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NILU report 23/2025

Screening Program 2024

Substances in electronic waste facilities and wastewater treatment

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Substances in electronic waste facilities and wastewater treatment

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NILU report 23/2025

Classification A-Open

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Org.nr. 941 705 561

Certifications

NS-EN ISO 9001
NS-EN ISO 14001

Accreditation

NS-EN ISO/IEC 17025

Göteborg

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Org.nr. 559442-9580
www.nilu-research.se

ISBN 978-82-425-3216-9
ISSN 2464-3327

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Title

Screening Program 2024
Substances in electronic waste facilities and wastewater treatment

Norwegian title

Screeningprogrammet 2024
Stoffer i EE gjenvinning og renseanlegg

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Short summary (English)

The 2024 Screening Programme investigated emerging and legacy contaminants in e-waste facilities and wastewater treatment. LCD substances, flame retardants, plasticizers, and their metabolites were found in air, dust, and water near e-waste sites. Bisphenol-related compounds and follow-up substances were detected in wastewater, particularly in sludge and particles. The findings highlight environmental dispersion, treatment efficiency, and the need for continued monitoring.

Short summary (Norwegian)

Screeningprogrammet 2024 undersøkte nye og klassiske miljøgifter i EE-avfallsanlegg og avløpsrenseanlegg. LCD-stoffer, flammehemmere, plasttilsetninger og deres metabolitter ble funnet i luft, støv og vann nær EE-anlegg. Bisfenolrelaterte stoffer og oppfølgingsstoffer ble påvist i avløpsvann, særlig i slam og partikler. Funnene viser spredning i miljøet, renseeffektivitet og behov for videre overvåking.

Keywords

LCD substances, EE recycling, Wastewater treatment

Number of pages

72

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Client/Report prepared for

Miljødirektoratet

Signature of the responsible person

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Citation

Nipen, M., Wulf, R., Sørmo, E., Rostkowski, P., Vogelsang, C., Langberg, H. A., Beylich, B., Nikiforov, V., Harju, M., Halse, A. K., Borgen, A. R. (2025). *Screening Program 2024. Substances in electronic waste facilities and wastewater treatment* (NILU report 23/2025). Kjeller: NILU.

NILU project number

124039

Quality assurer

Eldbjørg Sofie Heimstad

Contract reference

M-3034|2025

Date

16/10/2025

Preface

On behalf of the Norwegian Environment Agency (NEA), Stiftelsen NILU, Norwegian Geotechnical Institute (NGI), and the Norwegian Institute for Water Research (NIVA) have carried out the 2024 Screening Programme - Substances in electronic waste facilities and wastewater treatment.

Coordinator at NEA was Bård Nordbø, the project manager was Maja Nipen (NILU), with Erlend Sørmo and Raoul Wulf coordinating for NGI, and Christian Vogelsang coordinating for NIVA.

Sampling was carried out by Erlend Sørmo and Raoul Wulf (NGI), and Christian Vogelsang, Anne Luise Ribeiro, and Bjørnar Beylich (NIVA).

Chemical analysis was conducted by Anders Røsrud Borgen, Vladimir Nikiforov, Mikael Harju, Jøran Solnes Skaar, Ingeborg Lysberg, Heidi Eikenes, Nahla Ibrahim Zainalabdeen, Kirsten Davanger, Tsige Birhane Muhtsun, and Hans Gundersen (NILU). Data analyses and reporting were executed by Maja Nipen, Pawel Rostkowski, Vladimir Nikiforov, Mikael Harju, Cleo Lisa Davie-Martin, Anne Karine Halse (NILU), Raoul Wulf and Håkon Austad Langberg (NGI).

Reporting to the Vannmiljø Database was performed by Cleo Lisa Davie-Martin (NILU).

We thank everyone involved for a nice collaboration.

We would specifically like to thank the management and workers at the EE facilities and wastewater treatment plant for all their helpful support and for facilitating our sampling campaigns for this Screening Programme.

Kjeller 29.08.25

Maja Nipen

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Summary

The 2024 Screening Programme investigated the presence of emerging and legacy contaminants in two environmental contexts: (1) Facilities handling and recycling electronic waste (e-waste), and (2) municipal wastewater treatment plants. The programme aimed to identify substances of concern, assess their environmental dispersion, and evaluate potential ecological risks. Substance selection for the screening was based on priorities set by the Norwegian Environment Agency.

In the e-waste component, the focus was on liquid crystal display (LCD)-related substances, flame retardants (including brominated and chlorinated compounds), plasticizers, and their degradation products. Sampling was conducted at two facilities with different operational roles—one performing dismantling and processing, and the other serving as a collection and sorting hub. A wide range of environmental matrices were sampled, including air, dust, water, soil, moss, and rodents.

LCD substances were detected in high concentrations in indoor dust, air, and stormwater, with several fluorinated compounds (e.g., PCHPB, EDFPCHB, BTFPOMTP) appearing consistently across multiple matrices. Organophosphorus flame retardant metabolites (e.g., DEHPO, DPPO) and phthalate metabolites (e.g., MEP, MEHP) were also widely present, with notable concentrations in dust, air, and biota. Chlorinated paraffins (especially LCCPs) were found at high levels in particulate and solid samples, indicating environmental persistence and potential for dispersion.

In the wastewater component, the focus was on bisphenol-related substances and a set of follow-up compounds identified in previous screening efforts. Samples were collected from a large municipal treatment plant with both low and high degree treatment stages, as well as from recipient environments (sediments and blue mussels).

Several bisphenol derivatives were included in the analysis, but only a few were detected. BPA and BPS were found in sludge, while DDPM, APPPPA, and BBM showed higher detection frequencies in particulate and sludge samples. Among substances being followed up from a previous screening programme, metformin, TBAB, DM18D, and DBMPASBF were consistently detected across multiple sample types. Metformin showed particularly high concentrations in the water phase, while DM18D and DBMPASBF were more prevalent in sludge and particles, reflecting their hydrophobic nature.

The comparison between low and high degree treatment revealed that hydrophilic substances such as METFOR were partially removed during biological treatment, while hydrophobic and particle-associated compounds tended to accumulate in sludge. No substances were detected in blue mussels or sediments, suggesting limited bioaccumulation or persistence in the recipient environment under current conditions.

Overall, the screening programme highlights the environmental relevance of several emerging substances, particularly those associated with consumer products and industrial applications. The findings support continued monitoring and investigations of occupational exposure, and underscore the importance of understanding chemical behavior during treatment and in environmental compartments.

Norsk sammendrag

Screeningprogrammet 2024 undersøkte forekomst av nye og klassiske miljøgifter i to ulike kontekster: (1) Anlegg for håndtering og gjenvinning av elektronisk avfall (EE-avfall), og (2) kommunale avløpsrenseanlegg. Målet var å identifisere stoffer av bekymring, vurdere deres spredning i miljøet, og evaluere potensiell økologisk risiko. Valg av stoffer til screeningen var basert på prioriteringer satt av Miljødirektoratet.

I delen som omhandler EE-avfall, var fokus på liquid crystal display (LCD)-relaterte stoffer, flammehemmere (inkludert bromerte og klorerte forbindelser), plasttilsetningsstoffer og deres nedbrytningsprodukter. Prøver ble samlet inn fra to anlegg med ulike funksjoner – ett som utfører demontering og prosessering, og ett som fungerer som innsamlings- og sorteringsstasjon. Det ble samlet inn prøver fra luft, støv, vann, jord, mose og gnagere.

LCD-stoffer ble påvist i høye konsentrasjoner i innendørs støv, luft og overvann, med flere fluorerte forbindelser (f.eks. PCHPB, EDFPCHB, BTFPOMTP) som gikk igjen i flere matrikser. Metabolitter fra fosfororganiske flammehemmere (f.eks. DEHPO, DPPO) og ftalatmetabolitter (f.eks. MEP, MEHP) var også utbredt, med høye konsentrasjoner i støv, luft og biota. Klorparaffiner (spesielt LCCP) ble funnet i høye nivåer i partikulære og faste prøver, noe som indikerer miljømessig persistens og spredningspotensial.

I delen som omhandler avløpsvann, var fokus på bisfenolrelaterte stoffer og et sett oppfølgingsstoffer identifisert i tidligere screeningprogrammer. Prøver ble samlet inn fra et stort kommunalt renseanlegg med både lav og høy grad av behandling, samt fra resipientmiljøer (sedimenter og blåskjell).

Flere bisfenolderivater ble inkludert i analysen, men kun noen få ble påvist. BPA og BPS ble funnet i slam, mens DDPM, APPPPA og BBM hadde høyere deteksjonsfrekvens i partikler og slam. Blant stoffene som følges opp fra et tidligere screeningprogram ble METFOR, TBAB, DM18D og DBMPASBF påvist i flere prøvetyper. METFOR viste særlig høye konsentrasjoner i vannfasen, mens DM18D og DBMPASBF var mer fremtredende i slam og partikler, i tråd med deres hydrofobe egenskaper.

Sammenligningen mellom lav og høy grad av behandling viste at hydrofile stoffer som METFOR ble delvis fjernet under biologisk behandling, mens hydrofobe og partikkelbundne stoffer tenderte til å akkumulere i slam. Ingen stoffer ble påvist i blåskjell eller sedimenter, noe som tyder på begrenset bioakkumulering eller persistens i resipienten under gjeldende forhold.

Totalt sett gir screeningprogrammet verdifull innsikt i forekomst for både etablerte og nye miljøgifter, spesielt de som er del av forbrukerprodukter og industrielle prosesser. Funnene støtter videre overvåking og undersøkelse av yrkeseksponering av utvalgte stoffer, og understreker behovet for bedre forståelse av nedbrytningsveier og miljøskjebne, særlig for bisfenolderivater og industrielle tilsetningsstoffer.

Screening Program 2024

Substances in electronic waste facilities and wastewater treatment

1 Introduction

1.1 Aim of the 2024 Programme

The overall aim of the 2024 Screening Programme was to investigate the presence of substances of concern in: i) facilities for handling and recycling electronic waste (EE facilities), more specifically liquid crystal display (LCD) screens, and ii) wastewater treatment plants, and to:

- Investigate whether the substances of concern are found at these locations
- Investigate whether the substances of concern are found in surrounding nature
- Assess whether the levels may cause environmental damage

1.2 Information about the substances

1.2.1 EE facilities

Among the 215 substances and substance groups of concern targeted in the EE facilities part of the screening, 139 are so-called LCD substances. The molecular structure of LCD substances is generally based on a core structure of diphenyl or dicyclohexane, with various functional groups, e.g., cyano, fluorine, or other halogens. LCD substances are essential in LCD screens because they can shift between solid and liquid phases at specific temperatures. However, these substances are not covalently bound within the LCD screen, which means they have the potential to be released into the environment when the screen is damaged or processed for recycling. This poses a potential environmental concern, as several LCD substances are believed to be persistent, toxic, and capable of bioaccumulation and long-range transport (Cheng et al., 2023; Ge et al., 2023).

The EE facilities part of the screening also includes 39 other substances and substance groups relevant to facilities handling electronic waste. It is already well known that flame retardants and plastic additives can be found in large quantities at facilities handling e-waste—not only in less industrialized countries (Breivik et al., 2011; Nipen et al., 2022), but also in industrialized countries with conditions comparable to Norway (McGrath et al., 2018; Stubbings et al., 2019). Among the substances being investigated at EE facilities in this screening programme are metabolites or derivatives of such substances: metabolites of organophosphorus flame retardants (OPFRs), phthalate metabolites, and debrominated forms of tetrabromobisphenol A (TBBPA) and decabromodiphenyl ethane (DBDPE).

Chlorinated paraffins (CPs) are also a focus of this screening. CPs are already known to occur in significant amounts at e-waste handling facilities (Möckel et al., 2020; Nipen et al., 2022). In this study, in addition to the well-studied short, medium and long chain CPs, metabolites of CPs and several previously less-studied subgroups of CPs such as the very short chain CPs, bromo-chloro paraffins/olefins, and CP metabolites are included for investigation, due to their potential environmental persistence, toxicity, and bioaccumulative properties (Darnerud & Bergman, 2022; He et al., 2022).

1.2.2 Wastewater treatment

The substances investigated in the part concerning wastewater treatment plants include 26 new bisphenols and bisphenol derivatives. Bisphenol A (BPA) has been used in the production of polycarbonate plastics and has well-documented negative effects on health and the environment (Abraham & Chakraborty, 2020; Rochester, 2013). The use of BPA is therefore regulated in the EU under REACH, and several BPA-like substances are listed on the REACH Candidate List. A number of bisphenols, used both as substitutes for BPA and in various other applications, are relevant for regulation due to concerns that they may have similar health and environmental properties. In addition, several BPA derivatives are considered relevant for regulation because they may degrade into BPA in the environment.

In addition, 11 substances from previous screening programs are included. This list includes dyes and substances with known uses in the plastics and polymer industry, metalworking, and detergents. These substances exhibit a wide range of physicochemical properties.

For an overview of substance groups analysed in the different matrices see Table 1, and for a complete list of substances included in the 2024 Screening Programme, see Appendix 1.

Table 1: Overview of substance groups analysed in the different matrices (pink = analysed, light blue = not analysed).

		LCD-substances	Flame retardants/ plasticisers and their degradation products	Chlorinated paraffins and related substances	Follow-up substances from previous screening programme	New bisphenols and bisphenol derivatives
EE facilities	Air					
	Dust					
	Stormwater					
	Process water					
	Rodents					
EE facilities surroundings	Soil					
	Moss					
Other samples	Air Sofienberg park, Oslo					
	Air Zeppelin station, Svalbard					
WWTP High purification	Waste water					
	Sludge					
WWTP Low purification	Waste water					
	Sludge					
Recipient wastewater	Blue mussels					
	Sediment					

1.3 Rationale for sampling locations and sample types

1.3.1 *EE facilities*

The part of the screening concerning EE facilities investigated LCD substances and other substances potentially associated with electronic waste. The objective of this part of the screening was to assess the occurrence and release of these substances into the environment in and around facilities that handle or recycle electronic waste (specifically LCD screens), and based on the findings, evaluate whether these substances may pose an environmental risk.

No information was found indicating that any of the substances are produced in Norway, making hotspots from production-related factory emissions unlikely. Samples were therefore collected from the following locations:

- Electronic waste recycling facilities handling LCD screens
- The external environment surrounding electronic waste recycling facilities
- Air from an urban environment
- Air from an Arctic environment

The LCD substances and other compounds investigated in this part of the screening cover a wide range of physicochemical properties. As a result, it was expected that, if released, they could be detected in various environmental media in and around the e-waste recycling facilities. Accordingly, we analysed air, dust, and process water at the facilities, as well as air, stormwater, soil, vegetation, and rodents from the surrounding areas. Samples were collected from two electronic waste processing facilities, referred to in this report as EE facility 1 and EE facility 2 (see method chapter for further details on the two facilities).

Some LCD substances possess properties that suggest a potential for long-range atmospheric transport (Ge et al., 2023). To explore this, air samples were collected from NILU's atmospheric monitoring station at Zeppelin on Svalbard to investigate whether any LCD substances could be detected in the Arctic, far from known source areas. Additionally, air samples were collected from the urban monitoring station in Sofienberg Park in Oslo to examine whether an urban signal of LCD substances could be identified.

1.3.2 *Wastewater treatment plant*

The part of the screening programme concerning wastewater treatment plants included new bisphenols and bisphenol derivatives, in addition to follow-up on findings from the 2019 screening program. The purpose of this part of the screening was to investigate the occurrence of these substances in wastewater treatment plants and their release into the surrounding environment, and based on the results, assess whether the substances may pose an environmental risk. Wastewater is considered a "hot spot" for many substances, as wastewater receive substances from products in everyday use in households as well as residues from industrial and urban environments. Even though wastewater treatment removes substances to a varying degree, not all substances are removed before the treated wastewater is discharged into the environment. The treated wastewater from large parts of the Oslo area is discharged into the Bekkelaget basin of the Oslo fjord. Recipient samples of marine sediments and mussels will indicate if substances in the treated discharge are accumulating and/or taken up in the food web. Blue mussels filter water and can therefore take up substances present in the water phase and on small particles, while particle-bound substances will tend to accumulate in sediments.

No information was found indicating that any of the substances are produced or used directly in Norway, making any hotspots from production-related factory emissions unknown. Samples were therefore collected from the following suspected hotspot locations:

- Municipal wastewater treatment plants with both high and low treatment efficiency
- Recipient environments associated with municipal wastewater treatment plants

The substances investigated in this screening have a wide range of applications, making wastewater treatment plants well-suited for assessing ongoing use. Samples were collected from wastewater at both high and low treatment stages, as well as from sludge. One of the substances on the list, Carene (CAS No. 498-15-7), is so volatile that it was not expected to be found in solid samples; therefore, it was only analysed in water samples.

Details of the sampling procedures are described below in Section 2.1. and 2.2.

2 Materials and methods

2.1 Sampling strategy EE facilities

Background research during the tendering process for this screening programme revealed that LCD screens are not currently recycled in Norway. Screens are collected at various smaller collection points (environmental stations, waste facilities, and similar) and then sent to one of two main operators who remove the base from the screens before they are packed and shipped for recycling abroad. One of these main operators was selected for sampling, this location is referred to in this report as EE facility 1. EE facility 1 is a modern facility that, in addition to LCD screens, handles other types of electronic waste as well. We also collected samples at a smaller operator, referred to as EE facility 2. EE facility 2 serves as an intermediate station for the collection of LCD screens. They receive screens either directly or *via* smaller collection points, then pack and send them on to EE facility 1. EE facility 2 handle other types of electronic waste in addition to LCD screens but also scrap metal and used machinery and vehicle parts.

2.1.1 Sampling, EE facility 1

The location of EE facility 1 is shown in Figure 1. Sampling was concentrated around the building where screens are handled. Various types of screens—TVs, laptops, and monitors—are received here. The screens are placed on a conveyor belt and transported to a workbench where recyclable units are partially dismantled before being packed and sent to facilities abroad (Figure 2). Screens that are not to be recycled in this manner, such as older televisions, are dismantled more extensively before the remaining parts continue along the conveyor belt and drop into collection points outside the building. Laptops are opened using a circular saw to remove specific components before being packed and shipped.

An overview of the samples taken at this location, including sample codes and corresponding descriptions, is shown in Table 2.

