15 associated industries and products according to the NORMAN Suspect List Exchange database. The use of PFBS in AFFF is notable because it is an example of regretful substitution. PFBS was a replacement for PFOS, which was originally used in AFFF. Due to the PM(T) properties of PFOS it was replaced with (amongst other PFAS) PFBS, which we now know is also persistent and mobile. As of now, ChemSec Marketplace lists four evaluated alternatives for AFFF that are fluorine-free.

In this example we address the use of PFBS as a flame retardant in polycarbonate resins. There are multiple known alternatives for the use of PFBS as a flame retardant in plastic articles. ChemSec Marketplace lists 8 evaluated alternative flame retardants for plastic articles. The ZeroPM alternative assessment database also lists chlorinated and brominated flame retardants as alternatives for fluorinated flame retardants for specifically plastics used in the electronics and semiconductor sector, although their hazard has not been assessed.

- **Question 4: What are other prevention methods besides substitution?**

NA – For the use of PBFS in AFFF and as flame retardant in plastic articles there are alternative products available that have been evaluated to be safer and more sustainable.

5.1.2 6:2 FTS

- **Question 1: Is the substance persistent, mobile and/or toxic?**

According to the PM(T)-identifier tool, 6:2 FTS is very persistent, mobile, and toxic. The conservative P-score is 0.93, the conservative M-score is 0.34, and the T-classification is toxic. Due to its persistent, mobile and toxic properties, use and emission of 6:2 FTSA should be avoided as much as possible.

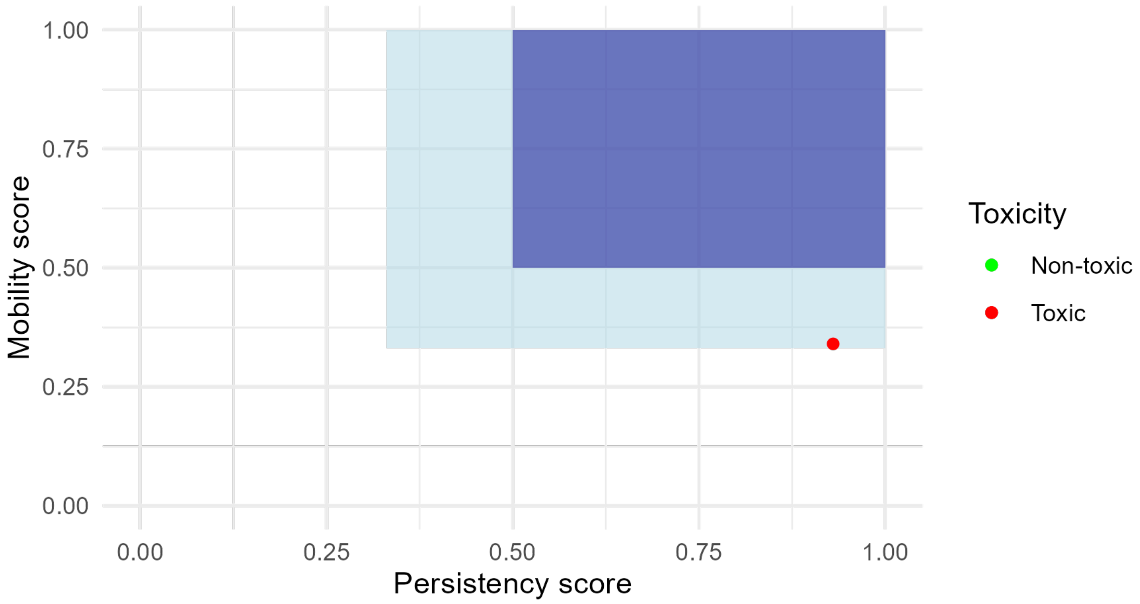


Figure 11 : PM(T) score for 6:2 FTS according to the PROMISCES PM(T) identifier tool.

- **Question 2: How and where is the substance used?**

There is no reported functional use based on US EPA CPDat, but based on the chemical structure of the substance it is predicted to have the functional use of surfactant, flame retardant, emulsion stabilizer and skin conditioner (Table 11).

Table 11: Functional use of 6:2 FTS according to US EPA CPDat.

Functional use	Type (reported or predicted)	Predicted Probability of Associated Functional Use
Surfactant	predicted	0.839
Flame retardant	predicted	0.782
Emulsion stabilizer	predicted	0.752
Skin conditioner	predicted	0.535

According to NORMAN Suspect List Exchange,6:2 FTS is associated with 18 industries and products. Some examples are the polymer industry, metal plating industry, personal care products and cosmetics industry, coatings, paints, and garnishes, and apparel. For a complete overview of industries and products associated with 6:2 FTS through the NORMAN Suspect List Exchange, The “Use and Manufacturing” chapter on the PubChem Substance page of 6:2 FTS provides the most accessible and concise overview.

- **Question 3: Are there substitutes for the substance?**

6:2 FTS is used in a wide variety of products. For this example, we focus on its use as a surfactant in the personal care products and cosmetics industry. Based on the NORMAN Suspect List Exchange database 6:2 FTS is used in multiple products in the personal care and cosmetics industry, including in concealer, hair spray, foundation, and body lotion. The products and cosmetics industry were chosen because of the high likelihood of exposure for humans and the environment through this use case.
There are multiple known alternatives for the use of 6:2 FTS as a surfactant in personal care products and cosmetics. The ChemSec Marketplace lists five evaluated alternatives for surfactants in this sector of use. Furthermore, the OECD Series on Risk Management of Chemicals includes a report on PFAS and alternatives in cosmetics. The report does not address 6:2 FTS specifically,but does conclude that there is a high substitution potential for PFAS in cosmetics, either through reformulation of the product or through replacement with non-fluorinated substances that provide the same function.

- **Question 4: What are other prevention methods besides substitution?**

NA – For the use of 6:2 FTS in the personal care and cosmetics industry there are alternative products available that have been evaluated to be safer and more sustainable.

5.1.3 PFBA

➢ **Question 1: Is the substance persistent, mobile and/or toxic?**

According to the PM(T)-identifier tool, PFBA is very persistent, very mobile, and toxic. The conservative P-score is 0.93, the conservative M-score is 0.51, and the T-classification is toxic. Due to its persistent, mobile and toxic properties, use and emission of PFBA should be avoided as much as possible.

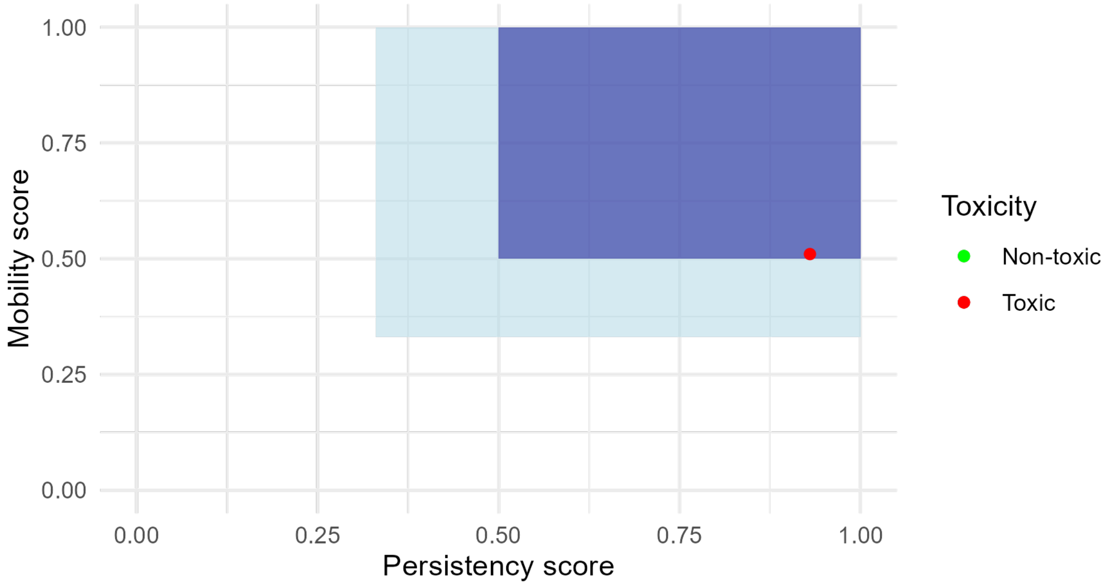


Figure 12 : PM(T) score for PFBA according to the PROMISCES PM(T) identifier tool.

➢ **Question 2: How and where is the substance used?**

There is no reported functional use based on US EPA CPDat, but based on the chemical structure of the substance it is predicted to have the functional use of foaming agent, skin conditioner, flame retardant and emulsion stabilizer and antimicrobial (Table 12).

Table 12: Functional use of PFBA according to US EPA CPDat.

Functional use	**Type (reported or predicted)**	**Predicted Probability of Associated Functional Use**
Foamer	predicted	0.835
Skin conditioner	predicted	0.766
Flame retardant	predicted	0.756
Emulsion stabilizer	predicted	0.745
antimicrobial	predicted	0.601

According to NORMAN Suspect List Exchange, PFBA is associated with over 20 industries and products. Some examples are paper food-contact articles, personal care products and cosmetics, paints, and bicycle lubricant. For a complete overview of industries and products associated with

PFBA through the NORMAN Suspect List Exchange, The “Use and Manufacturing” chapter on the PubChem Substance page of PFBA provides the most accessible and concise overview.