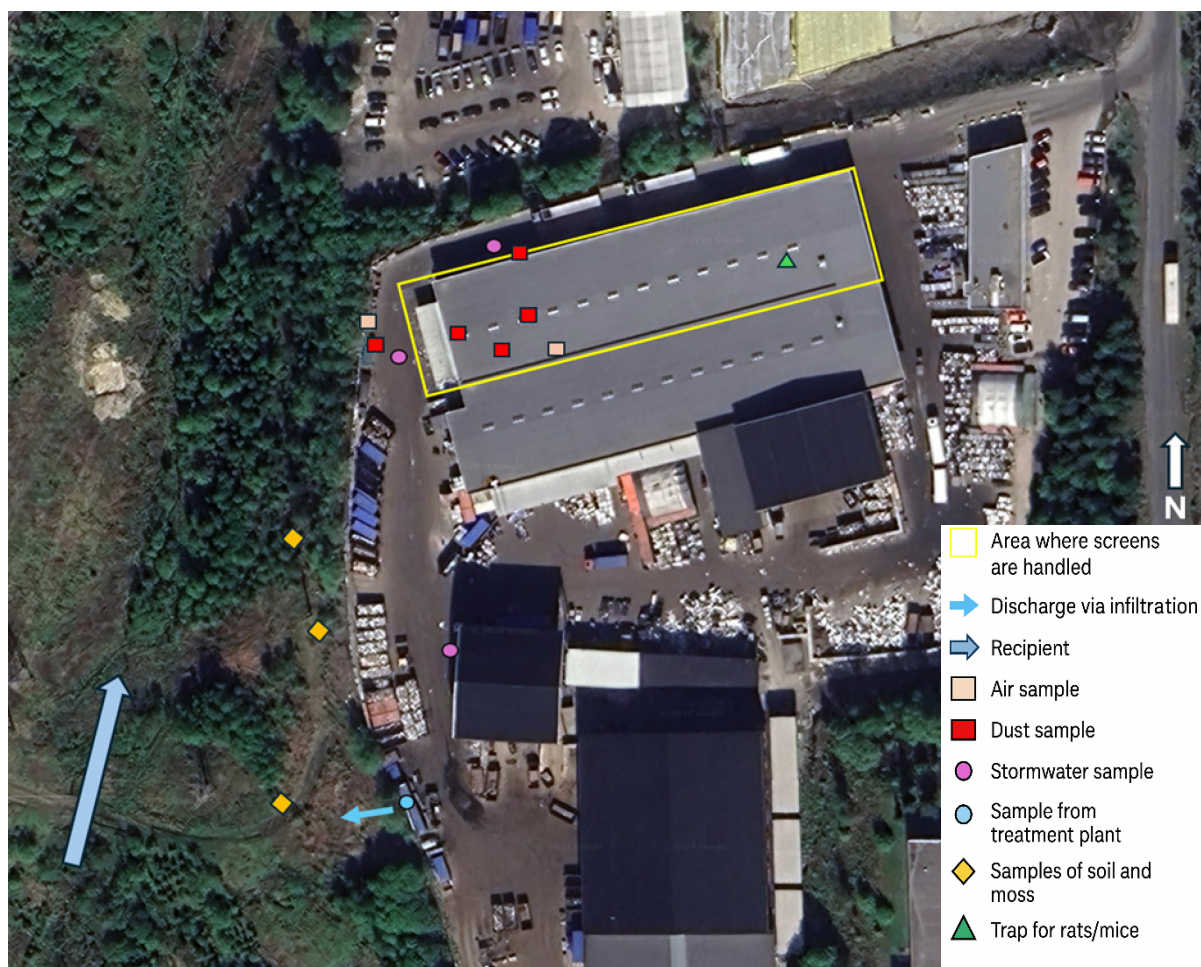


Figure 1: Overview of the site and sampling points, EE facility 1



Figure 2: Pictures from operations at EE facility 1.

Table 2: Overview of samples from EE facility 1

Area	Matrix		Number of samples
Inside the premises	Air	Outside	1
		Inside	1
	Dust	Outside	2
		Inside	3
	Process water	From treatment facility	3
	Surface water		3
	Rodents	Mice	2 (combined to one sample)
Outside the premises	Soil		3
	Moss		3

Air

Air samplers were set up at two (2) points: one (1) outdoors and one (1) indoors (Figure 1). Parallel samples were taken at each point to cover different analytical methods. Each sample represented approximately 48 hours, with total sampling volumes of 47.7 m³ and 45.1 m³ for the outdoor samples, and 57.6 m³ and 43.0 m³ for the indoor samples. The first two samples were collected between 16 and 18 September, and the final two between 18 and 20 September. For one of the samples, the sampling time and volume are uncertain, as it was discovered that the hose had become detached from the sampler when the sample was to be retrieved on 18 September.

The sampling points had to be adapted so as not to interfere with daily operations (Figure 3). The indoor sampling point was placed against the wall inside the building, approximately 30 metres from the workstation where screens are handled. The outdoor sampling point was placed by the fence, behind concrete blocks, to protect it from loading and unloading activities (lorries and forklifts). The sampler at the fence was approximately 20 metres from the point where electronics, including certain types of screens, exit the building *via* a conveyor belt and fall into open collection points (Figure 2).



Figure 3: Images of air sampling points, EE facility 1

Dust

Three duplicate dust samples were collected indoors at EE facility 1. Sampling was conducted using an industrial vacuum cleaner (Nilfisk GM 80P) equipped with a specially adapted nozzle (Krim. Teknisk Materiel AB, Bålsta, Sweden). Inside the nozzle, a cellulose membrane filter was placed in a filter holder (styrene-acrylonitrile polymer) to be able to collect the dust. The samples were taken next to a workstation where screens arriving *via* conveyor belt are dismantled (Figures 4a and 4b), at a workbench where laptops and screens are opened using a saw (Figure 4c), and on top of barrels positioned beneath one of the conveyor belts for screens and other electronic waste (Figure 4d). A significant amount of dust was observed on all surfaces inside the building.

Outdoor dust samples were taken at two points (Figure 1 and Figure 5). The first sample was collected on the north side of the building where screens are handled, beneath a canopy where various types of waste are temporarily stored. Near this sampling point, an open window/emergency exit was observed. It is assumed that this window is used for ventilation and that dust from indoor activities may escape through it. All dust samples were collected in duplicates to ensure sufficient sample material at each point.

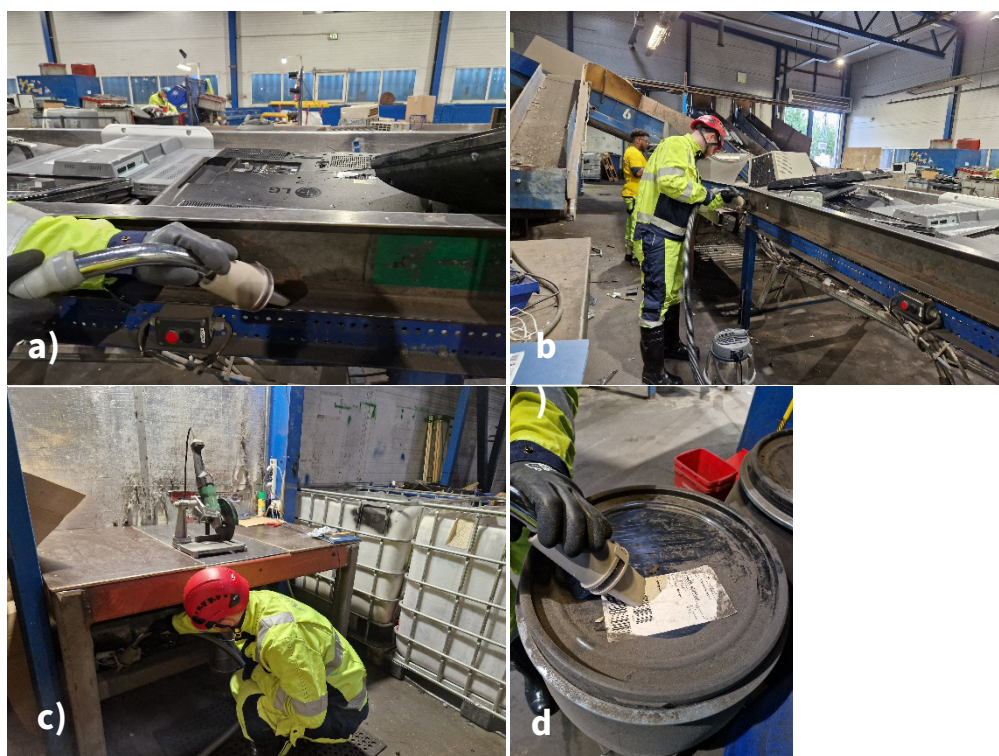


Figure 4: Indoor dust sampling, EE facility 1.



Figure 5: Outdoor dust sampling, EE facility 1.

Water

Samples were collected from the stormwater system at three manholes (Figure 1 and Figure 6). These manholes collect surface water from the area surrounding the building where screens are handled, and channel it to a larger retention basin. The retention basin is located next to a mobile treatment facility, where the water is further directed before being infiltrated into a stone bed at the edge of the site. In cases of heavy rainfall, overflow from the retention basin is discharged directly via pipes to the stone bed at the site's perimeter. The water from the stone bed is likely drained into a stream that runs through a low point in the terrain on the western side of the site (Figure 1).

Samples of the water phase were taken using a bottle mounted on a telescopic rod.



Figure 6: Images of stormwater system sampling, EE facility 1.

The treatment facility at the site (Figure 7) is a mobile setup (container) where stormwater is pumped into a particle filter, which removes suspended solids and returns them to a sand filter. The water then passes through three filters in sequence, each containing different sorbents, before being discharged.

Samples of the discharge water were taken from a collection tank used for composite sampling over time, with a standard frequency of one sample per 200 litres of treated water. The first sample was taken on 9 September and represented a sampling interval of seven days. The next two samples, taken on 11 and 13 September, each represented two-day intervals. For the final two samples, the composite sampling frequency was increased to obtain sufficient sample volume. However, higher-than-normal water volumes were observed in the treatment facility during the sampling period (9 to 13 September) due to heavy rainfall.

All water samples were stored cold (4 °C) and in darkness before being handed over to NILU on 20 September 2024.



Figure 7: Images from sampling of discharge water from the treatment facility.

Soil and moss

Samples of soil (topsoil) and moss were collected from a wooded slope outside the facility, southwest of the building where screens are handled (Figure 1). During work in the area, small fragments of electronics and other waste were observed along the edge of the fence bordering the slope where sampling took place. Remnants of waste were also noted in the forest outside the facility. Sampling directly west of the building was initially desired, but the terrain there was steep and inaccessible, characterised by extensive rock and stone. The sampling points were therefore concentrated further to the southwest. Samples were collected from the area directly below the treatment facility.

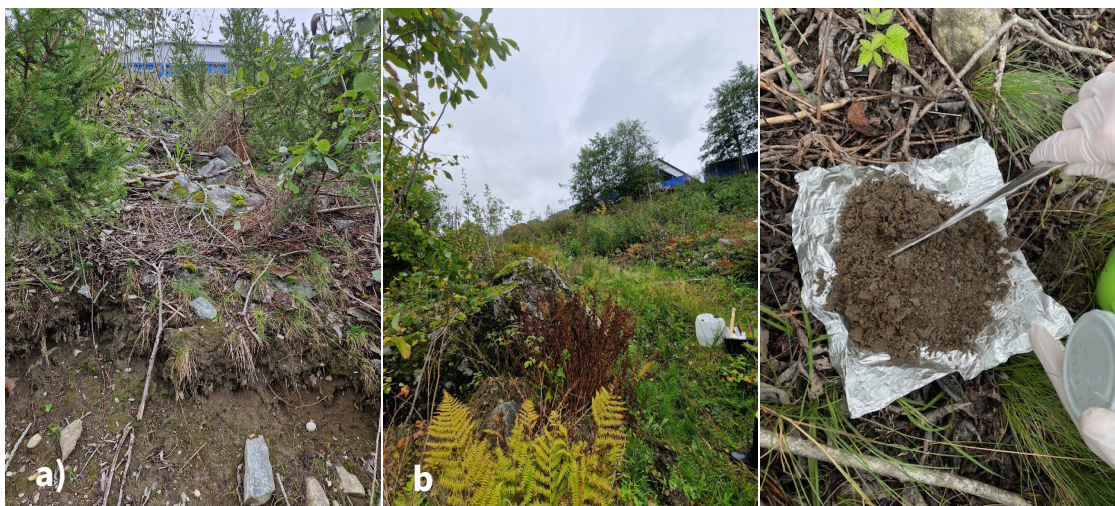


Figure 8: Images of sampling points for soil and moss, EE facility 1

Rodents

By agreement with EE facility 1, rodents caught in traps inside the screen-handling facility were collected between January and September 2024. During this period, two mice (29 January 2024; and 15 May 2024) were found in the traps (Figure 9). These were, packed, labelled and frozen at the time they were found. The samples were handed over to NGI on 9 September 2024. They were subsequently stored in a freezer (-18°C) until they were dissected on 27 September 2024, and the livers were extracted for analysis. Prior to dissection, the samples were gradually thawed in a refrigerator (4°C) to avoid unnecessary tissue damage and to minimise the time the liver remained thawed. The mouse livers were frozen immediately after extraction and handed over to NILU for analysis (7 August 2024). Given the small mass, the two livers were combined to one sample for analysis.

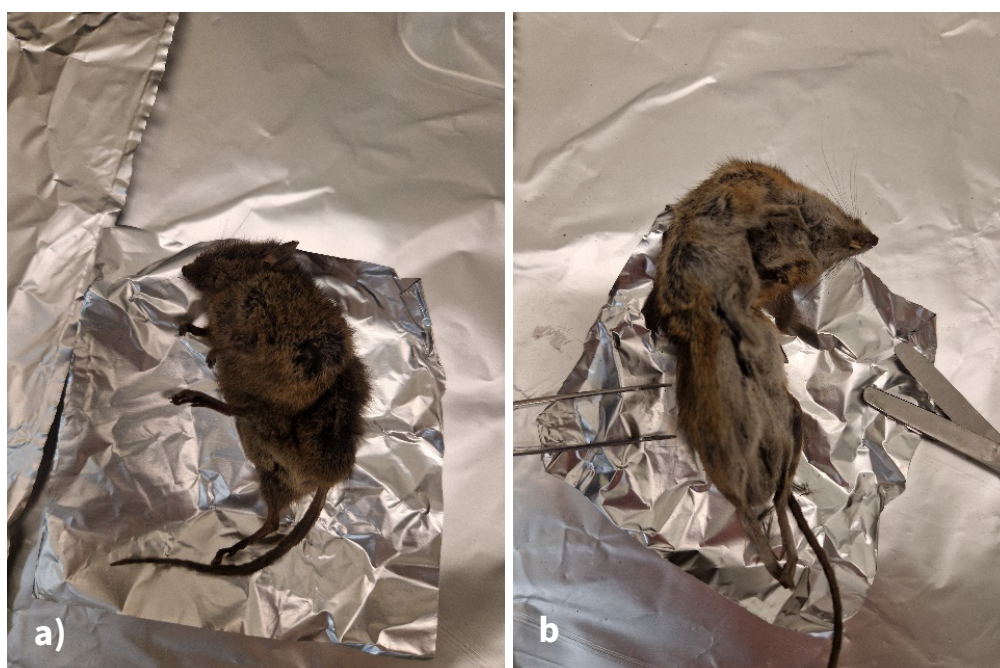


Figure 9: Rodents collected from traps at EE facility 1.

2.1.2 Sampling, EE facility 2

The location of EE facility 2 is shown in Figure 10. Sampling was focused around the building where screens are handled. Here, cages filled with electronic waste from smaller collection points in the region are received. These deliveries include various types of screens, TVs, laptops, and monitors. The cages are emptied in a covered open area located just outside the building where the screens are sorted. Once emptied, the waste is roughly sorted using an excavator with a claw, so that items intended for recycling, including screens, are placed onto a conveyor belt. The conveyor transports the waste indoors, where screens are removed at workstations along the belt. The screens are then packed into boxes and sent directly to EE facility 1. Images illustrating this process are shown in Figure 11.

A list of the samples collected at this location is presented in Table 3.



Figure 10: Overview of the sampling site and sampling points, EE facility 2.

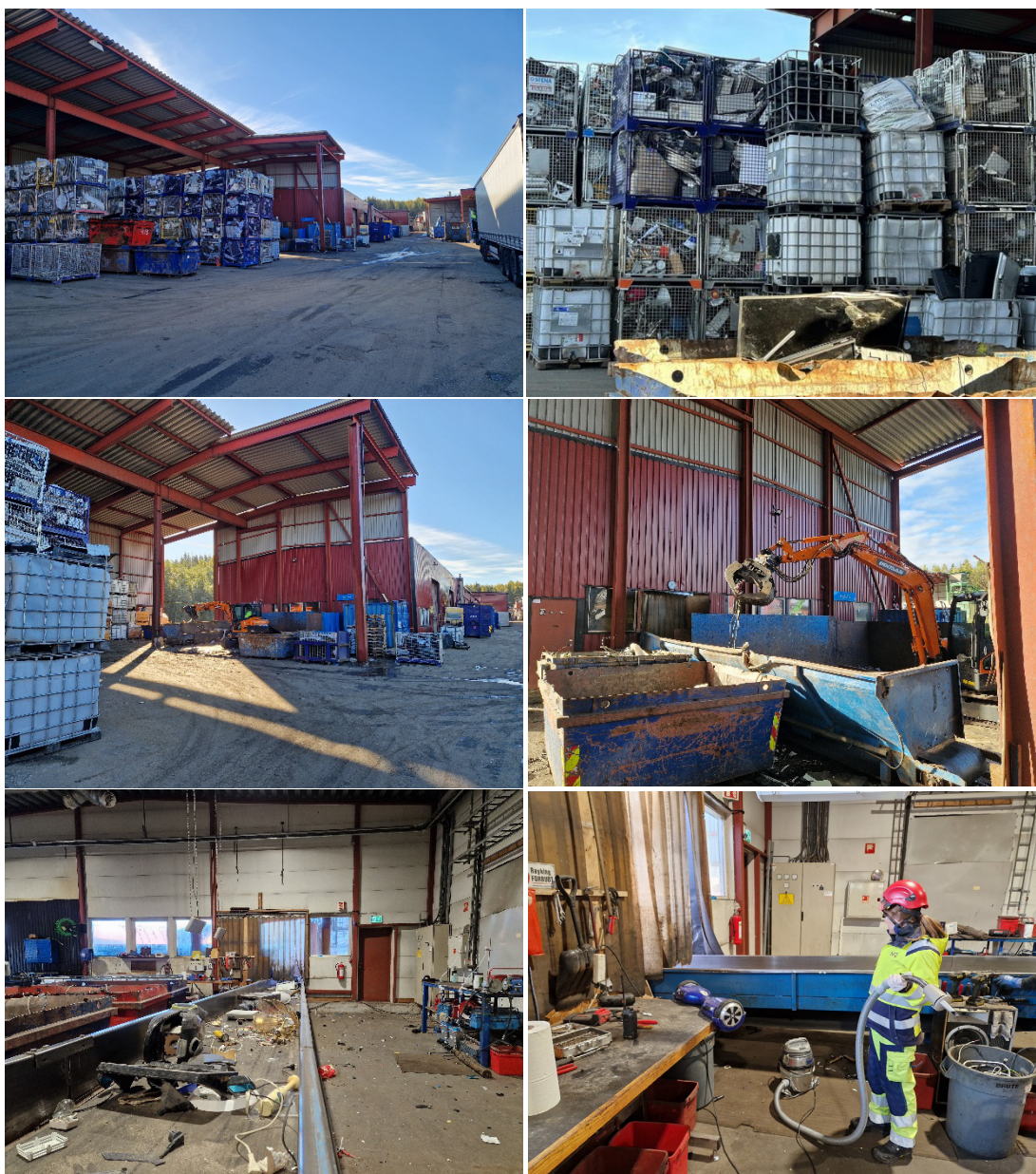


Figure 11: Pictures from EE facility 2.

Table 3: Overview of samples from EE facility 2

Area	Matrix		Number of samples
Inside the premises	Air	Outside	1
		Inside	1
	Dust	Outside	2
		Inside	2
	Process water	From treatment facility	3
	Surface water		3
Outside the premises	Soil		3
	Moss		3

Air

Air samplers were installed at two points: one outdoors and one indoors (Figure 10). Two parallel samples were taken at each point (1 and 2), each representing approximately 48 hours, with total sampling volumes of 49.1 m³ and 49.6 m³ for the outdoor samples, and 48.0 m³ and 50.4 m³ for the indoor samples. The first two samples were collected outdoors between 30 September and 2 October (MO-L-U), and the final two samples indoors between 2 and 4 October (MO-L-I) (Figure 12).

The sampling points were placed directly adjacent to the areas where screens are handled, both outdoors and indoors. Outdoors, cages containing e-waste collected from smaller collection points are emptied. The waste is roughly sorted using an excavator, and screens and other units intended for recycling are placed onto a conveyor belt that transports them into a facility for fine sorting. Indoors, larger-screen units (TVs, laptops, etc.) are picked from the conveyor belt and placed into boxes that are sent directly to EE facility 1.

*Figure 12: Images of air sampling points, EE facility 2.*

Dust

Dust samples were collected at two outdoor points. Both points were surfaces located directly next to the area where electronic waste from smaller collection points is emptied and roughly sorted before being placed onto a conveyor belt leading to sorting workstations.

Indoor dust samples were taken at two points. The samples were collected beneath the conveyor belt where screens enter the facility—next to a workbench where they are packed, and at another workbench further along the same conveyor belt. All dust samples were collected in duplicates to ensure sufficient sample material at each point.