- **Question 3: Are there substitutes for the substance?**

For this example, we focus on the use of PFBA in paper food contact articles. ChemSec Marketplace lists multiple alternative products. Furthermore, there are two OECD reports in the OECD series on Risk Management of Chemicals on the use of PFAS in paper food packaging and the available alternatives.

- **Question 4: What are other prevention methods besides substitution?**

NA – For the use of PFBA in paper food contact articles there are alternative products available that have been evaluated to be safer and more sustainable.

5.1.4 Diethyl phthalate

- **Question 1: Is the substance persistent, mobile and/or toxic?**

According to the PM(T)-identifier tool, diethyl phthalate is not persistent, very mobile, and toxic. The conservative P-score is 0.23, the conservative M-score is 0.53, and the T-classification is toxic. Even though diethyl phthalate is not considered persistent due to a P score of 0.23, it should be noted that this score is relatively close to the cut-off of 0.25 and has a certain uncertainty. Due to its mobile and toxic properties, diethyl phthalate could still be considered to be a candidate for prevention of its use and emission.

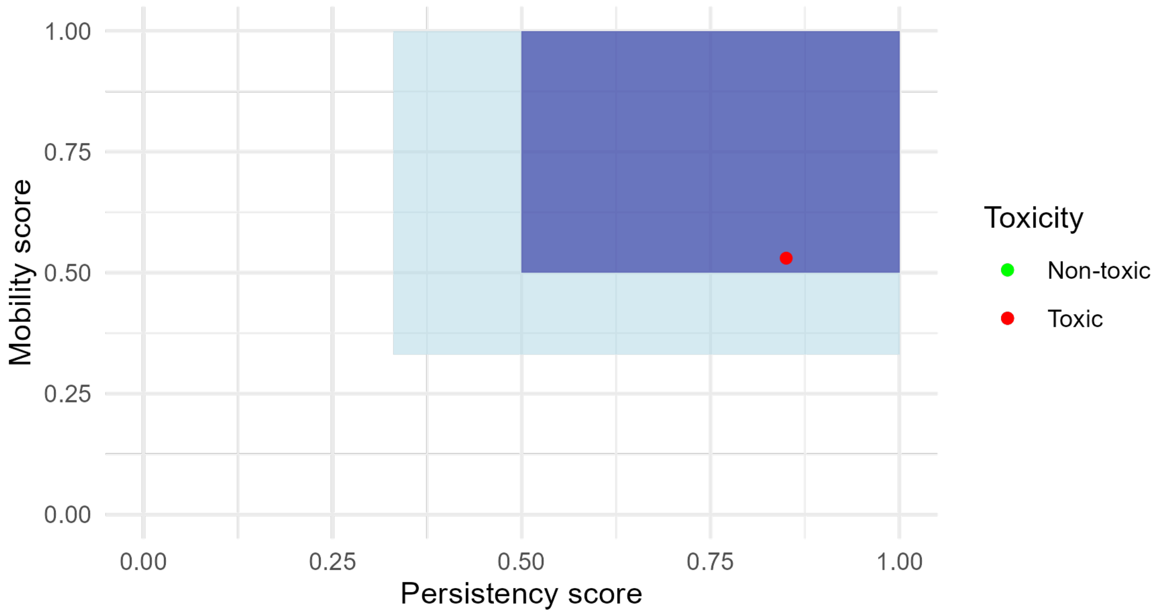


Figure 13 : PM(T) score for diethyl phthalate according to the PROMISCES PM(T) identifier tool.

➢ **Question 2: How and where is the substance used?**

According to US EPA CPDat diethyl phthalate has the following reported functional uses: solvent, film former and plasticizer (Table 13).

Table 13: Functional use of diethyl phthalate according to US EPA CPDat.

Functional use	Type (reported or predicted)	Predicted Probability of Associated Functional Use
Solvent	reported	NA
Film former	reported	NA
Plasticizer	reported	NA
Preservative	predicted	0.647
Catalyst	predicted	0.428

Associated industries and products according to NORMAN Suspect List Exchange.
There is no information on associated industries and products of Diethyl phthalate in the NORMAN Suspect List Exchange.

The US EPA CompTox Chemicals Dashboard does have information on product use of Diethyl phthalate.
Diethyl phthalate is used a solvent for fragrances, and the most reported product use categories are "industrial deodorizer" in the category of cleaning products (51 reported products), and "air freshener" in the category of cleaning products and household care (24 reported products).

➢ **Question 3: Are there substitutes for the substance?**

No alternative for the functional use of diethyl phthalate as solvent for fragrances in cleaning products was identified using the screening approach of the DSF. This means a more extensive search should be performed for existing substitutes, a substitute should be developed, and/or other prevention methods should be considered. Among these, it should be carefully considered whether the use of diethyl phthalate as a solvent for fragrances is essential.

➢ **Question 4: What are other prevention methods besides substitution?**
[to be determined]

5.1.5 Galaxolidone

➢ **Question 1: Is the substance persistent, mobile and/or toxic?**

According to the PM(T)-identifier tool, galaxolidone is very persistent, not mobile, and toxic. The conservative P-score is 0.64, the conservative M-score is 0.22, and the T-classification is toxic. Even though galaxolidone is not considered persistent due to a P score of 0.22, it should be noted that this score is relatively close to the cut-off of 0.25 and has a certain uncertainty. Due to its persistent and toxic properties, galaxolidone could still be considered to be a candidate for prevention of its use and emission.

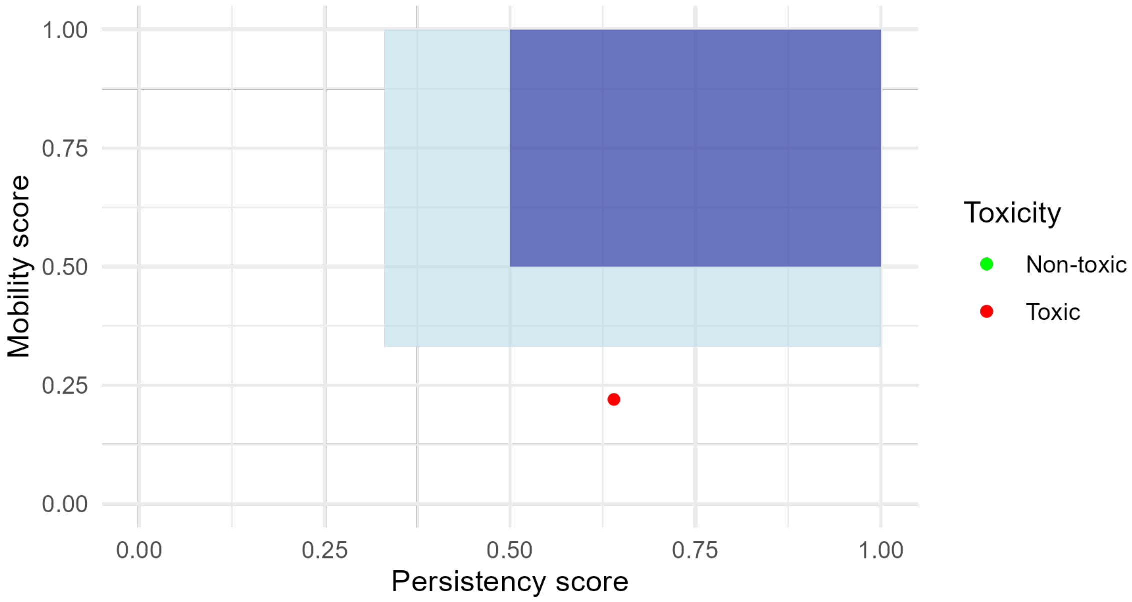


Figure 14 : PM(T) score for galaxolidone according to the PROMISCES PM(T) identifier tool.

➢ **Question 2: How and where is the substance used?**

According to US EPA CPDat, Galaxolidone is a transformation product of the commonly used synthetic musk galaxolide (fragrance).

Table 14: Functional use of galaxolide according to US EPA CPDat.

Functional use	Type (reported or predicted)	Predicted Probability of Associated Functional Use
Fragrance	reported	NA
antioxidant	predicted	0.597
flavouring agent	predicted	0.194

Associated industries and products according to NORMAN Suspect List Exchange.

There is no information about associated industrial sectors and products for galaxolide in the NORMAN Suspect List Exchange.

The US EPA CompTox Chemicals Dashboard provides information that galaxolide is used as a fragrance in a variety of cleaning and household care products.

- **Question 3: Are there substitutes for the substance?**

No alternative for the functional use galaxolide as fragrances in cleaning and household care products was identified.

- **Question 4: What are other prevention methods besides substitution?**

[to be determined]

5.2 Application of the systematic solution monitoring

The application of the systematic solution monitoring using the 5 pre-selected substance-use combinations is limited to question 1) Which substances are you interested in? and question 4) Which analytical methods exist for analysing PM(T) substances? These questions allow the user to identify substances of interest and the appropriate analytical method. At the moment of writing, models including a guidance on how to use them (question 2 of this systematic solution) are still under development and will be addressed in *Deliverable 2.3* and *Deliverable 2.4*, due in 2025. The factors important to include in a sampling strategy (question 3 of this systematic solution) are still under development. These will be addressed in *Deliverable 1.7*, due in 2025. Question 5 addresses biological methods for analysing complex mixture effects of PM(T) substance, therefore it is not specific to a single substance.