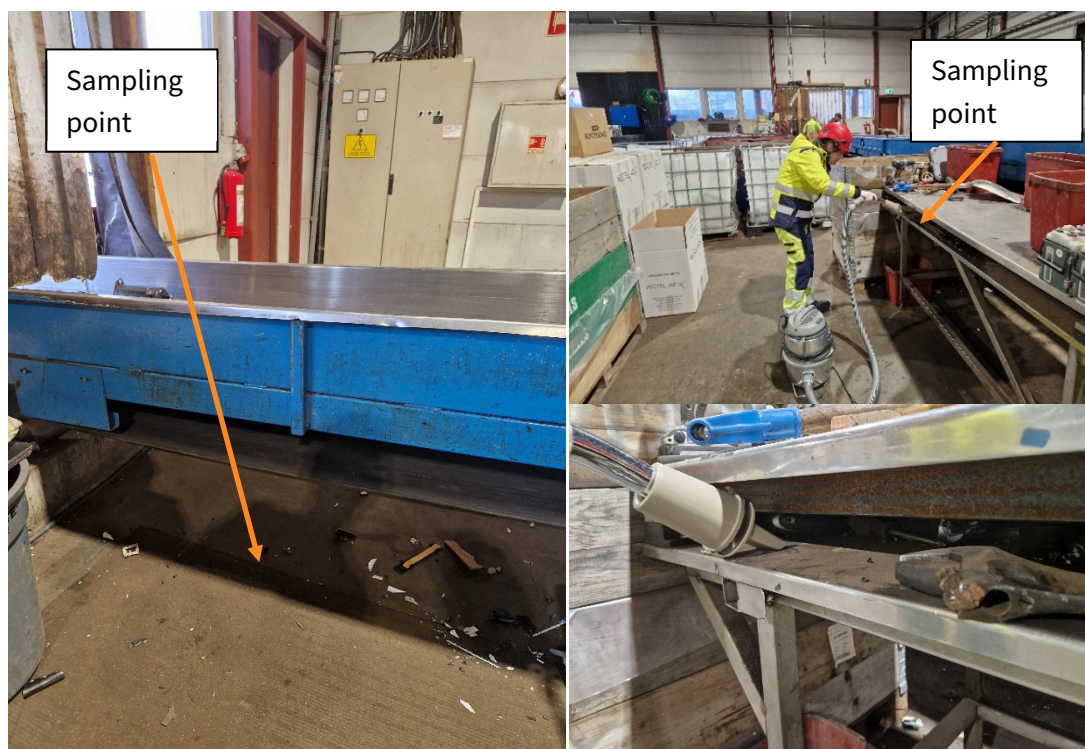


Figure 13: Images of dust sampling points, EE facility 2.

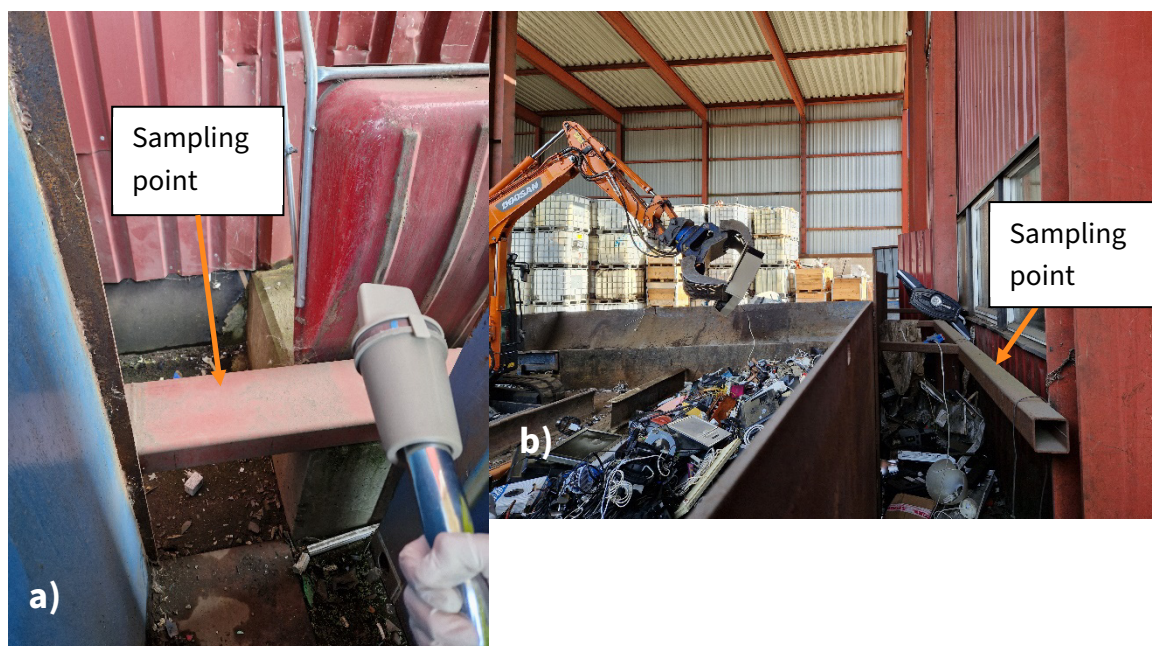


Figure 14: Images of dust sampling points, EE facility 2.

Water

Samples were collected from the stormwater system at three manholes (Figure 10 and Figure 15). These manholes collect surface water from the area surrounding the building where screens are handled and direct it through a series of oil separators and onward to a treatment facility.

Samples of the water phase were taken using a bottle mounted on a telescopic rod (Figure 15).

Samples of discharge water were taken from the pipe that releases treated water into the recipient watercourse (Figure 16). Three samples were collected at two-day intervals: 30 September, 2 October, and 4 October. Increased water flow was observed on 30 September due to rainfall during the preceding week. The flow was somewhat reduced during the subsequent two sampling events, as no rainfall occurred during that period. See Figure 17 for a schematic of the treatment facility setup. The treatment system consists of a combination of mechanical filtration (belt filter and sand filter) and sorption using rubber granulate.

All water samples were stored cold (4°C) and in darkness before being handed over to NILU for analysis on 7 October 2024.



Figure 15: Sampling points for stormwater at EE facility 2.



Figure 16: Treatment facility and sampling point for discharge of treated stormwater to the recipient.

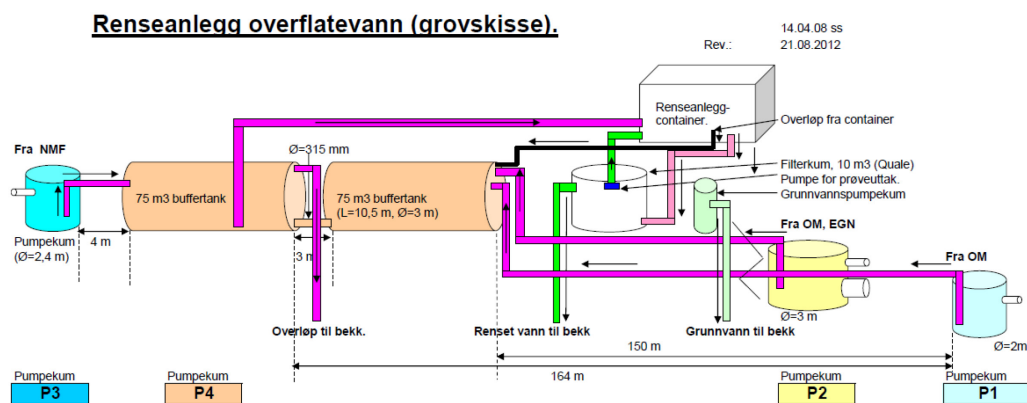


Figure 17: General schematic showing the layout of the treatment facility at EE facility 2.

Soil and moss

Samples of soil (topsoil) and moss were collected at three sampling points located on the slope leading down to the recipient stream (Figure 18). This area lies on the outskirts of the facility, east of the building where screens are handled (Figure 10). Soil and moss samples were taken at the same points. Plastic and small

fragments of electronics and other waste were observed along the edge of the asphalt and on the slope where sampling was conducted. The slope was likely constructed during the development of the facility, and therefore only a thin layer of topsoil (0–5 cm) was present above crushed stone and gravel. The area where the soil samples were taken is likely to receive dust stirred up during the rough sorting of e-waste, which takes place under cover nearby.

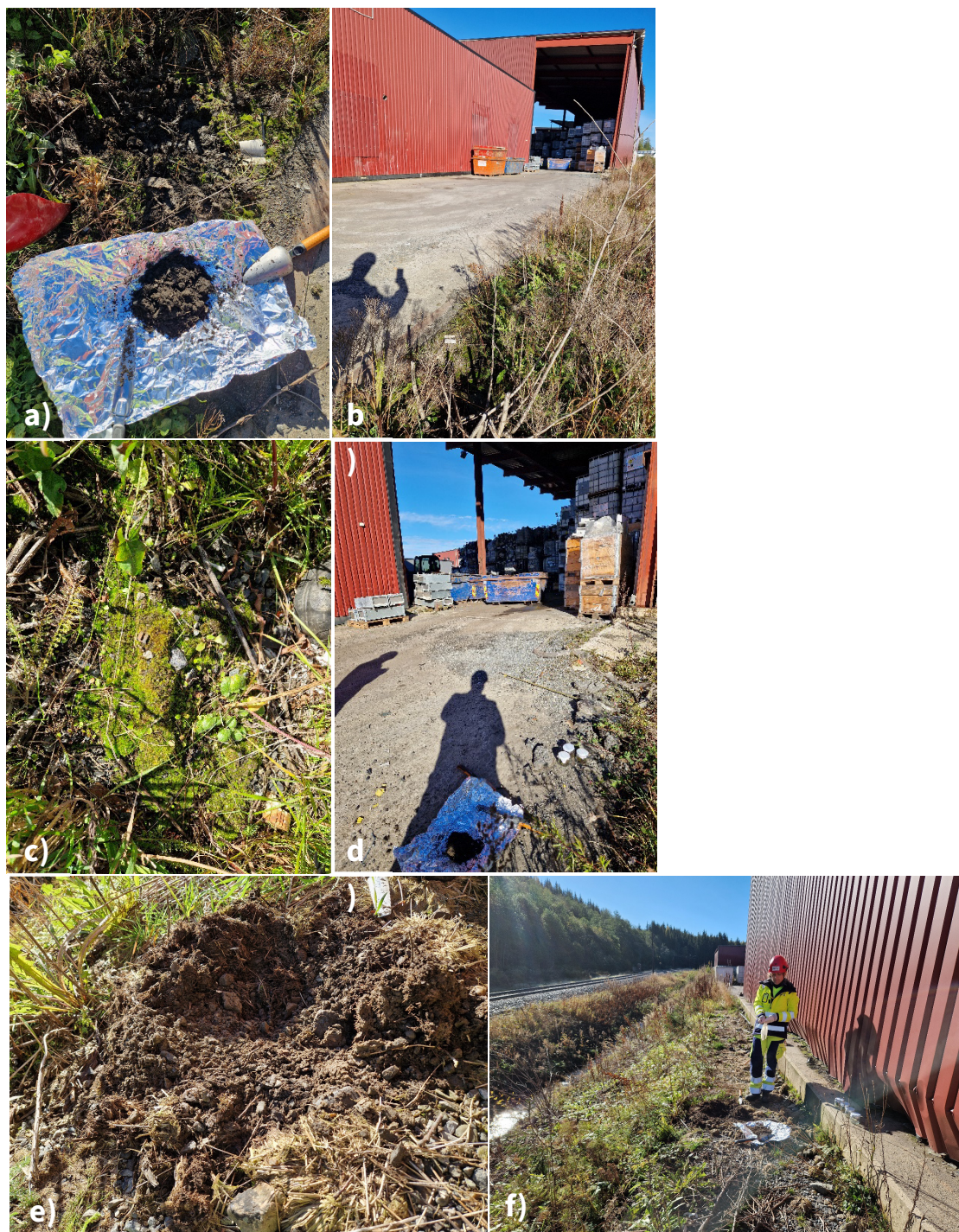


Figure 18: Sampling points for soil and moss at EE facility 2.

2.2 Sampling, Wastewater treatment plant

Bekkelaget wastewater treatment plant

Samples were collected from the Bekkelaget wastewater treatment plant, which is the second largest wastewater treatment plant in Norway (ca. 500,000 person equivalents). The plant is equipped with sequential simple primary (mechanical) and advanced tertiary (biological-chemical) treatment systems. Thus, the plant allows for sampling of wastewater treated with two different degrees of removal principles, treating the same incoming wastewater. The low degree (primary) treatment consists of mechanical treatment by a coarse screen, a sand- and grease trap, and pre-sedimentation. Scrap material from the coarse screen and sand from the fat trap are landfilled, while grease from the fat trap and settled solids from the pre-sedimentation basin (primary sludge) are transferred to further sludge treatment (anaerobic sludge digestion for biogas production). High degree (tertiary) treatment is achieved by subsequent biological treatment in a co-precipitation step that also include nitrogen removal (anoxic and aerobic treatment). The resulting effluent goes through a sand filter (polishing step) before the treated wastewater is discharged. Sludge from the biological treatment is co-digested with the primary sludge. The treated water is discharged into the Bekkelaget basin in the Oslo fjord (50 m depth). Bekkelaget wastewater treatment plant has also been sampled in several of the previously conducted screening programmes.

Samples of water and sludge were collected to represent both the low and high degree of treatment. To represent the simple/primary treatment, water samples were collected from the effluent from the pre-sedimentation basin while sludge samples were collected from the primary sludge (from the transport belt). To represent the advanced/tertiary treatment, water samples were collected from the final effluent water, while sludge samples were collected from the final (digested and dewatered) sludge at the downfall from any of the centrifuges in operation at the time of sampling. The samples were collected during at two different time periods, representing summer and autumn conditions, respectively. See Table 4 for an overview of the samples.

Water samples were collected as time-proportional twenty-four-hour composite samples using automatic sample collectors and directly transferred to 10-L annealed glass bottles, according to NS-EN ISO/IEC 17025. See Figure 19. The water samples were transferred in a cooling box to the NIVA lab and stored in a refrigerator at 4°C until further processing. The sludge samples were collected by personnel at the treatment plant taking out one grab sample per day using a stainless-steel rod (rinsed with water between each sampling) (see Figure 19) and transferring them to one Rilsan bag per one-week composite sample. The composite sample was stored frozen at -20°C until further handling. Sampling was carried out in accordance with the guidelines in NS-ISO 5667-10.

Table 4: Information on the samples collected from the wastewater treatment plant.

Condition	Season	Sample type	Number of samples
Low degree treatment	Summer	Water, filtered	2
		Water, particles	2
		Sludge	1
	Autumn	Water, filtered	2
		Water, particles	2
		Sludge	1
High degree treatment	Summer	Water, filtered	2
		Water, particles	2
		Sludge	1
	Autumn	Water, filtered	2
		Water, particles	2
		Sludge	1

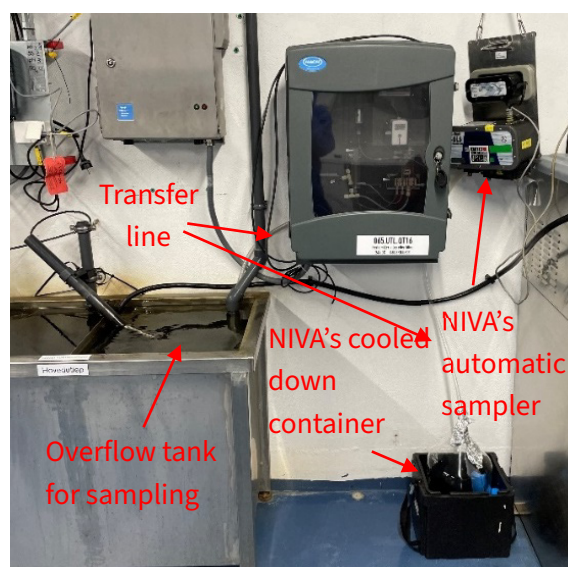


Figure 19: Photo of the automatic water sampler used at the wastewater treatment facility (left) and the site for sludge sample collection (right). Photos: NIVA/Christian Vogelsang.

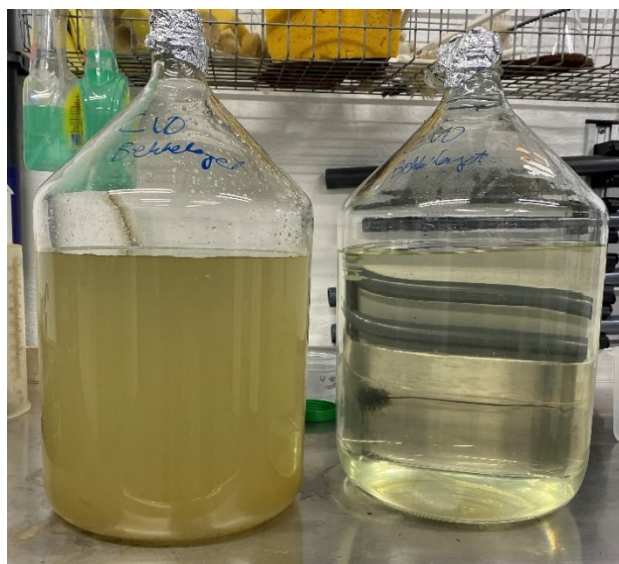


Figure 20: Photo of water samples collected (left) following low quality treatment (dark coloured) and high-quality treatment (light coloured). Photos: NIVA/Christian Vogelsang.

Recipients – treated wastewater

Recipient samples of marine sediments and blue mussels were collected from the Bekkelaget basin in the vicinity of the water discharged from the wastewater treatment plant described above. The samples were collected from three different sites, as outlined in Figure 21 and Table 5.

The sediments were collected from the top layer (0-2 cm) using a small van Veen-grab sampler from a boat (Figure 22). From each site, the sample was made as a composite of four, which is in accordance with The Norwegian Environment Agency's guide for risk assessment of contaminated sediment (TA-2802/2011, sediment guide).

The blue mussels (*Mytilus edulis*) were collected by snorkelling. From each site, approximately 100-200 shells with a size of 2-7 cm were collected. At the site, the shells were rinsed with sea water and placed in polyethylene plastic bags (approved for food storage). Malmøya and Bleikøya had a fair number of mussels, but it was challenging to find enough material on Gressholmen.

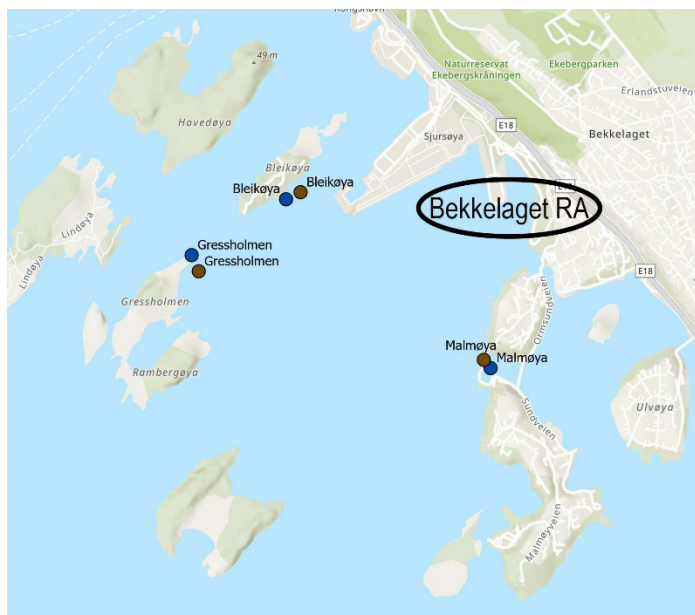


Figure 21: Map showing the three sites for sampling recipient sediment (brown) and blue mussel (blue) samples as well as the location of the wastewater treatment plant.



Figure 22: Sampling sediments from a boat (left) and snorkeling for blue mussels (right). Credit: NIVA.

Table 5: Information on the marine recipient samples collected near the wastewater treatment plant.

Location (in map)	Sample type	Water depth (m)	Composite of	N
Bleikøya (A)	Sediment	17.8, 19.4, 18.9, 18,9	4	1
	Blue mussel		29-80	1
Malmøya (B)	Sediment	17.6, 15.6, 19.2, 17.7	4	1
	Blue mussel		18-65	1
Gressholmen (C)	Sediment	16.2, 17.4, 16.5, 15,2	4	1
	Blue mussel		15-49	1

2.3 Analytical methods

Analytical methods are summarized in *Table 6*, and described in more detail in Appendix 2. In general, solid samples including biota, sediments, sludges and dust were extracted with an appropriate organic solvent mixture following the addition of internal standards. Liquid samples were extracted via liquid/liquid extraction or solid phase extraction. Analysis for all substances was via either LCMS or GCMS.

Table 6: Overview of the techniques used for sample extraction and analysis for each group of substance and matrix type.

Group	Water	Particles/sludge/sediment	Biota	Dust/soil	Instrument
LCD substances	SE	SE	SE	SE	GC-HRMS
Bisphenols	SE/SPE	ASE	SE	ASE	LC-HRMS
Previous screening subst.	SE/SPE	ASE/SUPRAS	ASE/SUPRAS	ASE/SUPRAS	LC-HRMS
Previous screening subst. (VOC)	Tenax				GC-HRMS
OPFR metabolites	SPE	SE/SPE	SE/SPE	SE/SPE	LC-HRMS
Phthalate metabolites	SPE	SE/SPE	SE/SPE	SP/SPE	LC-HRMS
PBDEs, other BFRs, S/M/LCCP, Dechloranes	SE	ASE	SE	ASE	GC-HRMS, LC-HRMS

ASE = Accelerated Solvent Extraction

SE = Solvent Extraction

SPE = Solid Phase Extraction

SUPRAS = Supramolecular solvent extraction

GC-(HR)MS = Gas Chromatography (High Resolution) Mass Spectrometry

LC-(HR)MS = Liquid Chromatography Mass Spectrometry

2.4 Calculations and data presentation

All calculations were conducted in excel or computed using the R programming language (R Core Team, 2023). The detection frequency is based on sample types. For the heatmap tables, presenting detection frequencies and average values, any observation below the method limit of detection (LOD) was replaced by the value of 0.5 * LOD, which was then included into the average value. Note that we here use LOD rather than the limit of quantification (LOQ) due to the nature of the programme which is screening. For the biological samples, soil and moss, concentrations are presented “as measured”, i.e. ng/g wet weight (w.w.)

2.5 Collection of EQS and PNEC

Toxicity data were obtained in the form of environmental quality standards (EQS) where available, but mainly in the form of PNECs (predicted-no-effect concentrations). In general, EQS are more robust parameters for assessing risk compared to PNECs, but for emerging substances EQS are typically not available. The PNECs are the concentrations of a chemical which marks the limit at which below no observed adverse effects of exposure in an ecosystem is expected. A PNEC is obtained through the application of an assessment factor to ecotoxicological endpoints (EC50 or no observed effect concentration, NOECs) using organisms from at least three trophic levels (usually algae, daphnids, and fish). The assessment factor depends on duration of the test (acute or chronic) and the number of trophic levels with available data. Higher assessment factors are used when only acute data have been used. Also, a higher assessment factor is typically used to encompass for higher uncertainty related to the PNEC value. The minimum requirement for deriving a PNEC is acute toxicity for algae, daphnids, and fish. The PNECs used herein were collected from two databases, by priority, of ECHA (European chemicals agency: <https://echa.europa.eu/>) and the Ecotoxicology Database from NORMAN (Network of reference laboratories, research centres and related organisations for monitoring of emerging environmental substances) (<https://www.norman-network.com/nds/ecotox/lowestPnecsIndex.php>). When no experimental derived PNECs were available, QSAR based prediction models can be used for prioritization purposes (Aalizadeh et al., 2017). However, modelled PNECs include additional simplifications and uncertainties compared to experimentally derived PNECs. In addition, most PNEC data have not been fully reviewed and verified by experts. This is particularly applicable to some of the PNECs from NORMAN, as demonstrated by (Welch et al., 2023). The environmental compartments of freshwater, soil, marine water and marine sediment have been used. The PNECs were collected as is, and without any further quality assurance.

3 Results and discussion

3.1 EE facilities

3.1.1 Detection frequencies and average concentrations

Here, results are presented for the substances that were found at levels above the LOD of the respective methods. For the EE facility part, comprising 40 different samples, 142 of the 215 analysed substances were found. This demonstrates that e-waste handling environments represent a complex mixture of both legacy and emerging contaminants. The breadth of detections itself is an important finding, showing that these facilities act as multi-pollutant hotspots, not just for one or two priority groups. In contrast, within the wastewater treatment part of the screening programme, the 18 samples collectively contained only nine of the analysed substances. Some substances were determined by so-called suspect screening. This means that only qualitative analysis has been conducted due to the lack of commercially available standard materials. These are presented in separate tables.

For a complete list of substances included in the 2024 Screening Programme see Appendix A1. The complete set of results can be downloaded from the Vannmiljø database (<https://vannmiljo.miljodirektoratet.no/>).

The wide coverage of substances and the clear differences between detection frequencies in indoor and outdoor samples strongly underline the role of handling processes inside the facilities as dominant emission sources. Dust and air, in particular, function as primary carriers for dispersal, while stormwater channels act as important vectors for secondary release into aquatic environments.

LCD Substances

Of the 139 LCD substances analysed, 73 were detected in one or more of the samples from the two EE facilities. 52 of the LCD substances were detected >30% in two or more matrices, and these are included in the figures and discussion below. Figure 23 shows detection frequencies and mean concentrations, while Figure 24 shows only detection frequencies (LCD substances analysed by suspect screening).

Dust collected inside the EE facilities showed the highest number of detected LCD substances. The LCD substances with the highest average concentrations in indoor dust were EDFPCHB (1 000 ng/g), DFTFPPBP (1 000 ng/g), EDFPCHBP (900 ng/g), BTFPOMTP (800 ng/g), PCHVCH (600 ng/g), TPEFP (600 ng/g), and PCHPB (600 ng/g) (Figure 23, Figure 24). Dust collected in areas outside at the facilities where electronics are stored or processed also contained a high number of LCD substances, but generally at lower concentrations compared to the indoor dust. The highest average concentrations of LCD substances in outdoor dust were PCHPB (300 ng/g), DFPCHB (300 ng/g), and ETFP (100 ng/g). The concentrations of LCD substances in indoor and outdoor dust were lower, or in the lower range of LCD substances found in dust from e-waste sites in China (Zhang et al., 2022; Zhu et al., 2021).

Detection frequency of the LCD compounds was also high in air samples collected indoors at EE recycling facilities, and the LCD substances with the highest mean concentrations were BEDFPC (20 000 pg/m³, ca 40% of the total LCD), MOPCHB (9 000 pg/m³), PCHPB (8 000 pg/m³), EOPRCHB (4 000 pg/m³), EDFPCHBP (2 000 pg/m³), DFTFPPBP (600 pg/m³), and BTFPOMTP (400 pg/m³). In ambient air samples collected directly outside the EE recycling facilities, the LCD substances with the highest mean concentrations were PCHPB (2 000 pg/m³),

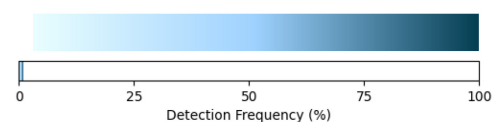
BTFPOMTP (700 pg/m³), and CDOOBP (300 pg/m³) which together made up about 90 % of the total measured LCD substances in ambient air.

LCD substances were generally not detected in ambient air from the Sofienberg park in Oslo (not included in Figure 23 and Figure 24). The only detection of LCD substances in the Sofienberg park was of PCHPB, with a concentration of 700 pg/m³. There were no detections of LCD substances in ambient air from the Zeppelin station at Svalbard. Detection limits varied for the analysed LCD substances, ranging from 10 to 200 pg/m³ for the LCD substances that were detected in other matrices in this study.

Detection frequency of LCD substances was lower in stormwater and process water from the EE facilities, but some notable concentrations were observed, particularly for stormwater. In stormwater samples collected near EE recycling facilities, the LCD substances with the highest mean concentrations were PCHPB (40 000 ng/L), EDFPCHB (4 000 ng/L), DFTFPTP (300 ng/L), EDFPCHBP (2 000 ng/L), and BTFPOMTP (2 000 ng/L). EDFPCHB was also detected in process water at notable concentrations (700 ng/L).

Several LCD substances were detected in soil and moss collected outside the EE facilities. Most notably, PCHPB was detected at 100 ng/g in soil and 70 ng/g in moss. EDFPCHBP and EDFPCHB were detected in all samples of moss (7 and 3 ng/g, respectively). Only three LCD substances were detected in mouse liver, two could be quantified, TFPCHB (3 ng/g) and EDFPCHB (0.3 ng/g), and one was determined qualitatively, EPHDFB. The latter LCD substance was also detected qualitatively in all samples of indoor and outdoor air and dust. TFPCHB and EDFPCHB have been found in urine from children in e-waste recycling regions in China, but also in comparable concentrations in urine from children in a reference group (Peng et al., 2025).

Several LCD-related substances were consistently detected across multiple environmental matrices, often at elevated concentrations. Notably, PCHPB, EDFPCHB, EDFPCHBP, DFTFPPBP, and BTFPOMTP appeared among the top compounds in indoor dust, outdoor dust, indoor and ambient air, and stormwater. The latter four of these LCD substances are fluorinated, but they should not be confused with the perfluoroalkyl substances (PFAS). PCHPB, EDFPCHB, EDFPCHBP, and DFTFPPBP have also been identified among the most frequently detected LCD substances in multiple matrices in a recent review of environmental occurrence of LCD substances (Stadelmann et al., 2024). The frequent detection, widespread presence and notable concentrations of these substances at and near EE facilities show that they are widely used in the type of electronics handled at the studied EE facilities and that they can be released during handling and dismantling. Further monitoring of these substances is recommended. Their occurrence in matrices such as air and stormwater indicates potential for both inhalation exposure and dispersion into surrounding ecosystems. The large number of LCD substances detected in this study is also notable.



Chemical	Ambient air (pg/m ³)	Indoor air (pg/m ³)	Dust Outside (ng/g)	Dust indoors (ng/g)	Mouse liver (ng/g)	Process water (ng/L)	Stormwater (ng/L)	Soil (ng/g)	Moss (ng/g)
EBDFPC	10	200	8	400		10	200	0.2	0.3
BBDFFPC	20	200	9	400		90	200	0.2	0.2
DFPCHB	20	100	300	200		10	500		3
DFTFPTP	20	100	10	500		100	3000	1	4
PPCHB	80	80		300					
PCHVCH			40	600			400		
PCHPB	1000	8000	300	600		200	40000	100	70
ETFPH	2	70	100	200		60	600	0.2	0.2
BTFTPCH	4	80	10	200		70	400	0.4	0.3
TFPCHB	30	90	20	500	3	60	700	0.2	0.2
EPHBP	20	200	20	300		200	300		2
DFTFPPBP	100	600	30	1000		100	400	0.9	1
DFMPCHB	2	10	9	100		70	400		0.6
EDFPCHB	70	300	100	1000	0.3	700	4000	0.6	3
PTFMPCH	7	40	10	300		80	1000		
BEDFFPC	200	20000	40	500		100	800	0.2	0.3
TPEFP	20	100	10	600		2	400		0.3
DFTFPEBP		50		100			100		
ECHTFMB		20		40					
EDFPCHBP	100	2000	90	900		500	2000	2	7
BPCHBP				90		4	400		
MOPCHB	90	9000	2	70			400		
EMOPEB							300	7	4
EOPRCHB	10	4000	3	70					
MPBP				50			1000		
TFECHB	1	50		50					
TFPTP	70	100	10	400		30	700	0.2	0.4
TFPRCHBP	2	4	0.5	10			20		

Continues next page:

Chemical	Ambient air (pg/m ³)	Indoor air (pg/m ³)	Dust Outside (ng/g)	Dust indoors (ng/g)	Mouse liver (ng/g)	Process water (ng/L)	Stormwater (ng/L)	Soil (ng/g)	Moss (ng/g)
DFPRCHBP		20		50					
FPCHBP		30		100					
DFMPECH		40	8	200		4			
TFPECHBP		6		20					
DFPECHBP		4		90					
EFPETP	3	30	0.6	200					
MPBUBCH		200		300			200		
BTFPOMTP	700	400	30	800		100	2000	2	8
BEOPEB				20		20			
DFECHB		20	10	80			2		
DFPRCHB	1	40		30					
DFBUCHB		20	6	200		3			
TFPRBCHBP		30	2	400		4	30		
DFMOPRCHB	1	10	1	30			40		

Figure 23: Average concentration of LCD substances with detection frequency > 30% in at least two different sample matrices. Observations below the method LOD is included in the averages as 0.5x the LOD value. Colour indicates detection frequency with pale blue indicating 0% detection.

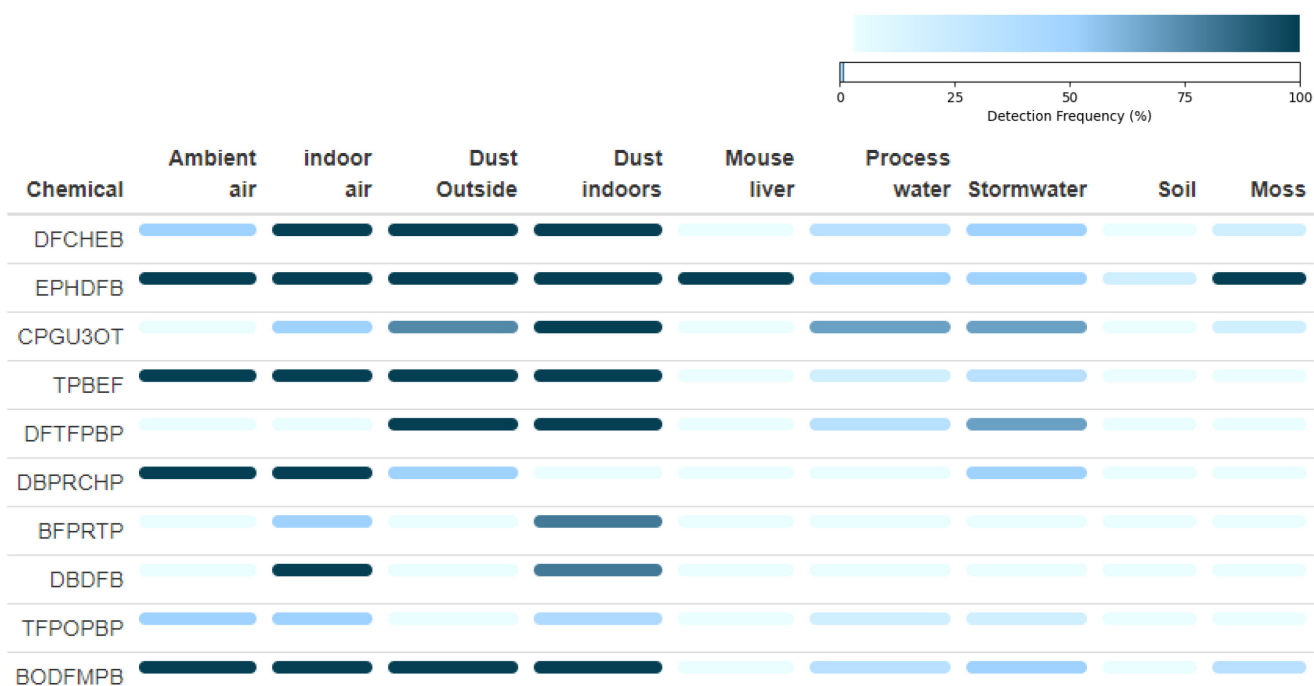


Figure 24: LCD substances analysed qualitatively with detection frequency > 30% in at least two different sample matrices. Colour indicates detection frequency with pale blue indicating 0% detection.

Flame retardants/plasticisers and their degradation products

Of the OPFR and Phthalate degradation products (referred to here as OPFR metabolites and phthalate metabolites) analysed, several were detected across multiple environmental matrices near the EE facilities.

Among the OPFR metabolites, DEHPO and DPPO stood out with consistently high concentrations. The highest average concentrations of OPFR metabolites were found for DPPO in indoor dust and outdoor dust (8 000 ng/g and 2 000 ng/g, respectively), and indoor air (DEHPO, 2 000 pg/m³) (Figure 25). Notably, DEHPO also showed elevated levels in ambient air (5 000 pg/m³), mouse liver (3 000 ng/g), and process water (800 ng/L), indicating both potential for inhalation exposure and bioaccumulation. Unfortunately, analytical difficulties made it impossible to determine presence or absence of the remaining targeted OPFR metabolites in mouse liver. In moss and soil samples, DPPO and DEHPO were again among the top compounds, suggesting environmental dispersion beyond the immediate facility.

Phthalate metabolites were also widely present, with MEP, MEHP, and MMP showing the highest concentrations across matrices (Figure 26). Indoor dust contained particularly high levels of MEP (40 000 ng/g), while MEHP dominated in outdoor dust (3 000 ng/g) and indoor air (3 000 pg/m³). MMP was most prominent in ambient air (2 000 pg/m³) and process water (100 ng/L). In biological and environmental samples, MEHP was the most abundant in mouse liver (1 000 ng/g), and MEP showed the highest concentrations in soil (200 ng/g) and moss (100 ng/g). These findings suggest that phthalate metabolites are not only prevalent in indoor environments but also capable of dispersing into surrounding ecosystems and accumulate in biota.

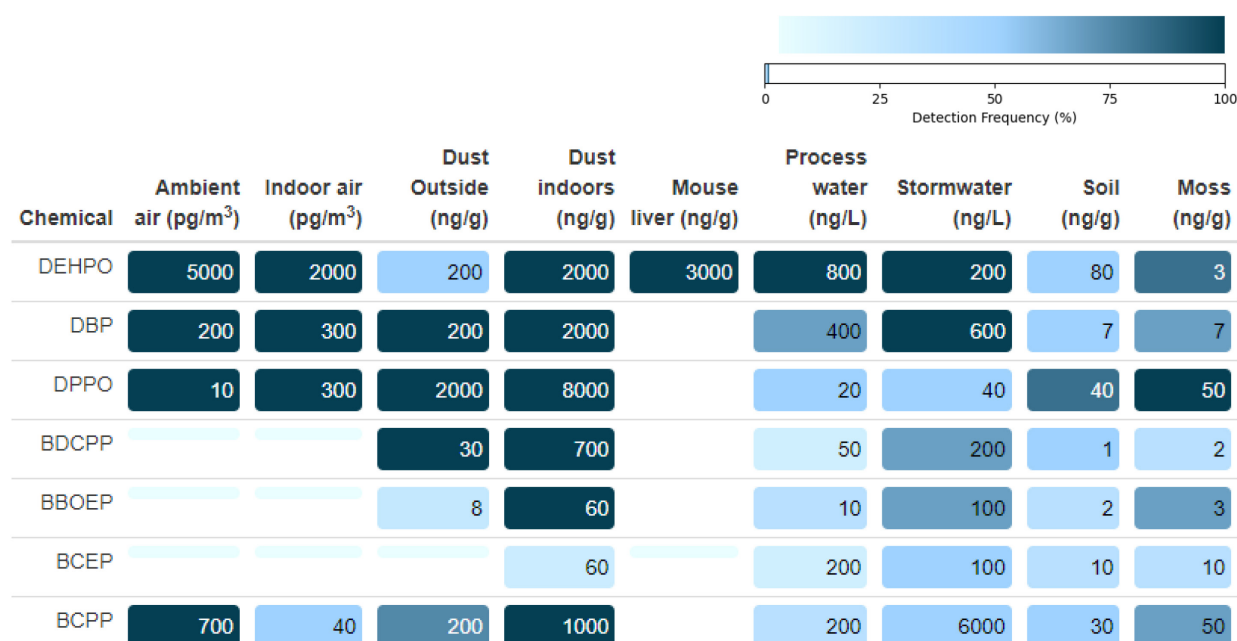


Figure 25: Average concentration of OPFR metabolites with detection frequency > 30% in at least two different sample matrices. Observations below the method LOD is included in the averages as 0.5x the LOD value. Colour indicates detection frequency with pale blue indicating 0% detection.