- **Question 1: Which substances are you interested in?**

The PROMISCES data from the case studies are still being collected and have not yet been uploaded to NORMAN. When these are uploaded, the user will also be able to filter based on the project that data was generated. This will ensure that the user can get a broad overview of all data in Norman across the different matrixes. For instance, if the user would apply the filter project equals PROMISCES, the user would see the data of PROMISCES (Figure 15 and 16). For this report, preliminary data was received from case study 2, 3 and 4 to provide an example of how this feature in the DSF will work. This data was received in the months May-June 2024.

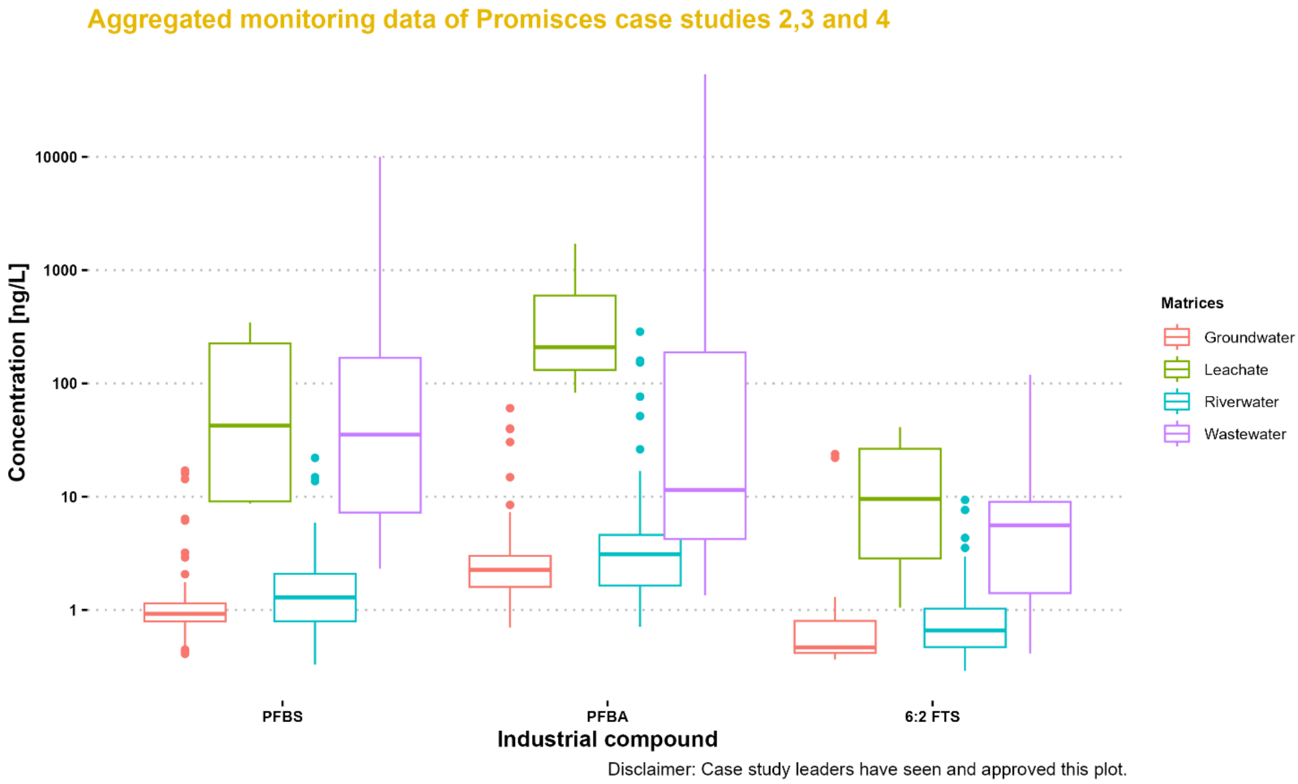


Figure 15 : Monitored concentrations of the PROMISCES case studies.

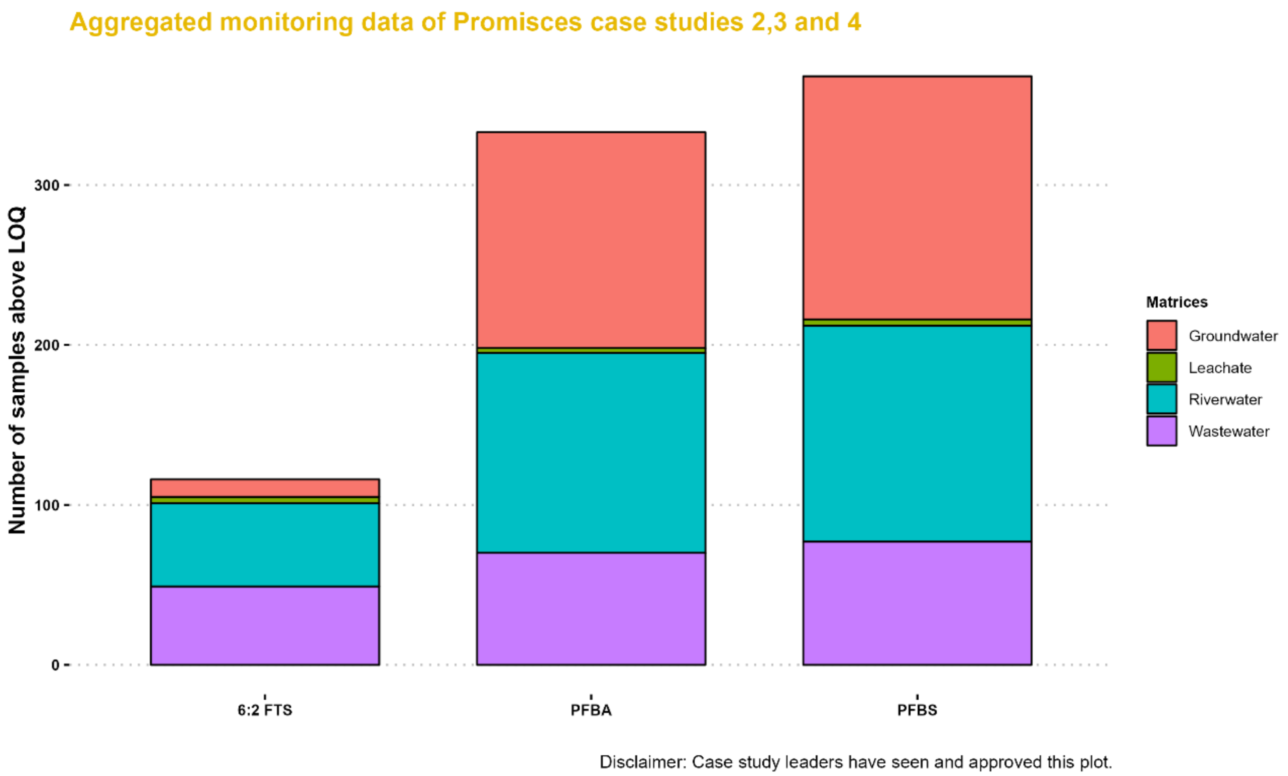


Figure 16 : Detection frequency above the limit of quantification (LOQ) of the selected substances.

From Figure 15, the user can for example gather which substances may be interesting to include in their monitoring program for each matrix. From Figure 16 the user can see that PFBS is often selected as substance of interest.

5.3 Application of the systematic solution risk assessment

The application of the systematic solution risk assessment to the 5 example substances is not included as questions 1,2 and 3 are self-explanatory based on the information in section 4.3. At the moment of writing, the models for question 4 are under development and not available yet to provide example calculations. Question 5 addresses mixture risk assessment using biological assays, and is not specific to single substances.

5.4 Application of the systematic solution treatment

The application of the systematic solution treatment using the 5 pre-selected substance-use combinations is limited to question 1) Which treatment technology is available for your target media? This question allows the user to filter through the currently 18 technologies based on the target media of interest. After a selection has been made the user can download the corresponding factsheet. For question 2 a brief explanation of the expected information is given below. At the moment of writing, the models for question 3 are under development and not available yet to provide example calculations. More detail of the factsheets corresponding with CE route B: Wastewater use for agricultural irrigation will be provided in *Deliverable 4.3*.

- **Question 1: Which treatment technology is available for your target media?**

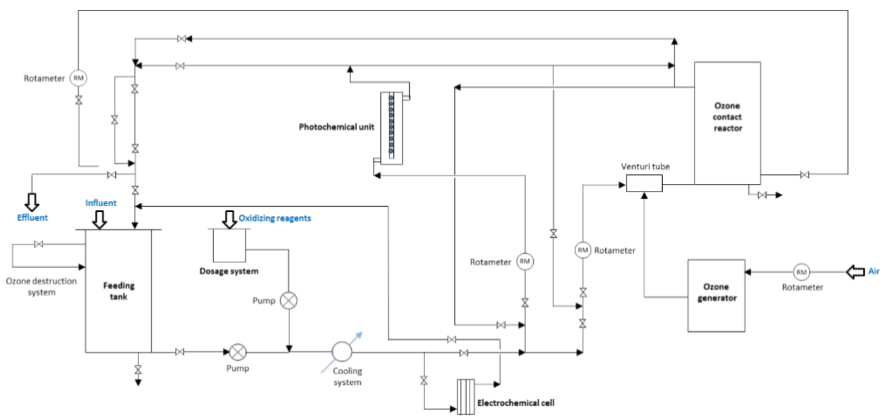
As mentioned in chapter 2 of this report, this deliverable contains information of CE route A, B and C. For these CE routes the next 4 pages represent draft factsheets available in October 2024.