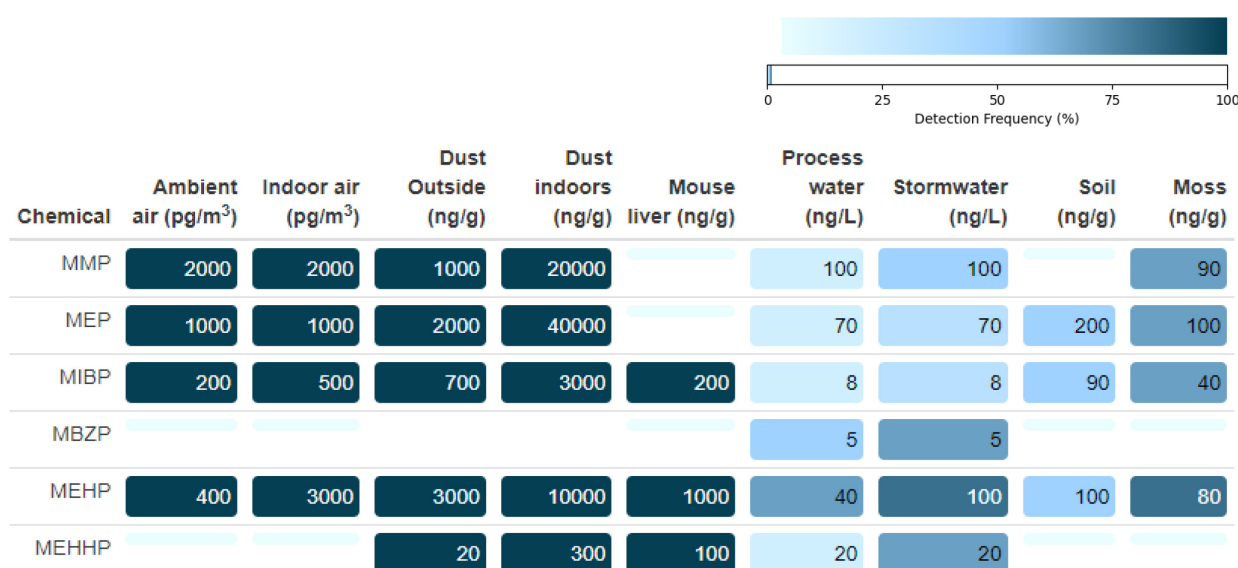


Figure 26: Average concentration of Phthalate metabolites with detection frequency > 30% in at least two different sample matrices. Observations below the method LOD is included in the averages as 0.5x the LOD value. Colour indicates detection frequency with pale blue indicating 0% detection.

A broad range of PBDE congeners and alternative flame retardants were included in the screening programme. The results show that several of these compounds are still widely present in environmental samples collected near EE waste facilities.

PBDEs were frequently detected across multiple matrices (Figure 27). Congeners such as BDE-47, BDE-99, BDE-183, and BDE-209 showed the highest detection frequencies and concentrations. BDE-209, a major component of decaBDE mixtures, was particularly prominent in indoor dust and stormwater particles, with maximum concentrations exceeding 20 000 ng/g in some samples. BDE206 and BDE207, both nona-brominated congeners and known debromination products of BDE-209, were also found in notably high concentrations, especially in dust and soil. Lower-brominated congeners such as BDE-17 and BDE-28 were detected in indoor air, suggesting volatilization from treated materials. BDE-47 and BDE-183, representative of commercial pentaBDE and octaBDE mixtures respectively, were found in dust, air, and stormwater particles, with generally higher concentrations at EE facility 1. This likely reflects emissions from older products and/or legacy contamination.

Alternative brominated flame retardants, including DBDPE, BTBPE, and BEHTBP, were also commonly detected (Figure 28). DBDPE, a widely used replacement for BDE-209, was found at high levels in indoor dust, stormwater particles, and ambient air, indicating widespread use and environmental dispersion. BTBPE and EHTBB were detected in both dust and stormwater, albeit at lower concentrations. The chlorinated flame retardants DDC_PS and DDC_PA, the syn and anti isomers of Dechlorane Plus, were detected at high concentrations in a wide range of matrices, including air, dust, soil, and moss, with concentrations up to 400 ng/g in moss. HBCD isomers (HBCDA, HBCDB, HBCDG) were also detected at high concentrations, particularly in indoor dust, where one sample had HBCDA levels too high to be quantified (estimated to exceed 50 000 ng/g).

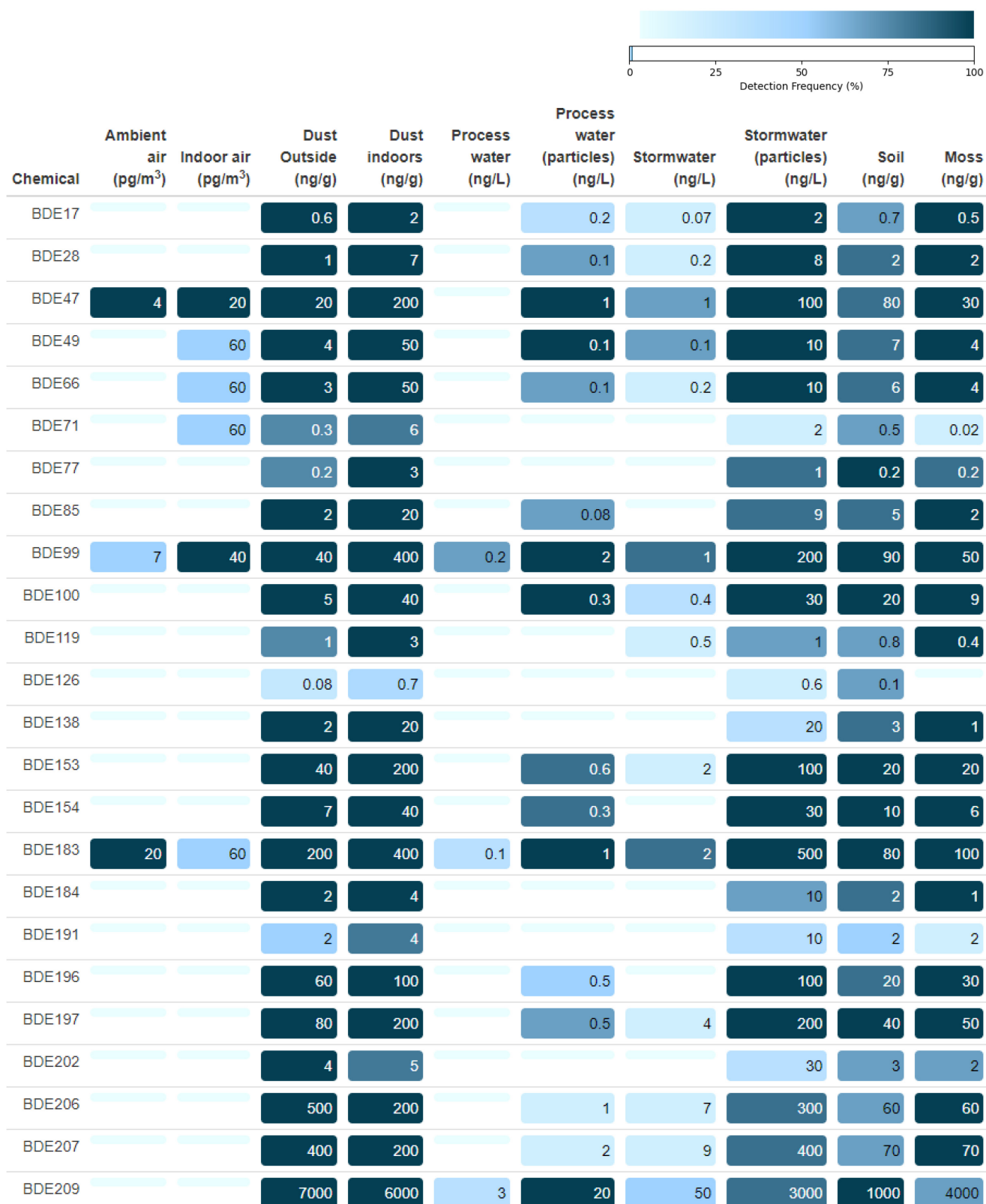


Figure 27: Average concentration of PBDEs with detection frequency > 30% in at least two different sample matrices. Observations below the method LOD is included in the averages as 0.5x the LOD value. Colour indicates detection frequency with pale blue indicating 0% detection.

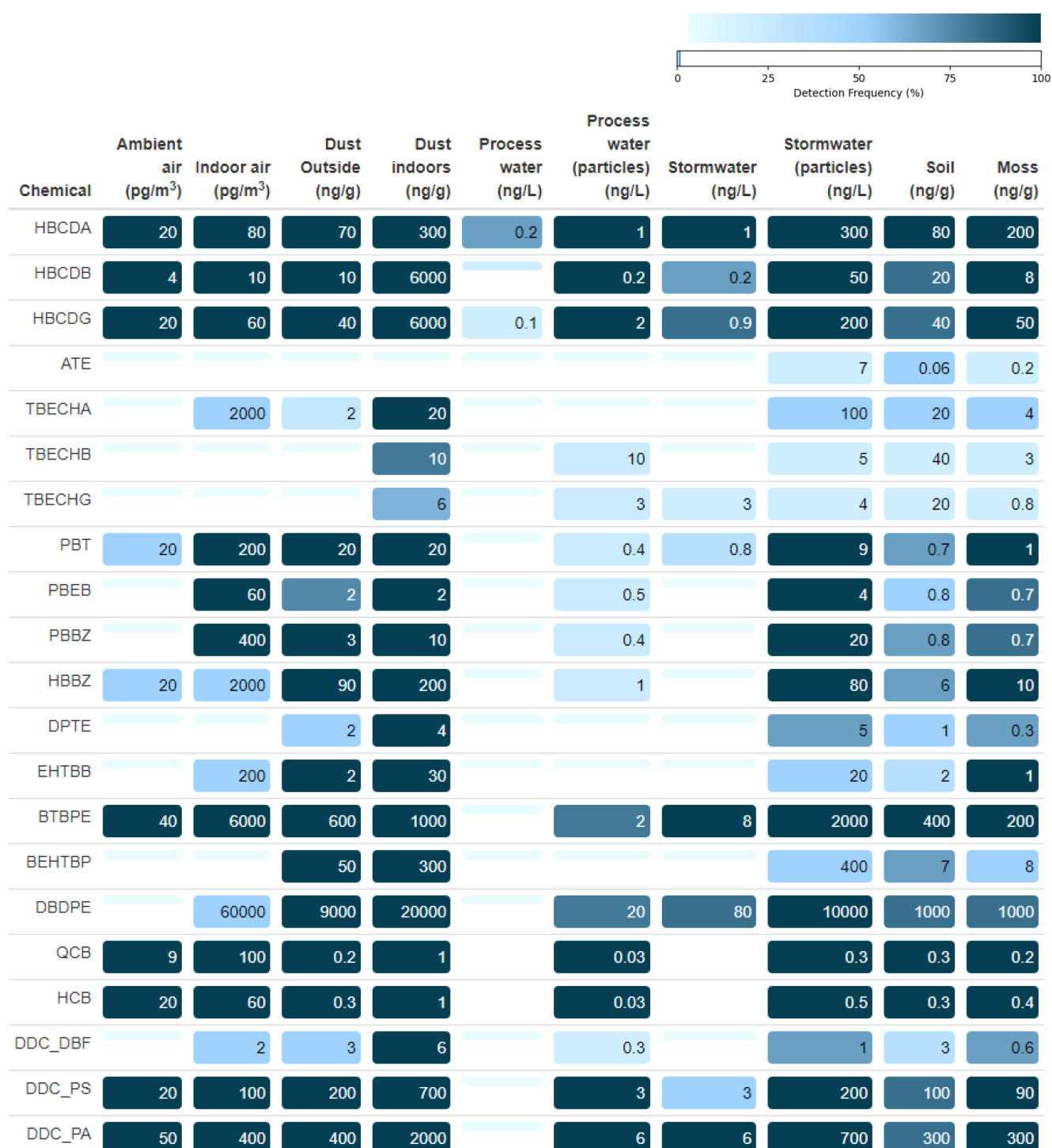


Figure 28: Average concentration of Alternative flame retardants with detection frequency > 30% in at least two different sample matrices. Observations below the method LOD is included in the averages as 0.5x the LOD value. Colour indicates detection frequency with pale blue indicating 0% detection. Average of HBCDA in indoor dust omits the result from one sample which had HBCDA concentrations too high to quantify.

Some halogenated analogues of bisphenol A, some of which may be degradation products of much used flame retardants such as tetrabromo bisphenol A TBBPA were analysed qualitatively (Figure 29). DeBrTBBPA was detected in most of the samples from the EE facilities.

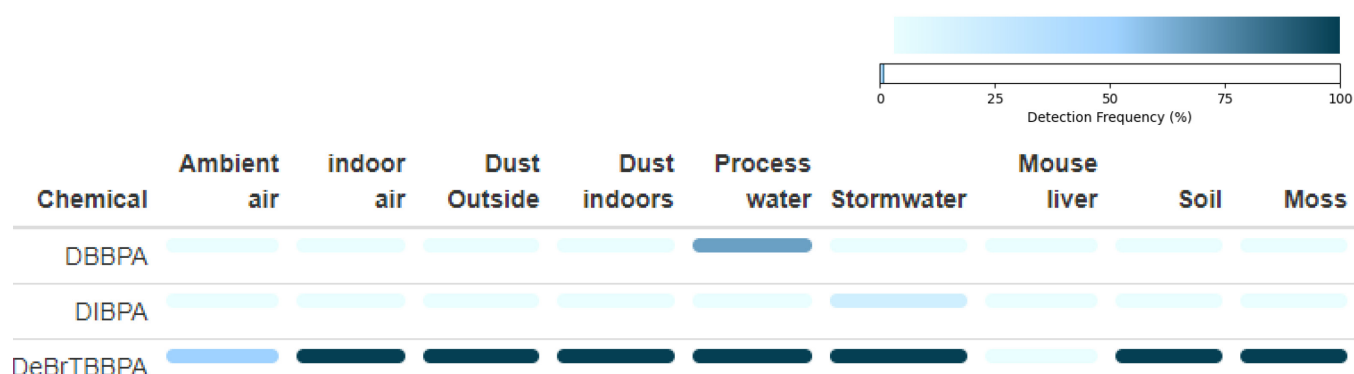


Figure 29: Potential degradation products from flame retardants analysed qualitatively. Colour indicates detection frequency with pale blue indicating 0% detection.

Chlorinated paraffins and related substances

SCCPs, MCCPs, and LCCPs were consistently detected across all environmental matrices sampled near the EE recycling facilities, with particularly high concentrations observed for LCCP (long-chain chlorinated paraffins) (Figure 30). LCCP showed the highest mean concentrations in dust indoors (40 000 ng/g), dust outdoors (30 000 ng/g), stormwater particles (50 000 ng/L), and process water particles (6 000 ng/L), all with 100% detection frequency. LCCP also dominated in soil (2 000 ng/g) and moss (3 000 ng/g), indicating widespread environmental dispersion. In air samples, MCCP (medium-chain CPs) was most prominent, with mean concentrations of 300 ng/m³ indoors and 100 ng/m³ in ambient air, again with 100% detection frequency. MCCP also had the highest concentration in stormwater (300 ng/L). These findings suggest that both LCCP and MCCP are prevalent in and around EE recycling facilities, with LCCP showing particularly high levels in particulate and solid matrices, and MCCP dominating in air and water. The consistent detection and elevated concentrations across matrices highlight the potential for both environmental dispersion and human exposure for these CPs.

The very short chain CPs (vSCCPs), typically defined as C₆₋₉, were also consistently detected across the environmental matrices. Semi-quantified concentrations of vSCCPs exceeded SCCP concentrations in indoor dust and particles in stormwater. vSCCPs are not known to be produced in large volumes as standalone commercial products but are often present as impurities or by-products in commercial CP mixtures (Wang et al., 2020; Zhou et al., 2019). Compared to SCCPs and MCCPs, their production volumes are significantly lower, yet they are widely detected in environmental samples, including indoor dust and wildlife (McGrath et al., 2023; Zhou et al., 2019). vSCCPs are not known to be intentionally blended with LCCPs to mimic SCCP or MCCP properties, but commercial CP formulations often contain a mix of chain lengths including vSCCPs. This may result in physical-chemical properties similar to regulated SCCPs, potentially complicating regulatory enforcement and environmental risk assessments.

Potential degradation products or metabolites of CPs and bromo-chloro paraffins and olefins were investigated qualitatively in all the samples from the EE facilities. We detected signals from two possible CP metabolites in one moss sample from EE facility 1. The signals corresponded to mono-hydroxylated versions of the MCCPs

C₁₄CL₆ and C₁₄CL₇. These corresponded to the most abundant congener groups of MCCPs present in the moss sample. No signals corresponding to bromo-chloro paraffins and olefins were detected. It is important to note that given the lack of available analytical standards for these substances it is not known whether this lack of detection reflects no presence in the studied environment or analytical challenges. We note that chloro or bromo olefins are not likely to be intentionally produced, as the production method applied for CPs will break any double bonds present in the alkane feedstock.

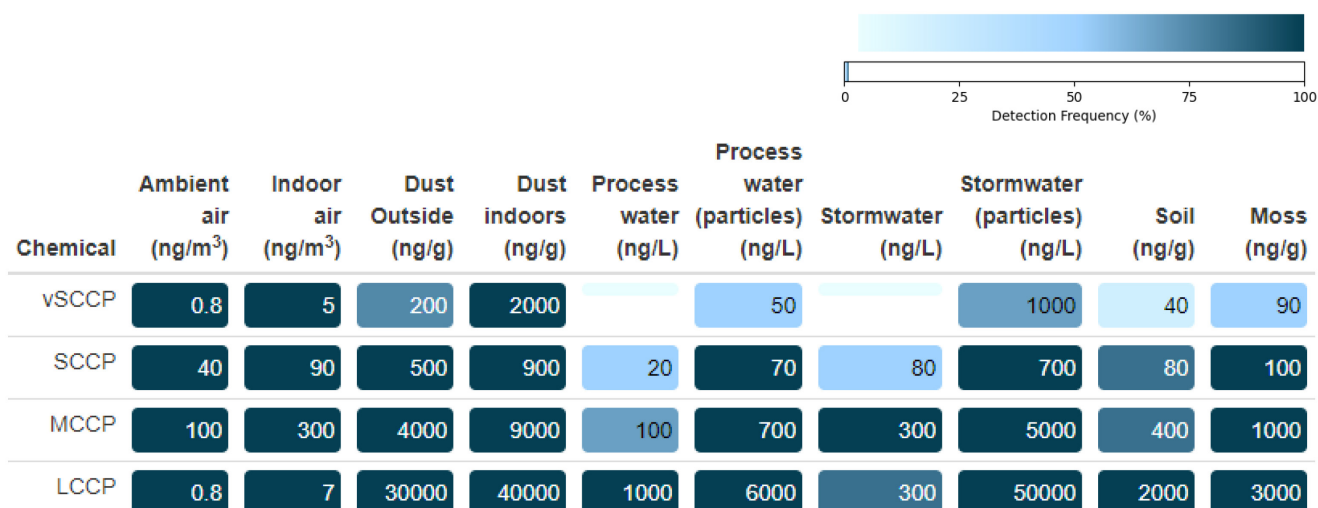


Figure 30: Average concentration of Chlorinated paraffins with detection frequency > 30% in at least two different sample matrices. Observations below the method LOD is included in the averages as 0.5x the LOD value. Colour indicates detection frequency with pale blue indicating 0% detection.

PCBs

Although PCBs were not originally included in the screening programme, unexpectedly high signals of PCBs were observed during the analysis of other substances, particularly in indoor air and dust samples. This prompted the inclusion of targeted PCB analyses (Figure 31). The results revealed high detection frequencies across most analysed congeners, with particularly elevated concentrations in indoor environments. PCB-118, PCB-138, and PCB-153 were all found in indoor dust at an average concentration of 5 000 ng/g. PCB-18 and PCB-52 were found in indoor air at 10 000 pg/m³ and 8 000 pg/m³, respectively. PCBs were consistently found in both indoor air and dust collected inside both the EE facilities, indicating ongoing release from materials handled at these sites. These findings underscore the relevance of PCBs as legacy contaminants still present in modern waste streams.

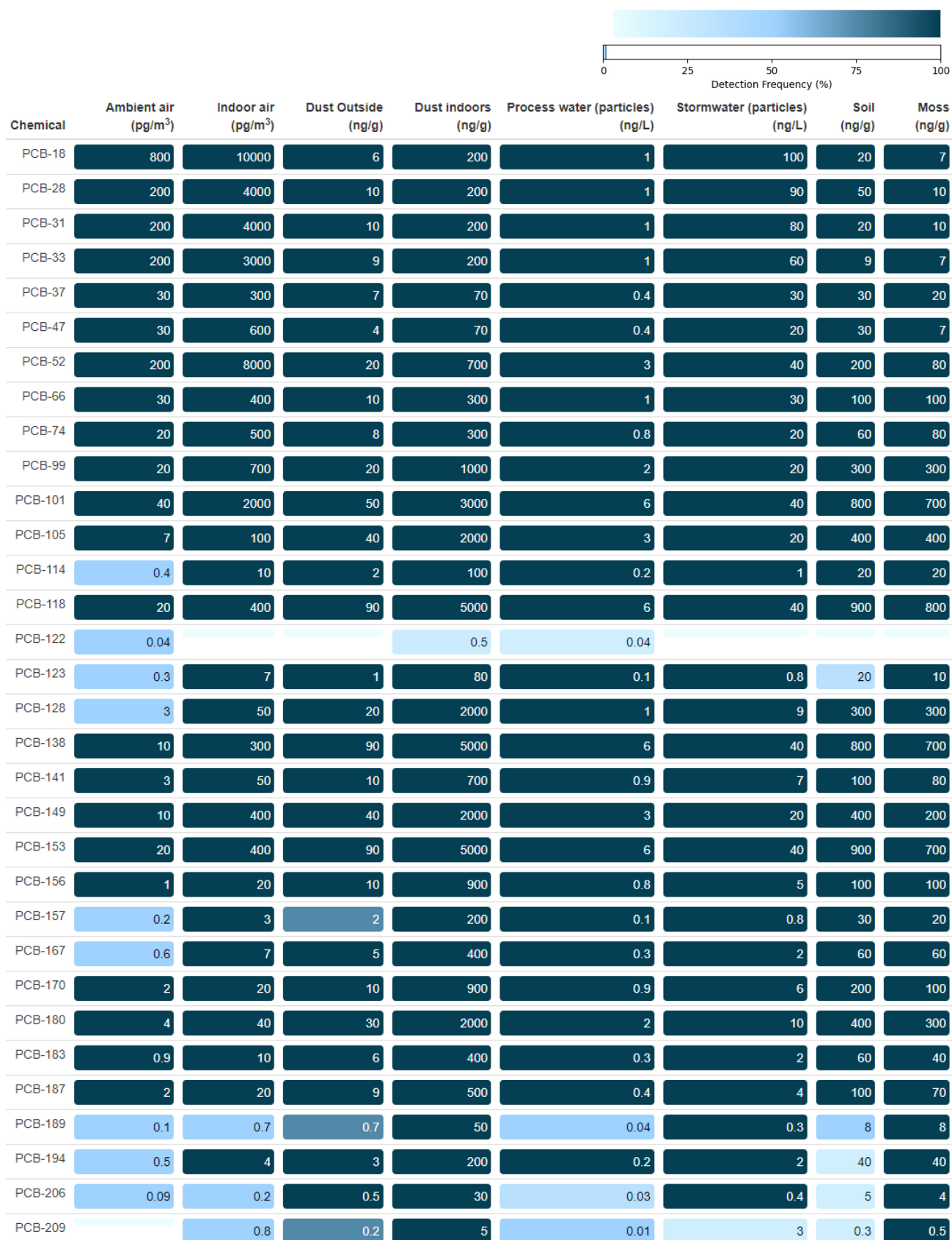


Figure 31: Average concentration of PCBs with detection frequency > 30% in at least two different sample matrices. Observations below the method LOD is included in the averages as 0.5x the LOD value.

3.1.2 Contamination patterns

LCD substances

The contamination profiles of LCD substances across the two EE facilities reveal distinct patterns linked to operational differences and environmental dispersion pathways (Figure 32). Indoor dust consistently showed the highest concentrations and diversity of LCD substances, particularly at EE facility 1, which performs dismantling and partial processing of screens. Fluorinated LCD compounds such as EDFPCHB, DFTFPBP, and BTFPOMTP were among the most abundant, suggesting their widespread use in screen components and potential for release during mechanical handling. Indoor air also contained high levels of LCD substances, with BEDFPC and MOPCHB dominating, indicating volatilization or particle-bound transport. Outdoor dust and stormwater samples reflected lower but still notable concentrations, pointing to dispersion via runoff and airborne particles.

EE facility 1 generally exhibited higher concentrations of LCD substances across most matrices, especially in indoor dust and stormwater, consistent with its role in active dismantling and processing. In contrast, EE facility 2, which primarily functions as a collection and sorting hub, showed lower overall concentrations but still notable levels in outdoor dust and moss, suggesting environmental dispersion from handling and storage activities. The presence of LCD substances in soil, moss, and biota near both facilities underscores their environmental mobility and persistence. These findings highlight the need for further investigation into the environmental fate and toxicity of LCD substances, particularly fluorinated variants.

High occupational exposure risk from LCD compounds have been indicated by studies from China (Cheng et al., 2022). Although conditions in Norway are likely not directly comparable, we recommend investigating potential for and magnitude of occupational exposure to LCD substances for workers at facilities that handle and dismantle LCD screens. We also see a need for harmonization of abbreviations used in the literature for LCD substances, as this would make comparisons across studies easier and thereby aid prioritizations for future monitoring efforts.

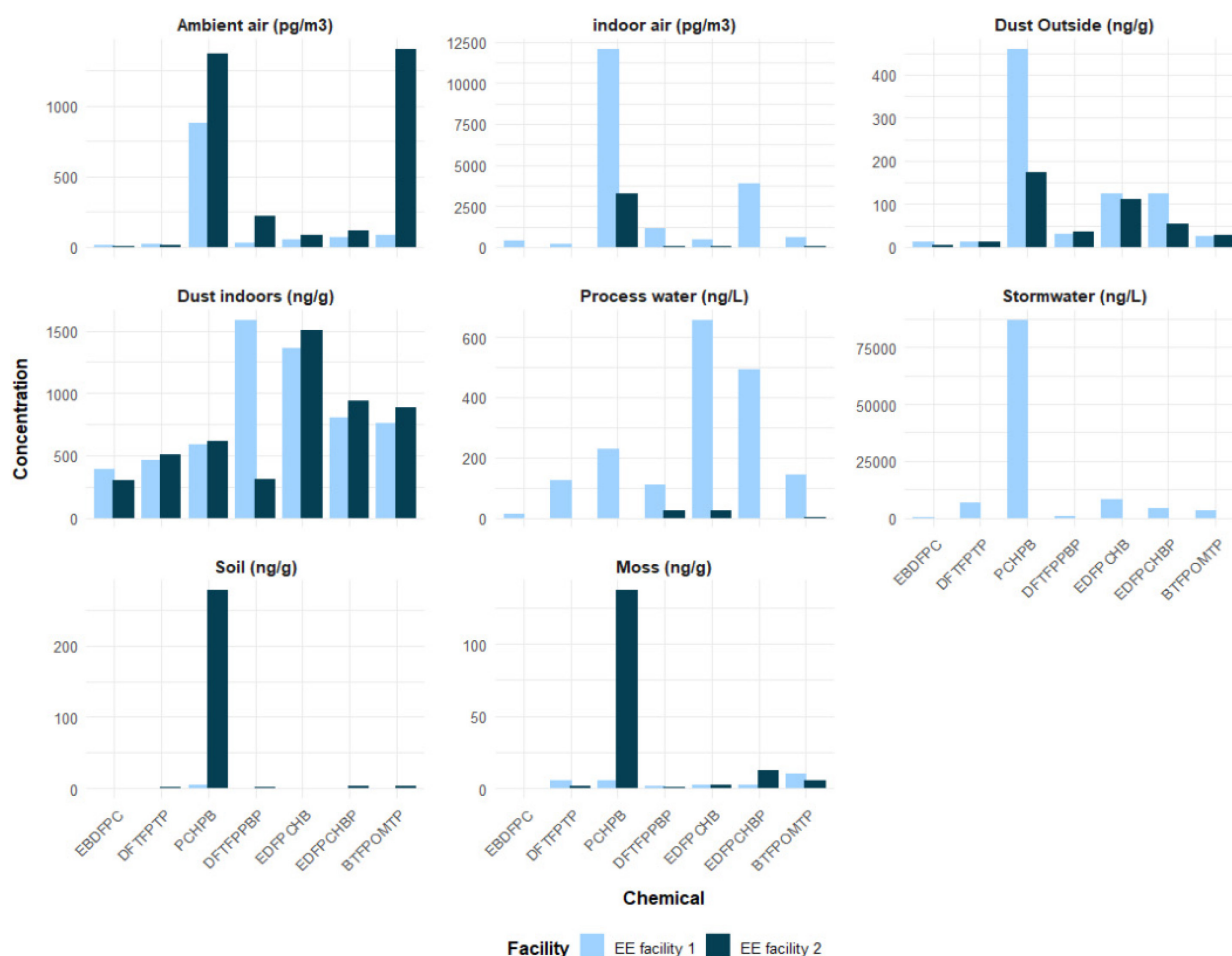


Figure 32: Average concentrations of selected LCD substances at EE facility 1 and EE facility 2.

Flame retardants/plasticisers and their degradation products

All studied OPFR metabolites were detected in one or more matrices, and particularly DEHPO, DPPO, and BCPP occurred at notable concentrations.

DEHPO, used in metal extraction and plasticizers, was found in nearly all matrices. It was particularly elevated in mouse liver (3 000 ng/g), suggesting potential bioaccumulation. High concentrations were also observed in ambient air, dust, soil, and stormwater, with generally higher levels at the facility performing on-site dismantling and component removal. The presence of DEHPO in biota and air aligns with its potential for airborne transport and occupational exposure. Its detection in unfiltered stormwater and process water, indicates that DEHPO may also be associated with particulate-bound transport.

DPPO, a degradation product of triphenyl phosphate (TPHP), was detected in all major matrices except mouse liver. It was especially abundant in indoor dust (up to 10 000 ng/g) and indoor air, indicating likely release from treated materials such as electronics or insulation. The facility with more intensive indoor processing showed higher concentrations, consistent with greater material abrasion and potential volatilization. Its presence in stormwater and soil suggests environmental dispersion via dust deposition and runoff (Figure 33).

BCPP, a metabolite of chlorinated OPFRs like TCIPP, was found in air, dust, soil, stormwater, and moss. Its presence in both indoor and outdoor environments reflects its use in polyurethane foams and plastic

components. The detection pattern supports its role as a ubiquitous contaminant in EE waste environments, with potential for both inhalation and environmental exposure. As with the other OPFRs, its detection in unfiltered water samples suggests that particulate-bound fractions may contribute significantly to environmental loading.

The differences in OPFR metabolite concentrations between the two facilities are likely influenced by their operational roles: one facility focuses on mechanical dismantling and partial processing, while the other serves as a collection and sorting hub. These functional differences help explain the observed variation in contaminant profiles across matrices.

Among the suite of phthalate metabolites analyzed, three compounds—MEP, MMP, and MEHP—were selected for closer examination due to their relatively high concentrations and broad occurrence across environmental matrices. These compounds are known degradation products of widely used phthalate plasticizers such as DEP, DMP, and DEHP, which are commonly found in electronic casings, cables, and flexible plastic components.

MEP was detected in indoor and outdoor dust, air, soil, stormwater, and process water, with particularly high concentrations in indoor dust (up to 40 000 ng/g) and indoor air. It was also detected in soil and moss, but not in mouse liver. The facility with more intensive indoor dismantling activities showed higher levels, suggesting release from treated surfaces or components during handling.

MMP was found in dust, air, and moss, but not in soil or mouse liver. Its presence in indoor environments supports its origin from materials such as adhesives, coatings, or flexible plastics.

MEHP, a primary metabolite of DEHP, was detected in dust, soil, moss, and notably also in mouse liver, indicating potential for bioaccumulation. This aligns with its known use in PVC and flexible electronics, and its detection in unfiltered water samples suggests that it may be associated with particulate-bound transport.

Other phthalate metabolites such as MIBP and MEHHP were also detected in mouse liver, further supporting the potential for biological uptake of phthalate-related compounds in EE waste environments.

Overall, the phthalate metabolite profiles reflect the widespread use of phthalate plasticizers in EE products. The higher concentrations observed at the facility with more intensive dismantling and indoor processing suggest that mechanical abrasion and surface wear are key release mechanisms. Their presence in air, dust, soil, moss, and biota highlights the potential for both occupational exposure and environmental risk.

The contamination profiles of PBDEs and alternative flame retardants show clear patterns across environmental media and between the two EE facilities. Indoor dust consistently exhibited the highest concentrations for most compounds, particularly at EE facility 1, which performs active dismantling and processing of electronic waste. This facility showed elevated levels of BDE209, DBDPE, BTBPE, and HBCD isomers, reflecting release from flame-retarded plastics, insulation foams, and circuit boards during mechanical handling. The high concentrations in indoor air and dust suggest that abrasion, volatilization, and particle-bound transport are key exposure pathways.

Stormwater particles also contained substantial levels of PBDEs and alternative BFRs, especially at EE facility 1. This indicates that dust and debris generated during processing are mobilized by runoff, contributing to environmental dispersion. The presence of BDE-209, DBDPE, and BTBPE in stormwater particles at concentrations exceeding 20 000 ng/g highlights the potential for these compounds to enter aquatic systems. In contrast, EE facility 2, which primarily functions as a collection and sorting hub, showed lower concentrations in

stormwater but higher levels in soil and moss, suggesting that outdoor handling and storage activities contribute to diffuse contamination.

The detection of BDE206 and BDE207, known debromination products of BDE-209, in dust and soil supports the hypothesis that transformation occurs in matrices exposed to light and microbial activity. Their co-occurrence with BDE-209 suggests ongoing degradation and environmental persistence. Similarly, the presence of lower-brominated congeners such as BDE-17 and BDE-28 in indoor air may reflect volatilization from treated materials, with potential for inhalation exposure.

Legacy PBDE mixtures such as pentaBDE and octaBDE were represented by BDE-47 and BDE-183, respectively. These congeners were more abundant at EE facility 1, particularly in indoor dust and stormwater, suggesting that older equipment or materials treated with phased-out formulations are still being handled. Their presence underscores the long-term relevance of legacy flame retardants in modern waste streams.

Among the alternative flame retardants, Dechlorane Plus isomers (DDC_PS and DDC_PA) were prominent in ambient air and outdoor dust at EE facility 2 and were elevated in indoor dust and stormwater particles at EE facility 1. This may reflect differences in product use, emission pathways, or site layout. Both isomers were also found in soil and moss, with concentrations up to 400 ng/g, indicating environmental persistence and potential for long-range transport. The dechlorane concentrations found in soil were about three orders of magnitude higher than those found in urban areas in Oslo, Norway (Heimstad, 2023).

HBCD isomers were detected in both indoor and outdoor matrices, with HBCDB and HBCDG reaching extremely high levels in indoor dust at EE facility 1. Their presence in soil and moss at both facilities suggests widespread dispersion and environmental mobility. The detection of HBCDA in moss and soil at concentrations up to 200 ng/g further supports this. The HBCD concentrations found in soil were about four orders of magnitude higher than those found in urban areas in Oslo (Heimstad, 2023).

Overall, the contamination patterns reflect both the chemical properties of the substances and the operational characteristics of the facilities. EE facility 1, with its focus on dismantling and processing, exhibited higher concentrations in indoor and waterborne matrices, while EE facility 2 showed more diffuse contamination in terrestrial matrices. These findings highlight the need for tailored mitigation strategies and continued monitoring of both legacy and replacement flame retardants in e-waste environments.

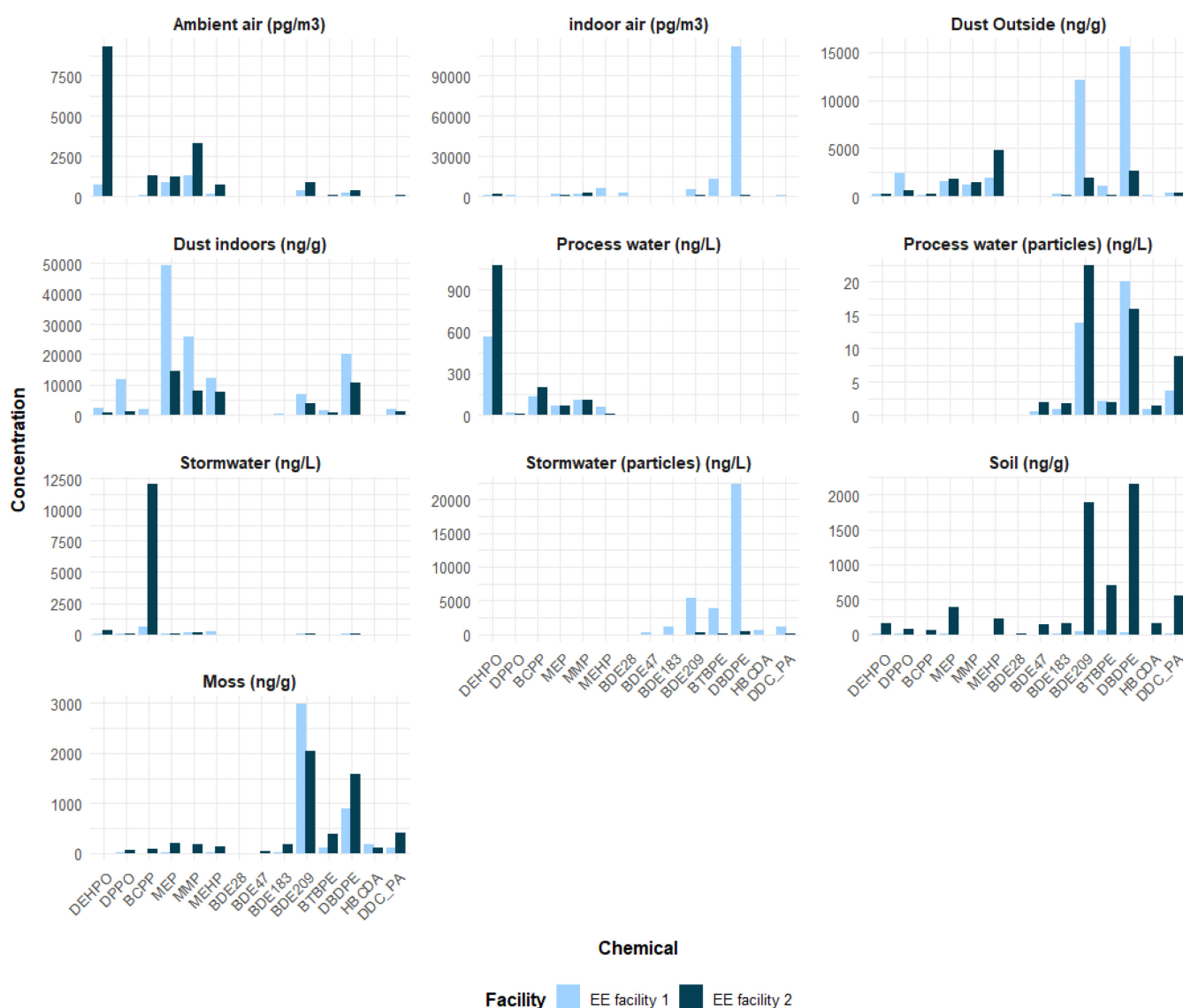


Figure 33: Average concentrations of selected flame retardants and related substances at EE facility 1 and EE facility 2.