- **Question 2: How can different treatment technologies be compared?**

For this question in chapter 4 there is already an example plot presented. Further information on the evaluation of remediation technologies developed in PROMISCES (WP3-WP4) and a comparison of these developed technologies with existing ones by presenting their advantages and disadvantages (from a technical, economic and environmental point of view) will be added to this question once the associated activities are completed.

Route B : Wastewater use for agricultural irrigation

E-peroxone based electrochemical advanced oxidation process (EAOP)		
The principle of the electro-peroxone (e-Peroxone) treatment is the merge of electrochemical oxidation and ozonation, offering an advanced solution for wastewater treatment. This method degrades PM(T) by generating hydroxyl radicals through an innovative, *in-situ* production of H_2O_2 via the cathodic oxygen reduction, enhanced by ozone gas sparging. Since hydroxyl radicals (E_0 = 2.80 V vs. SHE) are significantly stronger oxidants than ozone (E_0 = 2.07 V vs. SHE), they can rapidly degrade a wide range of organic pollutants at exceptionally high reaction rates (≈10^{8}-10^{10} M^{-1} s^{-1}). The H_2O_2 electro-generation may overcome the limitations of conventional methods, p.e., eliminating the need for high doses of H_2O_2 that pose safety risks during storage, transport, and handling or preventing the unwanted formation of bromate in contrast to other oxidation processes.		
1. ***Fields of application***		
Target compounds	***Receptors/media***	***Solution category***
PFAS and industrial PM(T)s	Water	Destruction-Chemical treatment
2. ***Implementation duration***		
From April to July 2024 at a scale treating 300 liters over 3 hours (each batch cycle)		
3. ***Risks***		
Deposition of struvite on the BDD electrodes, pipes, and pumps (maintenance required) Potential formation of inorganic ions (chlorate, perchlorate and bromate) Possible formation of byproducts (monitoring analyses required). Increase in temperature of the treated water resulting from the Joule effect in the electrochemical cell.		
4. ***Innovation potential***	5. ***Remediation yield***	6. ***Technology readiness level***
Higher oxidation rates lead to a significant improvement in the breakdown of highly persistent contaminants by enhancing the generation of hydroxyl radicals.	Up to 99% industrial PM(T)s removal: 2-aminophenol (99%), Carbendazim (99%), Terbutryn (99%), Venlafaxine (99%) Carbamazepine (86%), Ofloxacin (85%) Caffeine (72%), Flecainide (62%), Diuron (50%) Benzotriazole (45%), Triethyl phosphate (33%), Temazepam (25%). No PFAS removal	TRL 6
7. ***Energy aspects***	8. ***Cost aspects (€/ton or m3)***	9. ***Environmental evaluation***
5.10 kWh/m^3	≈ 1.02 €/m^3 (EU average price for non-household consumers: 0.2008 €/KWh in second-half 2023)	CALUX bioanalyses PFAS CALUX (72.6% toxicity reduction)
10. ***Flow schematic***		



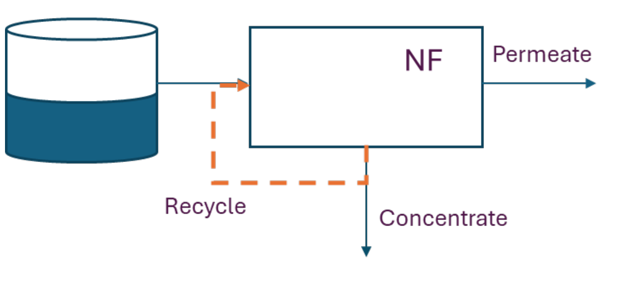
Route B : Wastewater use for agricultural irrigation

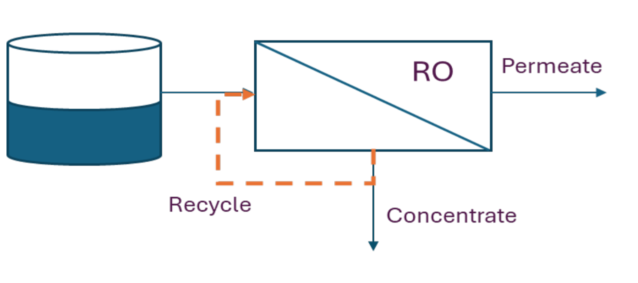
<table>
<tr><th colspan="3">Plant uptake (wetland)</th></tr>
<tr><td colspan="3">Constructed wetlands (CWs) are engineered ecosystems designed to mimic filtration and purification functions of natural wetlands to enhance the water quality. These systems are composed of three key components: well-balanced substrates made of sand, gravel, and other materials; diverse populations of microorganisms; and plant species selected for their capacity to absorb pollutants.</td></tr>
<tr><td colspan="3">1. Fields of application</td></tr>
<tr><td>Target compounds</td><td>Receptors/media</td><td>Solution category</td></tr>
<tr><td>PFAS and industrial PM(T)s</td><td>Water</td><td>Biological treatment</td></tr>
<tr><td colspan="3">2. Implementation duration</td></tr>
<tr><td colspan="3">From April to July 2024 at a scale treating 0.15 L WW/min</td></tr>
<tr><td colspan="3">3. Risks</td></tr>
<tr><td colspan="3">Water loss through evapotranspiration.
Factors such as prolonged droughts or excessive rainfall affect the treatment capacity.
Saturation of the media with the contaminants, reducing the process efficiency.
Limited understanding of the potential desorption of these pollutants accumulated in the roots after plant death.</td></tr>
<tr><td>4. Innovation potential</td><td>5. Remediation yield</td><td>6. Technology readiness level</td></tr>
<tr><td>More sustainable/eco-friendly approach, contributing climate change mitigation by carbon sequestration.
Long-term stability and low maintenance, making them a reliable and environmentally friendly solution.
Low power consumption</td><td>Up to 41% industrial PM(T)s removal:
2-aminophenol (Negligible)
Carbendazim (Negligible)
Terbutryn (Negligible)
Venlafaxine (Negligible)
Carbamazepine (9%)
Ofloxacin (26%)
Caffeine (31%)
Flecainide (41%)
Diuron (30%)
Benzotriazole (%)
Triethyl phosphate (Negligible)
Temazepam (14%)

No PFAS removal</td><td>TRL 6</td></tr>
<tr><td>7. Energy aspects</td><td>8. Cost aspects (€/ton or m3)</td><td>9. Environmental evaluation</td></tr>
<tr><td>Minimal energy requirements (only water pumping, 0.89 kWh/m³).
Gravity-driven design is recommended to reduce energy consumption.</td><td>≈ 0.18 €/m³
(EU average price for non-household consumers: 0.2008 €/KWh in second-half 2023)</td><td>CALUX bioanalyses
PFAS CALUX (≈ 64% toxicity reduction)</td></tr>
<tr><td colspan="3">10. Flow schematic</td></tr>
<tr><td colspan="3">
Two constructed wetland channels were designed to maximize their natural filtration capabilities, each measuring 74 cm in width, 47 cm in depth, and 3 meters in length. These artificial ecosystems incorporate a layered gravel system, enhancing water flow and filtration, along with the introduction of two macrophyte species: Iris pseudacorus and Phragmites australis. Both species were previously evaluated in other Urban River Lab projects, where they demonstrated their effectiveness in reducing nutrient levels. One of the flumes received water directly from the outlet of the Montornès del Vallés WWTP, utilizing secondary effluent without prior filtration, with an average inflow rate of 0.15 liters per minute. In contrast, the second channel was supplied with water from the PROMISCES buffer tank, which had undergone both filtration and e-Peroxone process (EAOPs prototype), achieving an average flow rate of 0.14 liters per minute.</td></tr>
</table>

Route C: Nutrient and energy recovery from treated sludge for fertilizers

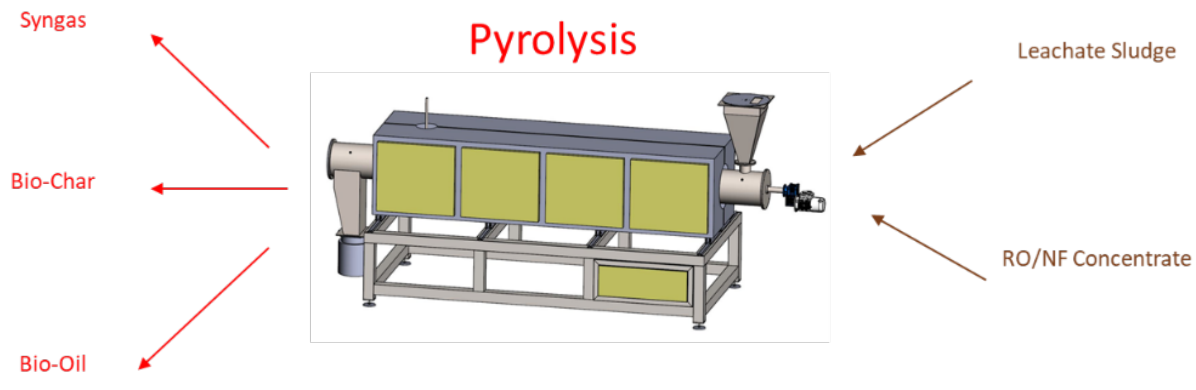
Membrane filtration (Nanofiltration, Reverse Osmosis) / remediation technique		
High PFAS loading from landfill leachate reaching municipal WWTPs prevents proper treatment and ultimately hinders zero pollution discharge and further water reuse due to higher PFAS discharges from WWTPs. Advanced filtration technologies such as nanofiltration and reverse osmosis to treat landfill leachate aim to prevent the presence of PFAS in impacted municipal wastewater. Filtration technologies were tested with a rate of 50% recirculation of concentrate to minimize concentrate production.		
1. ***Fields of application***		
Target compounds	***Receptors/media***	***Solution category***
PFAS, other industrial PM(T)s	Landfill Leachate	Physical separation
2. ***Implementation duration***		
Treated flow rate 5 m^3/day with 50% of concentrate recirculation		
3. ***Risks***		
The concentrate from this technology needs to be treated using destructive methods (e.g. using evaporation then pyrolysis).		
4. ***Innovation potentia)***	5. ***Remediation yield***	6. ***Technology readiness level***
Development of advanced treatments train to completely remove PFAS from landfill leachate	**Removal by NF**: 30 PFAS were analysed and Only 6 were detected. Observed removal were: PFBA (from 81% to 95%), PFBS (from 74% to 94%), PFHpA (from 90% to 97%), PFHxA (from 87% to 98%), PFOA (from 89% to 98%) and PFPeA (from 82% to 92%) **Removal by RO**: No PFAS were detected in the RO Permeate with LOQ=20 ng/l.	TRL 9
7. ***Energy aspects***	8. ***Cost aspects (€/ton or m3)***	9. ***Environmental evaluation***
NF: 3 kWh/m^3 Permeate (pilot data) RO: 5.6 kWh/m^3 Permeate (pilot data)	Estimate Operational treatment costs without costs for management of the concentrate NF: 3.5 €/m^3 (pilot data) RO: 3.6 €/m^3 (pilot data)	In progress within PROMISCES project.
10. ***Flow schematic***		