Chlorinated paraffins and related substances

The CP concentration profiles at EE facility 1 and EE facility 2 showed broadly similar patterns, with LCCPs consistently dominating across most matrices (Figure 34). However, concentrations of LCCPs and MCCPs tended to be notably higher at EE facility 1, often by a factor of two or more, particularly in dust, stormwater particles, and process water particles. For example, indoor dust at EE facility 1 contained roughly twice as much LCCP and MCCP as at EE facility 2, and stormwater particles showed nearly twenty times higher LCCP levels. SCCPs were present at both facilities in comparable amounts, though slightly elevated at EE facility 1 in dust and water samples. vSCCPs, generally detected at lower concentrations, showed a distinct pattern: they were more prominent in stormwater particles at EE facility 1, but appeared more strongly in moss at EE facility 2. Overall, EE facility 1 exhibited higher CP concentrations across most matrices, suggesting greater release or accumulation of these substances at that site, while EE facility 2 showed a more moderate but still widespread presence of CPs.

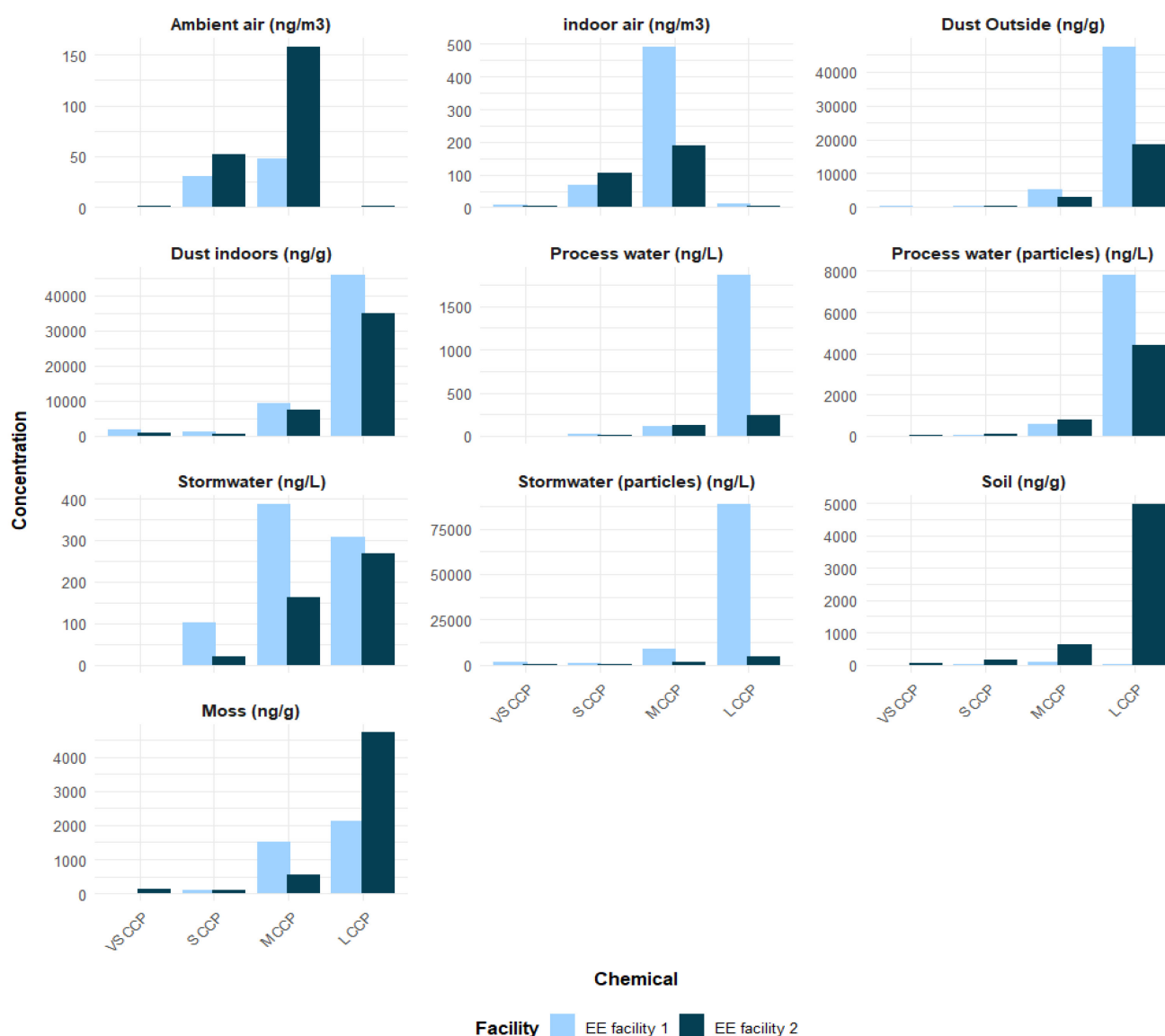


Figure 34: Average concentrations of CPs at EE facility 1 and EE facility 2.

PCBs

PCB concentrations varied markedly between the two e-waste facilities included in the screening (Figure 35). EE facility 2 consistently exhibited higher levels across all matrices, including ambient and indoor air, dust (both indoor and outdoor), process water, stormwater, soil, and moss. The elevated concentrations in soil and moss near facility 2 suggest substantial environmental dispersion and deposition of PCBs, likely linked to particle-bound transport and accumulated emissions over time. In contrast, the high levels observed in indoor air and dust point to active sources within the facility, likely related to ongoing handling and processing of contaminated materials. Notably, facility 2 also handles other types of waste in addition to electronic waste such as vehicles and scrap metal, whereas facility 1 primarily processes EE waste. The much lower PCB concentrations observed at facility 1, despite its larger volume of EE waste, suggest that additional waste streams at facility 2 may be contributing significantly to the elevated PCB levels. These findings indicate that facility 2 may represent a more

significant source of PCB emissions, both through air and water pathways and via particulate deposition to surrounding terrestrial environments.

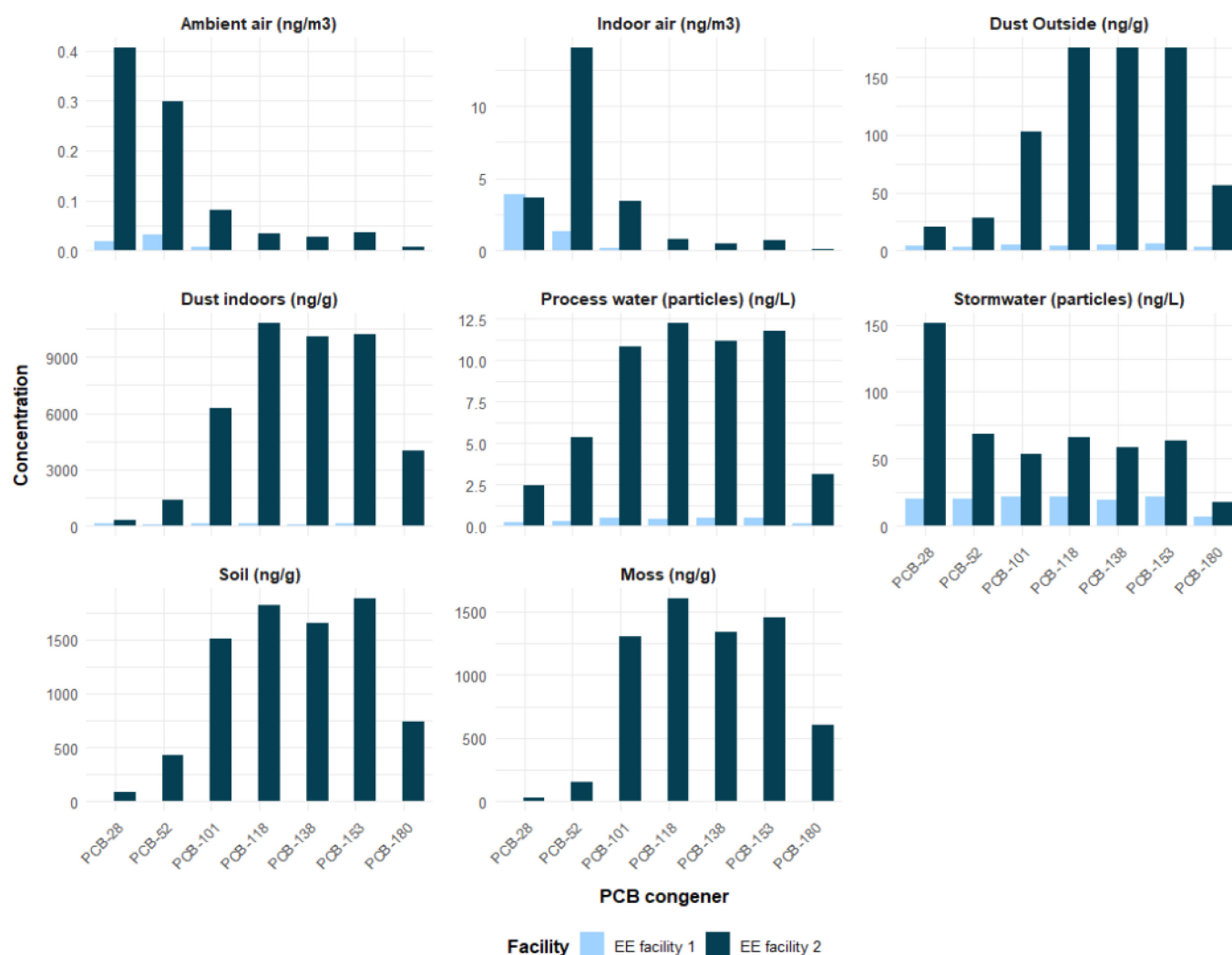


Figure 35: Average concentrations of selected PCB congeners at EE facility 1 and EE facility 2.

3.1.3 Risk assessment

EU EQS values were used when available (<https://echa.europa.eu/environmental-quality-standards>). For substance-media combinations with no available EQS value, the ECHA Chemicals Database was checked for available PNEC values (<https://chem.echa.europa.eu/substance-search>). If PNEC values were not available either, the Norman database was used to identify potential QSAR based PNEC values. Average concentrations for each media were compared to the EQS and PNEC values. Media with average concentrations that exceeded EQS or PNEC values are indicated with red cells in Table 7.

Substances that were not detected above the LOD or showed detection frequencies below 30% were not subject to risk assessments. LOD values were treated as half the LOD. PCBs, which were included for analysis at a later stage of the screening programme, were not included in the risk analysis.

EQS and PNEC values for freshwater were used for stormwater, while EQS and PNEC values for marine water were used for wastewater. No relevant EQS or PNEC values were found for the detected substances in biota. EQS and PNEC values for fish were considered not be representative for mouse liver.

Table 7: Available predicted no-effect concentrations (PNEC) for substances quantified in samples from EE facilities. Highlighted cells indicate that the average concentration in samples exceed the PNEC value.

Group	Short name	CAS	Freshwater (ng/L)	Marine water (ng/L)	STP (ng/L)	Soil (ng/g)	Sediment (ng/g)	Source
SVOC	BBDPFC	208709-55-1	10000000	-	-	-	-	ECHA
SVOC	EPHBP	84540-37-4	19*	-	-	-	-	Norman
SVOC	BEDPFC	174350-05-1	8600000	-	-	-	-	ECHA
SVOC	MPBP	64835-63-8	27*	-	-	-	-	Norman
OPFR metabolites	DEHPO	298-07-7	130000	-	-	670	-	ECHA
OPFR metabolites	DBP	107-66-4	850000	-	-	170	-	ECHA
OPFR metabolites	DPPO	838-85-7	28100*	-	-	-	-	Norman
OPFR metabolites	BDCPP	72236-72-7	6390*	-	-	-	-	Norman
OPFR metabolites	BBOEP	14260-97-0	30200*	-	-	-	-	Norman
FTAL met	MEHP	4376-20-9	190*	-	-	-	-	Norman
Bisphenols	DDPM	603-41-8	-	51*	-	-	124*	Norman
Bisphenols	BPA	80-05-7	-	-	-	-	240	EQS
Bisphenols	BPS	80-09-1	-	3000	20000000	-	174	ECHA
new BFRs	HBCDA	134237-50-6	19*	-	-	-	-	Norman
new BFRs	HBCDB	134237-51-7	19*	-	-	-	-	Norman
new BFRs	HBCDG	134237-52-8	180*	-	-	-	-	Norman
new BFRs	PBT	87-83-2	29*	-	-	-	-	Norman
new BFRs	PBEB	85-22-3	0.2*	-	-	-	-	Norman
new BFRs	PBBZ	608-90-2	170*	-	-	-	-	Norman
new BFRs	HBBZ	87-82-1	45*	-	-	-	-	Norman
new BFRs	BTBPE	37853-59-1	13*	-	-	-	-	Norman
new BFRs	BEHTBP	26040-51-7	-	-	-	7980000	-	ECHA
new BFRs	DBDPE	84852-53-9	1.2*	-	-	156000	-	Soil: ECHA Fw: Norman
new BFRs	QCB	608-93-5	7	-	-	-	-	EQS
new BFRs	HCB	118-74-1	50	-	-	-	-	EQS

*: QSAR based PNEC values, Fw: Freshwater

No exceedance of EQS or PNEC values from the ECHA Chemicals Database were reported. Seven QSAR based PNEC values for freshwater were exceeded, two LCD compounds (EPHBPH and MPBP) and five alternative flame retardants (HBCDA, HBCDB, PBEB, BTBPE, and DBDPE). It should be noted that the QSAR based PNEC values are associated with a large degree of uncertainty, and they may be biased low.

3.2 Waste water treatment and recipients

3.2.1 Detection frequencies

Several of the investigated compounds were detected in wastewater samples, particularly in the particle phase and sludge. The substances included in this part of the screening program fall into two categories: bisphenol-related substances, including BPA, BPS, and a selection of newer bisphenols and bisphenol derivatives; and follow-up substances selected based on previous findings in national screening efforts (Screening 2019), namely metformin (METFOR), tetrabutylammonium bromide (TBAB), N,N-dimethyloctadecylamine (DM18D), and 6'-(Dibutylamino)-3'-methyl-2'-(phenylamino)spiro[isobenzofuran-1(3H),9-(9H)-xanthen]-3-one (DBMPASBF).

Among the follow-up substances, METFOR, TBAB, DM18D, and DBMPASBF were consistently detected across multiple sample types. METFOR is a widely prescribed antidiabetic drug, frequently found in wastewater due to its high usage and limited biodegradability. TBAB is used as a phase-transfer catalyst in organic synthesis and may originate from industrial or laboratory discharges. DM18D is a long-chain tertiary amine used in pigment dispersion and surface-active formulations, with potential for environmental persistence. DBMPASBF is a leuco dye used in thermal paper, such as receipts, and its detection may reflect inputs from consumer products or urban runoff.

BPA and BPS were both detected, although their concentrations were generally low. These compounds are widely used in the production of polycarbonate plastics, epoxy resins, and thermal paper. However, it is difficult to determine whether the observed levels stem from direct use of BPA and BPS or from degradation of other bisphenol derivatives included in the analysis. Several newer bisphenols and bisphenol-based compounds were targeted but not detected, suggesting either low environmental prevalence or effective removal during wastewater treatment.

Among the bisphenol-related compounds that were detected, DDPM—a bisphenol derivative and pharmaceutical metabolite—showed high detection frequency and was present in both water and particle phases. APPPPA, a bisphenol-based monomer used in polyimide production and electronic components, was detected primarily in the particle phase. BBM, an antioxidant used in plastics and rubber, was found in sludge from highly treated wastewater.

None of the investigated compounds were detected in blue mussels or sediments, suggesting limited environmental persistence or bioaccumulation under current conditions. However, the presence of several compounds in sludge and particulate phases highlights their potential for accumulation in solid waste streams and possible release to the environment if not properly managed.

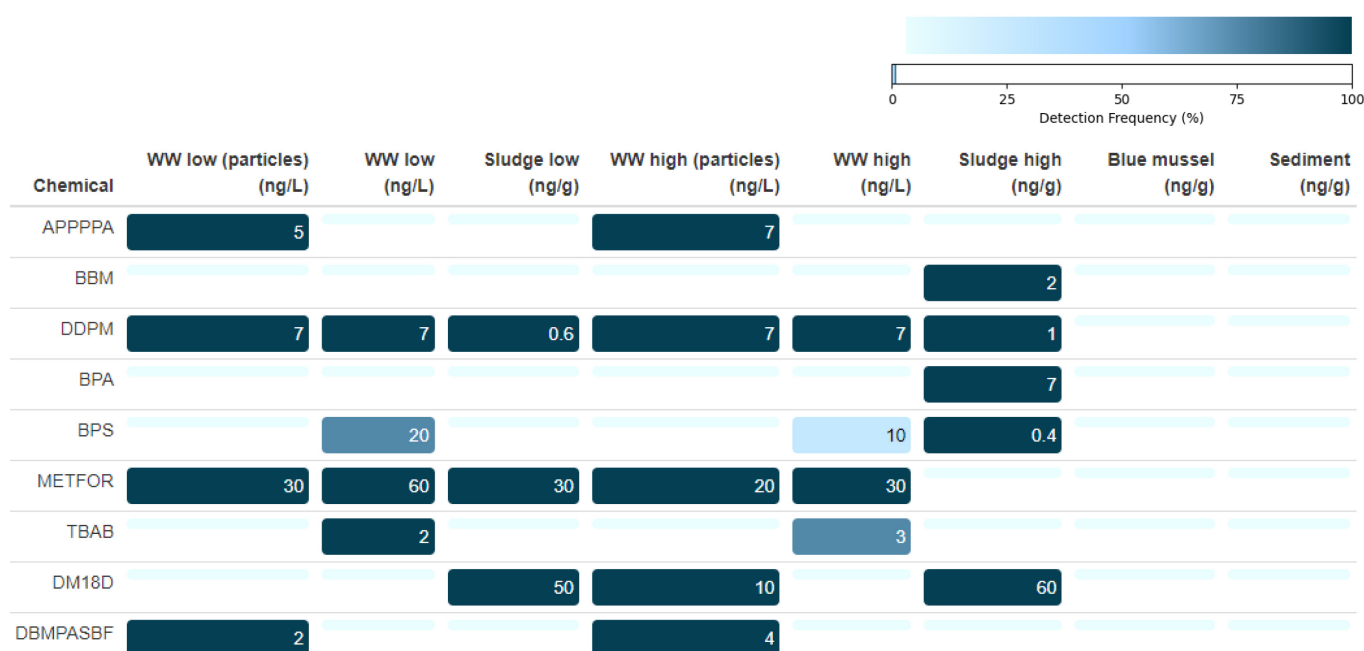


Figure 36: Average concentration of substances analysed in wastewater treatment plant and recipient samples. Observations below the method LOD is included in the averages as 0.5x the LOD value. Colour indicates detection frequency with pale blue indicating 0% detection.

3.2.2 Contamination patterns

The substances investigated in this screening were found in varying concentrations across water phase, particle phase, and sludge samples from a wastewater treatment plant (Figure 36). The plant includes both low and high degree treatment stages, allowing for comparison of removal efficiency and distribution patterns.

DDPM, METFOR, and TBAB were consistently detected in all sample types from both low and high degree treatment, indicating widespread presence and limited removal. DDPM, a bisphenol-related pharmaceutical metabolite, and METFOR, a highly prescribed antidiabetic drug, are known for their persistence in aqueous environments. TBAB, used as a phase-transfer catalyst, also showed high detection frequency, though its concentrations were somewhat reduced in the high degree treated water, suggesting partial removal.

DM18D and DBMPASBF were found primarily in sludge and particle phases, with higher concentrations in sludge from the high degree treatment. This pattern is consistent with their hydrophobic nature and potential for sorption to solids. The increase in concentration in high degree sludge likely reflects the reduction in sludge volume due to organic matter breakdown, concentrating stable compounds.