Route C: Nutrient and energy recovery from treated sludge for fertilizers

Co-pyrolysis of membrane concentrates and sewage sludge/ remediation technique		
A co-pyrolysis process of a mix of sludge and RO/NF concentrated salts was tested to investigate destruction of PFAS. The objective is to develop an innovative and compact technological solution, which can be operated on site and that combined with advanced filtration treatments (i.e., NF/RO) is able to assure zero PFAS discharge into the environment.		
1. ***Fields of application***		
Target compounds	***Receptors/media***	***Solution category***
PFAS	[2]WWTP Sludge, [3]LLTP Sludge, [4]NF/RO dried concentrate	Physical-Chemical Destruction
2. ***Implementation duration***		
Treated material 9 kg/ hour		
3. ***Risks***		
Additional checks should be made on the recovered products (i.e. Biochar, Biooil and Syngas) for a safe and profitable use		
4. ***Innovation potential***	5. ***Remediation yield***	6. ***Technology readiness level***
Development of Co-Pyrolysis treatment of LLTP sludge and NF/RO dried concentrate for a complete elimination of PFAS compounds. It is a compact technology that can be operated in site at the LLTP.	**Pyrolysis reactor operated at 600 °C and with 20 min of reaction time**: PFBA For all 30 PFAS treated nothing was found in the biochar and biooil (LOQ =1 ug/kg) Test to detect PFAS in the syngas are on-going	TRL 7
7. ***Energy aspects***	8. ***Cost aspects (€/ton or m³)***	9. ***Environmental evaluation***
Literature data: 16 kW for a treatment capacity of 100 kg/h	Non-available	In progress from PROMISCES project
10. ***Flow schematic***		



6 Stakeholder perceptions of solutions

As stated in Chapter 2, for the case studies related to CE routes A, B and C, co-creation workshops were held to gain the perspectives of stakeholders on how to implement the optimized/created solutions in different circular economy routes. The scientific and technical solutions developed/optimized within the corresponding PROMISCES case studies were presented during the co-creation workshops. Within these co-creation workshops, the stakeholders discussed PM(T)s in the respective circular economy route in a process that involved defining the problem to be addressed in the CE route, identifying barriers to solving this problem, and identifying priority. The stakeholders also identified relevant aspects that do not directly provide a solution for reaching a non-toxic environment and safe reuse of material directly, but focus on creating the necessary boundary conditions that should be fulfilled to aid the successful implementation of the provided scientific and technical solutions. An overview of the stakeholder sectors represented at the Route A, B and C co-creation workshops is presented in Figure 17.

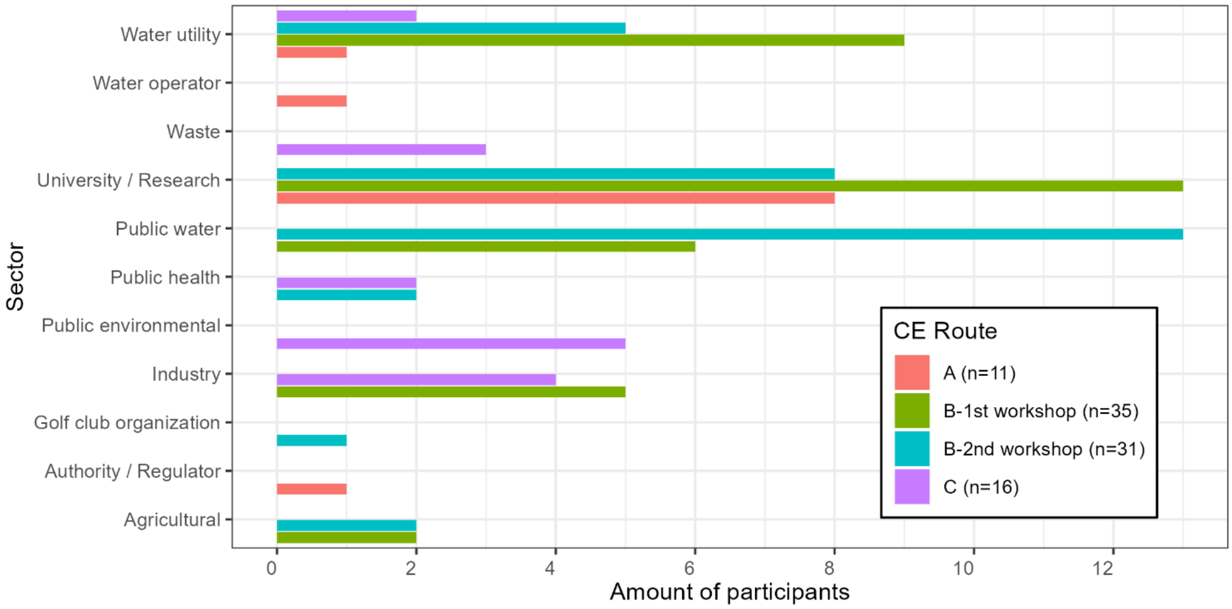


Figure 17 : Overview of the stakeholder sectors represented at the Route A, B and C co-creation workshops. For CE route B two workshops were held.

In this chapter, after a general introduction about gathering stakeholders' perspectives through co-creation workshops, the outcomes of the co-creation workshops are provided. This includes a summary of the main conclusions for each CE route. Note that some of the priority actions are not directly related to the four main systematic solution types of the DSF Solution module, namely prevention, monitoring, risk assessment and treatment. The stakeholders found that social, economic, and governance conditions can impact the successful implementation of solutions in a CE route, which are integrated into the "co-created zero pollution strategies for the risk management of PM(T) substances" module of the DSF as "boundary conditions".

6.1 Gathering stakeholders perspectives through co-creation workshops

The purpose of co-creation workshops is to gather perspectives from multiple stakeholders. In the first part of the PROMISCES co-creation workshops, barriers for enabling the CE route were discussed and prioritized (problem identification and barrier prioritization). It is important to note here that barriers may span several categories and the distinction often depends on the stakeholders' perceptions. For example, a barrier such as the generation of by-products during treatment could be considered as a technical barrier, as it pertains to the available technologies and processes, or it could be considered as an environmental barrier, as these by-products then enter the environment, or as a public health barrier, as the toxicity of these by-products may be unknown. The exact categorization of barriers is not what is important in such a co-creation process. What is important, is to allow participants the chance to contribute all the barriers or enablers that they encounter in their work. In the second part, priority actions for the barriers prioritized in the first part of the workshop were discussed. Stakeholders were also asked to think about their role in implementing these priority actions. Along with answering the question "What can I or my organization do to help realize this priority action?", they also assessed the feasibility of either the priority action (CS#2 and CS#3) or their individual actions (CS#4). To answer the question on feasibility, stakeholders were asked to use colored sticky notes (green = high feasibility, yellow = medium feasibility, red = low feasibility) to designate each solution. This ranking of feasibility is provided in the Tables 15, 16 and 17.

Worth noting is that each PROMISCES co-creation workshop differed in the phase that it reached due to practical issues such as interest of the stakeholders traveling to/from the workshop as well as participating in the workshop itself. For example, stakeholders related to CS#3 were very interested, so it was possible to have a full day live workshop, followed by a half day online workshop (Figure 17). Further details concerning organizing co-creation workshops including the bottlenecks associated to them are provided in *Deliverable 5.6 Guidance on transdisciplinary co-creation of solution strategies to reach a non-toxic environment and safe reuse of resources* (2025).

6.2 Co-creation workshop on CE route A: Semi-closed water cycle for drinking water supply

6.2.1 Problem definition according to stakeholders

The chemical water quality of the Danube River, a fundamental drinking water source, is increasingly impacted by various discharges into the river. These discharges contain a range of persistent, mobile and potentially toxic (PM(T)) substances. Some of these ***PM(T) substances***, such as PFAS, ***are hardly removed in the RBF systems***. In addition, ***legacy contamination*** within the river system has a long-term impact on existing PM(T) pollution. Another barrier regarding PM(T) substances that the stakeholders identified is an ***information gap***: it is not always known which substances should be measured, which are important, what methods are available for treatment, what the price of such treatments are, or how well treatments perform. Furthermore, stakeholders discussed that ***treatment methods are costly***, for which financial means must be made available, and not all countries are able to afford such treatment. Stakeholders also note that ***treatment techniques can undermine other environmental priorities*** because they are energy intensive, so it is difficult to balance what is more important: reducing risk or preventing carbon emissions.

Regulatory updates are expected to play a critical role in addressing water quality issues. The stakeholders noted that ***legislation is always lacking behind advances of research and/or the creation of new chemicals***. Additionally, stakeholders noted that it is difficult to ***balance regulation between protection and economic interests*** for the production and use of chemicals. The stakeholders noted that there is a high societal request for products that contain PM(T) substances, which makes it difficult to completely ban or restrict harmful substances.

6.2.2 Priority actions and feasibility

The solutions selected by the stakeholders as "priority actions" are listed in Table 15 and mapped to the DSF Solution modules.

Table 15: Overview priority actions and their category and feasibility as identified and discussed in the workshop.

	Priority Actions	Feasibility	Solution Category
1.	Prevent harmful chemicals from being used or produced, focus on strengthening use restrictions, demand producer proof of chemical behaviour	Medium-high	**Prevention**
2.	Regulation by demanding producer proof of chemical behavior	Medium-high	
3.	Extend the responsibilities of producers	Medium-high	**Prevention/ Boundary conditions (Financial/governance)**
4.	Raise public awareness in order to lower demand for products containing PM(T)s	Medium-low	**Prevention / Boundary conditions (Social)**
5.	Standardize (monitoring) methods	Medium-high	**Monitoring**
6.	Require more strict monitoring of production sites	Medium-high	
7.	Facilitate synergies between technologies to make them more energy efficient	Medium	**Treatment**

6.2.3 Output summary

The workshop made clear that an action plan is needed, and priority actions for this were identified. Two of the priority actions call for clear and strong regulation via legislation: 1) prevent the use of toxic substances (such as PFAS) by strengthening use restrictions, and 2) regulate new chemicals by demanding producer proof of chemical behavior. An additional focus on prevention was suggested by raising public awareness to reduce the demand for products with harmful components. The costs of additional treatment and monitoring are a financial boundary for effective solutions. The stakeholders suggested that the costs could be covered via extended producer responsibility. Even though there were no chemicals? producers present in the workshop, this solution provoked discussion on whether this would actually be acceptable for the producers. According to the stakeholders, extended producer responsibility requires strong political and societal support to be considered a viable solution. Another selected priority solution was to focus on facilitating synergies in technologies, although none of the participants indicated that they could contribute to this action, and there were doubts on the feasibility for this solution. To conclude, the proposed priority actions highlight legislative, social and financial boundary conditions that must be met to address problems along the circular economy route. Special importance was given to clear and strong regulation.

6.3 Co-creation workshop on CE route B: Wastewater use for agricultural irrigation

6.3.1 Problem definition according to stakeholders

In the first part of the workshop, the participants talked generally about concerns and experiences related to the use of reclaimed water. Stakeholders from the Besòs River Basin emphasized that addressing pollution in agricultural water reuse requires not only ***improved treatment technologies*** but also ***clear regulatory frameworks***, which are currently lacking for many pollutants. They underscored the need for ***comprehensive regulations on acceptable levels of microcontaminants*** (i.e. limit values), ***quantification of public health and environmental risk***, and ***active communication to inform the public*** on the safety of reclaimed water. Additionally, they highlighted the need for ***collaboration between industries, farmers and water management authorities*** to implement source-control measures, ***fund investments*** in wastewater treatment plants, and ensure that ***those responsible for pollution contribute to the costs*** for additional treatment. ***Political commitment*** and ***financial support*** along with technological advancements and reliable monitoring are critical to overcoming these technical, political, social, financial barriers (e.g. lack of clear regulatory frameworks, public awareness and funding) to address PM(T)s effectively in water reuse efforts.

6.3.2 Priority actions and feasibility

The solutions selected by the stakeholders as "priority actions" are listed in Table 16 and mapped to the DSF Solution module.

Table 16: Priority actions identified by stakeholders in the Besòs River region, mapped to the four systematic solutions of the DSF, including boundary conditions. The feasibility of their implementation, as judged by the participants, is also provided.

	Priority Actions	**Feasibility**	***Solution Category***
1.	Control discharges at the source; update industrial discharge limits to include PM(T)s (monitoring origin of industrial pollution)	Medium-Low	**Prevention / Monitoring**
2.	Research on toxicity, presence, risks, etc.	Medium	**Risk Assessment**
3.	Protocol to estimate risks to human health / methodology for risk assessment	High	
4.	Regular updates of CEC watchlists	Low	
5.	Establish & communicate performance indicators of treatment technologies (e.g. energy/m^3)	N/A*	**Treatment**
6.	Conduct more research needed on by-product recovery and redox processes	Medium	
7.	Prioritize financing for water cycle management in budgets (e.g., for developing Regenerated Water Master Plans by basin, hiring specialized technicians)	Medium	**Boundary Conditions (Social, Financial, Governance)**
8.	Implement variable price for water based on consumption and/or incentives for savings	Low	
9.	Include CEC/PM(T) substances explicitly in legislation	Low	
10.	Create groups/round tables for each case study / shared responsibility	High	
11.	Use targeted and adapted communication for each type of user	High	
12.	Hire communication professionals in each of the operators and water management administrations	High	

**N/A means that the stakeholders did not rate the feasibility of the priority action.*

6.3.3 Output summary

Moving towards creating a strategy, the stakeholders assessed the priority actions in Table 16 to identify those that should be undertaken first, which would then facilitate future actions. Stakeholders generally agreed that starting with "creating working groups or roundtables" (priority action #10) where all sectors of society can participate and offer their knowledge and/or concerns would be beneficial. The goal of this working group would be to create a communal strategy on water management in the Besòs River Basin that includes reuse for agriculture as well as reuse for drinking water. A second key action would be to prioritize financing of water management in the regional/national budget (priority action #7), but questions of who pays and how much were not answerable during the workshops, and, generally, actions related to financing were rated as less feasible.

For many of the identified actions, there is currently no institutional support for their implementation, highlighting the need for policymakers to not only enact supporting legislation, but also to participate in working groups at the local level. Some key policy needs were identified from this workshop and will help inform policy recommendations listed in Deliverable 5.8, such as:

- Establish a process for regular updates of contaminants of emerging concern (CEC) watchlists
- Explicitly include CEC/PM(T) substances in relevant legislation
- Define performance indicators for treatment technologies (e.g. energy/m^3), considering CO_2 and water footprints
- Implement control measures for discharges at the source, such as monitoring at the origin of industrial pollution

During the workshop, it was brought up that it was generally accepted to use reclaimed water for agriculture and the need was expressed to develop a strategy for the use of reclaimed water that focuses on potable use as well. The question remains whether this need for and focus on potable usage can be turned into an argument for proactive wastewater treatment (the reasoning being that for potable usage, safety is of even greater importance), thereby overcoming difficulties in decision making and creating shared responsibility.

Beyond policymakers, the solutions and the implementation support offered by the participants highlights the need for cross-sectoral collaboration and communication in the Besòs River Basin to successfully address water scarcity and to move towards a circular economy.

6.4 Co-creation workshop on CE route C: Nutrient and energy recovery from treated sludge for fertilizers

6.4.1 Problem definition according to stakeholders

During the first part of the co-creation workshop, the participants reflected on the barriers identified via a survey and added barriers as needed. Most prioritized barriers could be categorized as public/environmental health, governance, societal and technical. For public/environmental health barriers, stakeholders emphasized ***a lack of regulations*** and a ***slow bureaucratic system for releasing landfill permits and answering clarification requests limits***. Additionally, with regards to public health barriers, they highlighted ***a lack of risk analysis methodologies*** and a ***lack of suitable monitoring programs for PFAS***. The latter could also be classified as an environmental health or technical barrier. Regarding technical barriers, the lack of technological solutions in relation to closing the cycle/loop was also accentuated.

To conclude, the stakeholders underscored that the lack of proper communication to the public and to plant operators about the state-of-the-art on treatment, such as those presented in the PROMISCES Case Study 4, leads to a societal barrier for the implementation of landfill leachate treatment to enable resource recovery. This societal barrier goes hand-in-hand with a lack of societal awareness of the level of PFAS in various products. Furthermore, it leads to limited cost allocation for the installation of sustainable advanced treatment systems at landfill leachate treatment plants, which can hinder progress.

6.4.2 Priority actions and feasibility

The solutions selected by the stakeholders as “priority actions” are listed in Table 17. Due to the time constraint of the stakeholder workshop, some of the actions from the involved stakeholders are merely listed, without specifics regarding feasibility.

Table 17: Overview priority actions and their category and feasibility as identified and discussed in the workshop.

	Priority Actions	**Feasibility**	***Solution Category***
1.	Leverage economic taxation for impactful products and concessions for sustainable ones. Product certification and labeling system.	N/A*	**Prevention**
2.	Quickly define the limits for PFAS in discharge into surface waters and sewers.	Medium-high	
3.	Implement labeling system for products containing PFAS and promote actions on green public procurement.	Medium	
4.	Develop public opinion information programs (at different age levels including school age).	Medium-high	
5.	Define clear monitoring program and methodology (analytical methods, identification of indicator parameters for specific matrix) for managing leachate.	High	**Monitoring**
6.	Provide public funding for monitoring programs and finding solutions.	N/A*	
7.	Raise awareness in the National System for Environmental Protection (SNPA) for the need to issue guidelines and best practices.	High	**Monitoring/ Treatment**
8.	Promote awareness among plant managers about existing technical solutions.	Medium-high	**Treatment**
9.	Define guidelines for risk analyses for emerging contaminants at the European level. Knowledge and best practices from researchers should be collected and shared to support this.	High-medium	**Risk assessment**
10.	Develop guidelines and training courses for public administration to reduce the bureaucratic delays of landfill permit authorizations and interpreting new rules/regulations. Suggestion to create these guidelines in tabular form to ease understanding.	N/A*	**Boundary Conditions (Governance)**
11.	Expand the extended producer responsibility (EPR) system to cover PFAS to reduce costs and cover not only the costs of treatment, but also those of monitoring and research.	N/A*	**Boundary Conditions**

**N/A means that the stakeholders did not rate the feasibility of the priority action.*

6.4.3 Output summary

The structure of the workshop resulted in an action list of how to deal with PM(T) substances in landfill leachate. The workshop made clear that an action plan is needed, and priority actions for this were identified that focus on governance and legislation, social and financial aspects such as leveraging economic taxation for impactful products and concessions for sustainable ones. This highlights the importance of boundary conditions that must be met to address problems along the circular economy route, thereby enabling the prevention or substitution of PM(T) substances or the implementation of technical solutions.

7 Discussion and conclusions

7.1 Reflection on the design of the DSF Solutions module

The design of the DSF Solutions module provides an inventory of the systematic solutions for prevention, monitoring, risk assessment and treatment. Each systematic solution is based on a series of questions that guide the user through the module. The DSF primarily allows for identification of solutions at the screening level, and as such provides a starting point for stakeholders to address PM(T) substances in the environment and circular economy. To further assist stakeholders, the DSF provides reference to more advanced methods and tools for the assessment of solutions for PM(T) substances in the circular economy, such as guidelines and tools being developed within PROMISCES for the Monitoring module. In addition, it should be emphasized that while the design of the DSF is based on the principle that prevention trumps treatment, not all types of solutions can be deployed in all contexts or by all types of stakeholders. This is the case for legacy pollution, in particular persistent substances, which cannot be managed by prevention solutions but must be addressed through other systematic solutions. There is therefore a need for an approach to be taken at all levels and there is no single solution towards a non-toxic environment. The solution for PM(T) substances in the circular economy requires advancement in all four categories - prevention, monitoring, risk assessment and treatment - and the involvement of local stakeholders to define solutions that work in the local context.

7.2 Reflection on the application of the DSF Solutions module

The design of the Solutions module of the DSF has been tested by applying it to five example substances. Overall, this demonstrated the success of the framework, as several approaches to solutions were identified using the DSF. For example, by applying the systematic solution prevention, a need for substitution could be identified for all five substances, and for theoretically three substance-use combinations existing substitutes could be identified. The functioning of the DSF could not be fully tested, as additional data is still required for the DSF to be complete. At the time of writing, the DSF is not yet fully implemented as the following information regarding the assessment of solutions will be added by the end of the project: factsheets for the systematic solution treatment and the toolbox and guidance documents (*Deliverable 2.3* and *Deliverable 2.4*). Hence, slight modifications may still be implemented once all the data, tools and deliverable from the PROMISCES project become available.

The developed DSF Solutions module depends on the availability and quality of data required for its modules. This emphasizes the need for adequate data sharing, both within and between projects, research institutes, and stakeholders, in order to successfully provide solutions for PM(T) substances in the circular economy. The CEN Workshop Agreement on *"Soil-sediment-water system - Solutions to deal with PMT/vPvM substances"*, which is developing a standardized factsheet for reporting data on treatment technologies for PM(T) substances, is a step forward in this direction.

7.3 Reflection on the outcomes of the co-creation workshops

The stakeholder co-creation workshops focused on different case studies and different circular economy routes. It is therefore difficult to draw specific, overarching conclusions on solutions from these workshops. However, the differences between the workshops highlight the importance of defining the local problem when building a solution strategy. A well-defined problem statement that takes into account all local conditions helps with identifying the relevant aspects of the problem and to identify and evaluate the possible solutions. For a well-defined local problem statement, relevant stakeholders need to be consulted.

There were some common themes across the workshops. In general, the stakeholders found that in addition to scientific and technical solutions, social, economic, and governance conditions can impact the successful implementation of solutions in a CE route. It is worth noting that the Solutions module within the DSF focuses on scientific and technical solutions. Other aspects that are needed for successful implementation are integrated into the Strategy module of the DSF as “boundary conditions”.

7.4 Conclusion

To conclude, a framework was developed to assess solutions for PM(T) substances in the circular economy, which is an important step towards realizing the European Zero Pollution ambition. This framework presents a way of thinking and allows users to identify solutions at four levels: prevention, monitoring, risk assessment and treatment. The framework is easy to apply at screening level and was demonstrated to be a successful starting point for scientific and technical solutions. Effectively implementing solutions for PM(T) substances in the circular economy also requires stakeholder engagement to not only define the local problem, but also to identify the barriers for social, economic, and governance conditions. Finally, we stress that there is not a single best solution for PM(T) substances in the circular economy. A successful strategy for the safe implementation of the circular economy and the management of PM(T) substances is one that is delivered at all levels and through the cooperation of multiple stakeholders to achieve the common goal of facilitating the implementation of the Zero Pollution and Circular Economy Action Plans.

8 References

Arp, H. P. H., Hale, S. E., Schliebner, I., & Neumann, M. (2023). Prioritised PMT/vPvM substances in the REACH registration database. G. E. Agency. https://www.umweltbundesamt.de/sites/default/files/medien/11850/publikationen/21_2023_texte_pmt_vpvm_substances_reach_v23032023.pdf

Carere, M., Wernersson, A.-S., Lettieri, T., Buchinger, S., Pasanen-Kase, R., Reifferscheid, G., Duffek, A., Larsson, J., Kahlert, M., Goedkoop, W., Förlin, L., Chalon, C., Marneffe, Y., Volsem, S., Hoebeke, L., Perceval, O., Ait-Aissa, S., Soldán, P., Tusil, P., & Brack, W. (2021). Technical Proposal for Effect-Based Monitoring and Assessment under the Water Framework Directive. https://doi.org/10.13140/RG.2.2.19954.27847

ChemSec. (2023). Welcome to the PFAS Guide. Retrieved 10-10-2024 from https://pfas.chemsec.org/

ChemSec. (2024). Marketplace. Retrieved 1-11-2024 from https://marketplace.chemsec.org/

Commission, E. (2024a). BAT reference documents. https://eippcb.jrc.ec.europa.eu/reference

Commission, E. (2024b). Communication from the Commission – Guiding criteria and principles for the essential use concept in EU legislation dealing with chemicals. https://op.europa.eu/en/publication-detail/-/publication/90926c62-0365-11ef-a251-01aa75ed71a1/language-en

Commission), D.-G. f. H. a. F. S. E. (2017). Technical guidance for deriving environmental quality standards. https://op.europa.eu/en/publication-detail/-/publication/d5b2b9b9-32fb-11e8-b5fe-01aa75ed71a1

Council. (2024). Urban wastewater: Council and Parliament reach a deal on new rules for more efficient treatment and monitoring. https://www.consilium.europa.eu/en/press/press-releases/2024/01/29/urban-wastewater-council-and-parliament-reach-a-deal-on-new-rules-for-more-efficient-treatment-and-monitoring/

Cousins, I. T., Ng, C. A., Wang, Z., & Scheringer, M. (2019). Why is high persistence alone a major cause of concern? [10.1039/C8EM00515J]. Environmental Science: Processes & Impacts, 21(5), 781-792. https://doi.org/10.1039/C8EM00515J

Deliverable D1.1 - Methods for PFAS in waters and complex matrices. https://zenodo.org/records/14332693

Deliverable D1.2 – Targeted methods for relevant iPM(T) substances in waters. https://promisces.eu/Results/_/D1.2.pdf

Deliverable D1.3 – Methods for global organic fluorinated content (TOP, TOF/AOF/EOF) for relevant matrices. https://promisces.eu/Results/_/D1.3.pdf

Deliverable 1.5 Set of novel QSAR models/grouping/read-across and in vitro bioassay approaches predicting relevant toxicological endpoints for PFAS/PM(T) chemicals. https://promisces.eu/Results/_/D1.5.pdf

Deliverable D1.7- Implementation of monitoring strategies including new approaches and feedbacks. [in preparation] https://cordis.europa.eu/project/id/101036449/results

Deliverable D2.1 – Toolbox improved in silico models for identification of PMT properties. https://promisces.eu/Results/_/D2.1.pdf

Deliverable D2.3 Toolbox Fate & Transport modeling. [in preparation] https://cordis.europa.eu/project/id/101036449/results

Deliverable D2.4 Guidance Document on Emission Fate and Transport [in preparation] https://cordis.europa.eu/project/id/101036449/results

Deliverable D4.3 Recommendations on EAOP-CW based treatment system for water reuse applications. [in preparation] https://cordis.europa.eu/project/id/101036449/results

Deliverable D4.6 Performance and comparitive analyses of landfill leachate treatment options for the removal of PFAS. [in preparation] https://cordis.europa.eu/project/id/101036449/results

Deliverable D5.1 - Mapping of PM(T) concerns in EU, including essential uses - Report and Annexes 1 and 2 (database and documentation). https://zenodo.org/records/14204373

Deliverable D5.6 Guidance on transdisciplinary co-creation of solution strategies to reach a non-toxic environment and safe reuse of resources. [in preparation] https://cordis.europa.eu/project/id/101036449/results

Deliverable 5.7 Final version of the DSF published and usage guidance for the end-users https://cordis.europa.eu/project/id/101036449/results

Deliverable D5.8 Modular recommendations for evaluation and implementation of relevant EU directives, strategies and action plans. [in preparation] https://cordis.europa.eu/project/id/101036449/results

Dulio, V., Alygizakis, N., Ng, K., Schymanski, E. L., Andres, S., Vorkamp, K., Hollender, J., Finckh, S., Aalizadeh, R., Ahrens, L., Bouhoulle, E., Cirka, L., Derksen, A., Deviller, G., Duffek, A., Esperanza, M., Fischer, S., Fu, Q. G., Gago-Ferrero, P.,…von der Ohe, P. C. (2024). Beyond target chemicals: updating the NORMAN prioritisation scheme to support the EU chemicals strategy with semi-quantitative suspect/non-target screening data. Environmental Sciences Europe, 36(1). https://link.springer.com/article/10.1186/s12302-024-00936-3

EC. (2023). 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 1907/2006 (Text with EEA relevance). Official Journal of the European Union Retrieved from https://eur-lex.europa.eu/legal-content/en/TXT/?uri=CELEX%3A32008R1272

ECHA. Four new substances added to Candidate List ECHA/PR/20/02. Retrieved 15-11-2024 from https://echa.europa.eu/nl/-/four-new-substances-added-to-candidate-list

ECHA. Substance Infocard. Retrieved 15-11-2024 from https://echa.europa.eu/nl/substance-information/-/substanceinfo/100.001.409

ECHA. (2024). Socio-economic analysis in REACH. Retrieved 1-11-2024 from https://echa.europa.eu/support/socio-economic-analysis-in-reach

EPA. (2024). CompTox Chemicals Dashboard. Retrieved 01-10-2024 from https://comptox.epa.gov/dashboard/

EUR-Lex. (2000). Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000 establishing a framework for Community action in the field of water policy. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32000L0060

EUR-Lex. (2006). Directive 2006/118/EC of the European Parliament and of the Council of 12 December 2006 on the protection of groundwater against pollution and deterioration. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32006L0118

EUR-Lex. (2013). Directive 2013/39/EU of the European Parliament and of the Council of 12 August 2013 amending Directives 2000/60/EC and 2008/105/EC as regards priority substances in the field of water policy Text with EEA relevance. https://eur-lex.europa.eu/legal-content/EN/ALL/?uri=CELEX:32013L0039

EUR-Lex. (2020a). Directive (EU) 2020/2184 of the European Parliament and of the Council of 16 December 2020 on the quality of water intended for human consumption (recast) (Text with EEA relevance). https://eur-lex.europa.eu/eli/dir/2020/2184/oj

EUR-Lex. (2020b). Regulation (EU) 2020/741 of the European Parliament and of the Council of 25 May 2020 on minimum requirements for water reuse (Text with EEA relevance). https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A32020R0741

EUR-Lex. (2022). Proposal for a DIRECTIVE OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL concerning urban wastewater treatment (recast) - COM/2022/541 final. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52022PC0541

EUR-Lex. (2024). DIRECTIVE (EU) 2024/3019 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 27 November 2024 concerning urban wastewater treatment. https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=OJ:L_202403019

Evich, M. G., Davis, M. J. B., McCord, J. P., Acrey, B., Awkerman, J. A., Knappe, D. R. U., Lindstrom, A. B., Speth, T. F., Tebes-Stevens, C., Strynar, M. J., Wang, Z. Y., Weber, E. J., Henderson, W. M., & Washington, J. W. (2022). Per- and polyfluoroalkyl substances in the environment. Science, 375(6580), 512-+. https://doi.org/ARTN eabg906510.1126/science.abg9065

FIOSH, & Health), F. I. f. O. S. a. (2024). Substitution Support Portal. Retrieved 1-10-2024 from https://www.subsportplus.eu/subsportplus/DE/Home

Georisques. (2024). Expert file on soil pollution, SIS and former industrial sites.

Hale, S. E., Neumann, M., Schliebner, I., Schulze, J., Averbeck, F. S., Castell-Exner, C., Collard, M., Drmač, D., Hartmann, J., Hofman-Caris, R., Hollender, J., de Jonge, M., Kullick, T., Lennquist, A., Letzel, T., Nödler, K., Pawlowski, S., Reineke, N., Rorije, E.,…Arp, H. P. H. (2022). Getting in control of persistent, mobile and toxic

(PMT) and very persistent and very mobile (vPvM) substances to protect water resources: strategies from diverse perspectives. Environmental Sciences Europe, 34(1). https://doi.org/10.1186/s12302-022-00604-4

Holmberg, R., Wedebye, E. B., Nikolov, N. G., & Tyle, H. (2021). How many potential vPvM/PMT substances have been registered under REACH? - vPvM/PMT-screening by using the Danish (Q)SAR database. D. T. U. (DTU). https://orbit.dtu.dk/en/publications/how-many-potential-vpvmpmt-substances-have-been-registered-under-

INERIS. (2024). Per- and polyfluoroalkyl substances (PFAS) and persistent, mobile and toxic substances (PMT) substitution. Retrieved 1-06-2024 from https://substitution-perfluores.ineris.fr/en

Joint Research Centre, & Commission, E. (2024). Safe and sustainable by design chemicals and materials - Methodological guidance. Publications Office of the European union. Retrieved 1-11-2024 from https://publications.jrc.ec.europa.eu/repository/handle/JRC138035

Lallas, P. L. (2017). Stockholm convention on persistent organic pollutants. Retrieved 31-10-2024 from https://www.cambridge.org/core/journals/american-journal-of-international-law/article/abs/stockholm-convention-on-persistent-organic-pollutants/47E6AE71CC66943C239D5383B2B935C0

Meesters, J. (2024). SimpleBox Aquatic Persistence Dashboard. https://zenodo.org/records/13752192

NORMAN. (2024a). NORMAN Ecotoxicology Database — Lowest PNECs. Retrieved 01-10-2024 from https://www.norman-network.com/nds/ecotox/lowestPnecsIndex.php

NORMAN. (2024b). NORMAN EMPODAT Database - Chemical Occurrence Data. https://www.norman-network.com/nds/empodat/

NORMAN. (2024c). NORMAN Suspect List Exchange – NORMAN SLE. https://www.norman-network.com/nds/SLE/

OECD. (2024a). The costs and benefits of regulating chemicals. Retrieved 01-12-2024 from https://www.oecd.org/en/topics/sub-issues/risk-management-risk-reduction-and-sustainable-chemistry/the-costs-and-benefits-of-regulating-chemicals.html

OECD. (2024b). OECD Series on Risk Management of Chemicals. Retrieved 1-11-2024 from https://www.oecd-ilibrary.org/environment/oecd-series-on-risk-management-of-chemicals_f7f30439-en

Posthuma, L., Viljanen, M., Tostrams, L., Slootweg, J., Swart, E., & Soeteman-Hernandez, L. (2024). A science-based innovative dashboard to operationalise Safe & Sustainable-by-Design. https://zenodo.org/records/14264967

Project, P. (2024). P-A-R-C SSbD Toolbox. Retrieved 01-12-2024 from https://www.parc-ssbd.eu/

PROMISCES. (2024). Circular Economy Routes. https://promisces.eu/Circular+Economy+Routes.html

Co-created zero pollution strategies for the risk management of PM(T) substances” module of the DSF. https://promisces.eurecatprojects.com/#/strategy

Solutions assessment module of the DSF. https://promisces.eurecatprojects.com/#/solution

PubChem. Explore Chemistry - Quickly find chemical information from authoritative sources. Retrieved July from https://pubchem.ncbi.nlm.nih.gov/

Reinikainen, J., Bouhoulle, E., & Sorvari, J. (2024). Inconsistencies in the EU regulatory risk assessment of PFAS call for readjustment. Environment International, 186. https://doi.org/10.1016/j.envint.2024.108614

RISE. (2024). The Swedish Centre for Chemical Substitution. https://www.ri.se/en/the-swedish-centre-for-chemical-substitution

Schymanski, E. L., Jeon, J., Gulde, R., Fenner, K., Ruff, M., Singer, H. P., & Hollender, J. (2014). Identifying Small Molecules via High Resolution Mass Spectrometry: Communicating Confidence. Environmental Science & Technology, 48(4), 2097-2098. https://doi.org/10.1021/es5002105

UPWATER. (2023). Deliverable D5.1 UPWATER ASSESSMENT FRAMEWORK. https://www.upwater.eu/wp-content/uploads/2024/10/D5.1.pdf

ZeroPM. (2024). ZeroPM Alternative Assessment Database. Retrieved 1-11-2024 from https://zeropm.eu/alternative-assessment-database/

Zhiteneva, V., Zamzow, M., de Buen Lapena, H., & Mesas, M. (2024). Risk-Based Human Exposure Assessment of Chemicals in the Circular Economy. Retrieved 1-11-2024 from https://zenodo.org/records/13141743