APPPPA was detected only in the particle phase, with slightly higher concentrations in the high degree treatment. This may suggest limited removal and strong association with particulate matter. BBM was only found in sludge from the high degree treatment, again likely due to concentration effects from sludge volume reduction.

No substances were detected in blue mussels or sediments, suggesting limited environmental persistence or bioaccumulation under current conditions. However, the presence of several compounds in sludge and

particulate phases highlights their potential for accumulation in solid waste streams and possible release to the environment if not properly managed.

Overall, the high degree treatment appears to reduce concentrations in the water phase for several substances, particularly those with hydrophilic properties. In contrast, hydrophobic and particle-associated compounds tend to accumulate in sludge, with concentrations often increasing due to volume reduction during treatment. These patterns reflect both the chemical properties of the substances and the mechanisms of the treatment process.

3.2.3 Risk assessment

No exceedance of EQS or PNEC values were observed for the samples from the wastewater treatment plant or recipient samples (Table 8).

Table 8: Available predicted no-effect concentrations (PNEC) for substances quantified in samples from the wastewater treatment plant. Highlighted cells indicate that the average concentration in samples exceed the PNEC value.

Short name	CAS	Freshwater (ng/L)	Marine water (ng/L)	STP (ng/L)	Soil (ng/g)	Sediment (ng/g)	Source
METFOR	657-24-9	-	16000*	-	-	331*	Norman
TBAB	1643-19-2	-	300	186000	-	-	ECHA
DM18D	124-28-7	-	-	-	-	125	ECHA
DBMPASBF	89331-94-2	-	161	400000	-	-	ECHA

*: QSAR based PNEC values

4 Conclusions

The combined results from EE facilities and wastewater treatment underscore the interconnected nature of pollution pathways. Indoor dust and air act as primary emission vectors, stormwater mobilizes contaminants toward aquatic environments, and wastewater treatment processes reveal both removal efficiencies and accumulation issues in sludge.

The 2024 Screening Programme successfully identified a range of emerging and legacy contaminants in both e-waste facilities and wastewater treatment environments. The results demonstrate that several substances of concern are still in use or present in waste streams, and that they can be released into the environment through handling, processing, or discharge.

In the EE facilities, LCD substances, flame retardants, plasticizers, and their degradation products were detected across multiple environmental matrices. Indoor dust and air showed the highest concentrations, particularly at facilities performing dismantling and processing. The presence of these substances in outdoor dust, stormwater,

and surrounding soil and moss indicates environmental dispersion beyond the immediate handling areas. These findings also suggest a potential for occupational exposure, particularly at facilities performing dismantling and processing, where elevated concentrations of LCD substances, flame retardant metabolites, and plasticizer degradation products were observed in indoor air and dust.

We recommend conducting targeted occupational exposure studies at EE facilities, particularly for workers involved in dismantling and processing LCD screens and other electronics. Such studies should include air and dust monitoring in work zones, biomonitoring of workers (e.g., urine or blood samples), and evaluation of personal protective equipment and ventilation systems. This will help assess potential health risks and inform mitigation strategies for substances such as LCD compounds, OPFR metabolites, and phthalate degradation products.

In wastewater treatment, bisphenol-related compounds and follow-up substances were found in water, particles, and sludge. Hydrophilic substances such as metformin were partially removed during biological treatment, while hydrophobic and particle-associated compounds tended to accumulate in sludge. The absence of detections in blue mussels and sediments suggests limited bioaccumulation or persistence in the recipient environment under current conditions.

These findings highlight the importance of continued monitoring of selected substances, particularly those with known persistence, bioaccumulative potential, or widespread use. The results also underscore the need for improved understanding of treatment efficiency and environmental fate, especially for newer bisphenol derivatives and industrial additives. The dual focus on e-waste and wastewater provides a comprehensive picture of contamination pathways and supports future prioritization efforts.

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Appendix 1

Substances

Substance name	Abbreviation	CASnr	Compound group	Analytical method	Target/Suspect
1-Ethoxy-2,3-difluoro-4-(trans-4-pentylcyclohexyl) benzene	EBDFPC	124729-02-8	LCD substances	SVOC	target
1-Butoxy-2,3-difluoro-4-(trans-4-propylcyclohexyl) benzene	BBDFPC	208709-55-1	LCD substances	SVOC	target
2,3-difluoro-1-ethoxy-4-(4-(4-ethylcyclohexyl)phenyl) benzene	EPHDFB	323178-01-4	LCD substances	SVOC	suspect
2,3-difluoro-1-propoxy-4-(4-(4-propylcyclohexyl) cyclohexyl) benzene	DFPCHB	473257-14-6	LCD substances	SVOC	target
1-[4-(4-butylcyclohexyl) cyclohexyl]-4-ethoxy-2, 3-difluoro-benzene	DFCHEB	473257-15-7	LCD substances	SVOC	suspect
4-[difluoro(3,4,5-trifluorophenoxy)methyl]-3,5-difluoro-2'-fluoro-4"-propyl-1,1':4',1"-terphenyl	DFTFPTP	303186-36-9	LCD substances	SVOC	target
1-propyl-4-(4-(4-propylcyclohexyl) cyclohexyl) benzene	PPCHB	84656-77-9	LCD substances	SVOC	target
1-(4-propylcyclohexyl)-4-vinylcyclohexane	PCHVCH	116020-44-1	LCD substances	SVOC	target
trans,trans-4-Methoxy-4'-propylcyclohexylcyclohexane	MPDCH	97398-80-6	LCD substances	SVOC	target
1-(trans-4-Pentylcyclohexyl)-4-propylbenzene	PCHPB	82991-48-8	LCD substances	SVOC	target
4''-Ethyl-2',3,4,5-tetrafluoro-1,1':4',1"-terphenyl	ETFPH	326894-55-7	LCD substances	SVOC	target
1-Methyl-4-[4-(4-propylcyclohexyl)cyclohexyl] benzene	MPCHB	84656-75-7	LCD substances	SVOC	target
3,4,5-Trifluoro-4'-(trans-4-propylcyclohexyl)biphenyl	BTFTPCH	132123-39-8	LCD substances	SVOC	target
1,2,3-trifluoro-5-[3-(3-propylcyclohexyl) cyclohexyl] benzene	TFPCHB	131819-23-3	LCD substances	SVOC	target
4-Ethyl-4'-(trans-4-propylcyclohexyl)biphenyl	EPHBPB	84540-37-4	LCD substances	SVOC	target
4-[difluoro(3,4,5-trifluorophenoxy) methyl]-3,5-difluoro-4'-propylbiphenyl	DFTFPPBP	303186-20-1	LCD substances	SVOC	target
2,3-difluoro-1-methoxy-4-(4-(4-propylcyclohexyl) cyclohexyl)benzene	DFMPCHB	431947-34-1	LCD substances	SVOC	target
1-ethoxy-2,3-difluoro-4-(4-(4-propylcyclohexyl) cyclohexyl)benzene	EDFPCHB	123560-48-5	LCD substances	SVOC	target
4-trifluoromethoxy-3,5-difluoro-2'-fluoro-4"- (4-propylcyclohexyl)-1,1':4',1"-terphenyl	CPGU3OT	524709-77-1	LCD substances	SVOC	suspect
4-propyl-4'-[4-(trifluoromethoxy)phenyl]-1,1'-bicyclohexyl	PTFMPCH	133937-72-1	LCD substances	SVOC	target

Substance name	Abbreviation	CASnr	Compound group	Analytical method	Target/Suspect
1-ethoxy-2,3-difluoro-4-(4-propylcyclohexyl)benzene	BEDFPC	174350-05-1	LCD substances	SVOC	target
4-butyl-4''-ethyl-2'-fluoro-1,1':4',1''-terphenyl	TPBEF	825633-75-8	LCD substances	SVOC	suspect
4''-ethyl-2'-fluoro-4-propyl-1,1':4',1''-terphenyl	TPEFP	95759-44-7	LCD substances	SVOC	target
4-[difluoro(3,4,5-trifluorophenoxy)methyl]-3,5-difluoro-4'-[(5-propyl-tetrahydro-2H-pyran)-yl]-biphenyl	DFTFPBP	700863-48-5	LCD substances	SVOC	suspect
1-(prop-1-enyl)-4-(4-propylcyclohexyl)cyclohexane	PPCHCH	279246-65-0	LCD substances	SVOC	target
1-Ethyl-4-[(4-methylphenyl)ethynyl] benzene	EMPEB	22692-80-4	LCD substances	SVOC	target
4-[Difluoro(3,4,5-trifluorophenoxy)methyl]-3,5-difluoro-4'-ethyl-biphenyl	DFTFPEBP	303186-19-8	LCD substances	SVOC	target
1-[4-(4-ethylcyclohexyl) cyclohexyl]-4-(trifluoromethoxy)benzene	ECHTFMB	135734-59-7	LCD substances	SVOC	target
4-Ethoxy-2,3-difluoro-4'-(trans-4-propylcyclohexyl)biphenyl	EDFPCHBP	189750-98-9	LCD substances	SVOC	target
10-bromo-9-phenylanthracene	BPANT	23674-20-6	LCD substances	SVOC	target
4-Bromo-4',4''-dimethyltriphenylamine	BDMTPA	58047-42-0	LCD substances	SVOC	target
2-(4-Bromophenyl)-4,6-diphenyl-1,3,5-triazine	24BPDT	23449-08-3	LCD substances	SVOC	target
2-(3-Bromophenyl)-4,6-diphenyl-1,3,5-triazine	23BPDT	864377-31-1	LCD substances	SVOC	target
4-Ethyl-4'-(trans-4-pentylcyclohexyl)biphenyl	EPCHBP	79709-85-6	LCD substances	SVOC	target
4,4'-Bis(trans-4-propylcyclohexyl)biphenyl	BPCHBP	85600-56-2	LCD substances	SVOC	target
4-(4-pentylcyclohexyl)-4'-(4-propylcyclohexyl)biphenyl	PPCHBP	80955-71-1	LCD substances	SVOC	suspect
1-Methoxy-4-(trans-4-propylcyclohexyl)benzene	MOPCHB	81936-32-5	LCD substances	SVOC	target
1-ethoxy-4-(p-tolylethynyl) benzene	EOTEB	116903-46-9	LCD substances	SVOC	target
1-ethyl-4-[2-(4-methoxyphenyl)ethynyl]benzene	EMOPEB	63221-88-5	LCD substances	SVOC	target
1-Ethoxy-4-(trans-4-propylcyclohexyl)benzene	EOPRCHB	80944-44-1	LCD substances	SVOC	target
1-Ethoxy-4-(trans-4-pentylcyclohexyl)benzene	EOPECHB	84540-32-9	LCD substances	SVOC	target
1-methoxy-4-[2-(4-pentylphenyl)ethynyl] benzene	MOPPEB	39969-28-3	LCD substances	SVOC	target
4'-Methyl-4-pentyl-biphenyl	MPBP	64835-63-8	LCD substances	SVOC	target
1-(4-trans-Propylcyclohexyl)-4-[4(4-propyloxyphenyl)ethynyl]-benzol	PCHPOEB	116903-49-2	LCD substances	SVOC	target
4-(trans-4-Ethylcyclohexyl)benzonitrile	ECHBN	72928-54-2	LCD substances	SVOC	target
4-[trans-4-[(E)-1-Propenyl]cyclohexyl] benzonitrile	EPCHBN	96184-40-6	LCD substances	SVOC	target
4-(4-Propylcyclohexyl)benzonitrile	PRCHBN	61203-99-4	LCD substances	SVOC	target
4-Butyl-4'-cyanobiphenyl	BCBP	52709-83-8	LCD substances	SVOC	target
4-(trans-4-Butylcyclohexyl)benzonitrile	BCHBN	61204-00-0	LCD substances	SVOC	target
4-(2-Methylbutyl)-4'-cyanobiphenyl	MBCBP	63799-11-1	LCD substances	SVOC	target

Substance name	Abbreviation	CASnr	Compound group	Analytical method	Target/Suspect
4-Cyano-4'-pentylbiphenyl	CPEBP	40817-08-1	LCD substances	SVOC	target
4-(4-Pentylcyclohexyl)benzonitrile	PECHBN	61204-01-1	LCD substances	SVOC	target
4-Hexyl-4'-cyanobiphenyl	CHXBP	41122-70-7	LCD substances	SVOC	target
4-Heptyl-4'-cyanobiphenyl	CHPBP	41122-71-8	LCD substances	SVOC	target
4-Cyano-4'-octylbiphenyl	COCBP	52709-84-9	LCD substances	SVOC	target
4-Cyano-4'-n-propyl-p-terphenyl	CP RTP	54296-25-2	LCD substances	SVOC	target
4-Cyano-4'-nonylbiphenyl	CNOBP	52709-85-0	LCD substances	SVOC	target
4-[4-(4-pentylcyclohexyl)phenyl] benzonitrile	PCHPBN	68065-81-6	LCD substances	SVOC	target
4-Cyano-4'-undecylbiphenyl	CUNBP	65860-74-4	LCD substances	SVOC	target
4-Cyano-4'-dodecylbiphenyl	CDOBP	57125-49-2	LCD substances	SVOC	target
N-([1,1'-Biphenyl]-4-yl)-9,9-dimethyl-9H-fluoren-2-amine	DMEFLEDPA	897671-69-1	LCD substances	SVOC	target
4-Cyano-4'-ethoxybiphenyl	CEOBP	58743-78-5	LCD substances	SVOC	target
4-Butoxy-4'-cyanobiphenyl	BOCBP	52709-87-2	LCD substances	SVOC	target
4'-Heptyloxy-4-cyanobiphenyl	HOCBP	52364-72-4	LCD substances	SVOC	target
4-Cyano-4'-nonoxybiphenyl	CNOOBP	58932-13-1	LCD substances	SVOC	target
4-Cyano-4'-decyloxybiphenyl	CDEOBP	70247-25-5	LCD substances	SVOC	target
1-methyl-4-(4-(4-vinylcyclohexyl)cyclohexyl)benzene	MVCHB	155041-85-3	LCD substances	SVOC	target
4'-Cyano-4-dodecyloxybiphenyl	CDOOBP	57125-50-5	LCD substances	SVOC	target
3,4-Difluoro-4'-(trans-4-ethylcyclohexyl)biphenyl	DFECHBP	134412-18-3	LCD substances	SVOC	target
trans,trans-4-(3,4-Difluorophenyl)-4'-vinylbicyclohexyl	DFPV BCH	142400-92-8	LCD substances	SVOC	target
3,4,5-Trifluoro-1-[trans-4'-(trans-4''-ethylcyclohexyl)cyclohexyl]benzene	TFECHB	139215-80-8	LCD substances	SVOC	target
2',3,4,5-Tetrafluoro-4''-propyl-1,1':4',1''-terphenyl	TFPTP	205806-87-7	LCD substances	SVOC	target
2',3,4,5-Tetrafluoro-4'-(trans-4-propylbicyclohexyl)biphenyl	TFPRCHBP	173837-35-9	LCD substances	SVOC	target
3,4-Difluoro-4'-(trans-4-propylcyclohexyl)biphenyl	DFPRCHBP	85312-59-0	LCD substances	SVOC	target
4-fluoro-4'-(trans-4-propylcyclohexyl)biphenyl	FPCHBP	87260-24-0	LCD substances	SVOC	target
trans,trans-4-(2,3-Difluoro-4-methylphenyl)-4'-ethylbicyclohexyl	DFMPECH	174350-08-4	LCD substances	SVOC	target
3,4,5-Trifluoro-4'-(trans-4-pentylcyclohexyl)biphenyl	TFPECHBP	137019-95-5	LCD substances	SVOC	target
3,4-Difluoro-4'-(trans-4-pentylcyclohexyl)biphenyl	DFPECHBP	134412-17-2	LCD substances	SVOC	target
3,4,5-Trifluoro-1-[trans-4'-(trans-4''-pentylcyclohexyl)cyclohexyl]benzene	TFPECHB	137644-54-3	LCD substances	SVOC	target
4''-Ethyl-2'-fluoro-4-pentyl-1,1':4',1''-terphenyl	EFPETP	95759-59-4	LCD substances	SVOC	target
4-(4-methylphenyl)-4'-(3-butenyl)bicyclohexyl	MPBUBCH	129738-42-7	LCD substances	SVOC	target

Substance name	Abbreviation	CASnr	Compound group	Analytical method	Target/Suspect
4'-hexyloxy-4-biphenylcarbonitrile	HEOBPCN	41424-11-7	LCD substances	SVOC	target
4-cyano-4'-pentyloxybiphenyl	CPEOBP	52364-71-3	LCD substances	SVOC	target
4'-(octyloxy)-4-biphenylcarbonitrile	OCOBPCN	52364-73-5	LCD substances	SVOC	target
4'-propoxy-4-biphenylcarbonitrile	POBPCN	52709-86-1	LCD substances	SVOC	target
4-cyano-4''-penty-p-terphenyl	CPETP	54211-46-0	LCD substances	SVOC	target
4'-ethylbiphenyl-4-carbonitril	EBPCN	58743-75-2	LCD substances	SVOC	target
(Trans,trans)-4-(4-ethylphenyl)-4'-propyl-1,1'-bi(cyclohexane)	EPPBCHE	84656-76-8	LCD substances	SVOC	target
4-fluorophenyl 4-hexylcyclohexane-1-carboxylate	FPHXCHC	79912-84-8	LCD substances	SVOC	suspect
4-(4-ethylcyclohexyl)-4'-(trifluoromethoxy)biphenyl	ECFTMOBP	650634-92-7	LCD substances	SVOC	suspect
4-Propyl-4'-(trans-4-propylcyclohexyl)-1,1'-biphenyl	PRCHBP	122957-72-6	LCD substances	SVOC	suspect
4-fluorophenyl 4-(4-pentylcyclohexyl) cyclohexane carboxylate	FPPECHC	88878-50-6	LCD substances	SVOC	target
4-[difluoro(3,4,5trifluorophenoxy)methyl]-3,5-difluoro-4'-[(5-propyl-tetrahydro-2H-pyran)-yl]-biphenyl	FMPOFPBP	1700444-88-7	LCD substances	SVOC	suspect
4''-Butyl-4-[difluoro(3,4,5-trifluorophenoxy)methyl]-2',3,5-trifluoro-1,1':4',1''-terphenyl	BTFPOMTP	914087-74-4	LCD substances	SVOC	target
2,7-Dibromo-9,9-diphenylfluorene	DBDPFE	186259-63-2	LCD substances	SVOC	target
9-Bromo-10-(1-naphthalenyl)anthracene	BNAP1ANT	400607-04-7	LCD substances	SVOC	target
9-Bromo-10-(2-naphthyl)anthracene	BNAP2ANT	474688-73-8	LCD substances	SVOC	target
2-Bromo-9,9-diphenylfluorene	2BDPFLE	474918-32-6	LCD substances	SVOC	target
4-Bromo-9,9-diphenyl-9Hfluorene	4BDPFLE	713125-22-5	LCD substances	SVOC	target
1-(4-Bromophenyl)-1,2,2-triphenylethylene	BPTPE	34699-28-0	LCD substances	SVOC	target
1-(4-butylcyclohexyl)-4-(p-tolyethynyl) benzene	BCHTEB	133856-91-4	LCD substances	SVOC	suspect
4-Bromo-4'-(diphenylamino)biphenyl	BDPABP	202831-65-0	LCD substances	SVOC	target
1-ethyl-4-(2-(4-(4-propylcyclohexyl) phenyl) ethynyl) benzene	EPRCHPEB	202205-77-4	LCD substances	SVOC	target
4-ethyl-4'-[2-(4-pentylcyclohexyl) ethyl] biphenyl	EPECHEBP	85872-01-1	LCD substances	SVOC	suspect
1-butyl-4-[2-(4-ethoxyphenyl)ethynyl]-benzene	BEOPEB	85583-83-1	LCD substances	SVOC	target
2,6-di-tert-butyl-4-(4-propylcyclohexyl) phenol	DBPRCHP	400031-56-3	LCD substances	SVOC	suspect
1-(2-(4-(4-butylcyclohexyl) phenyl) ethynyl) -4-ethoxybenzene	BCHPEEOB	199795-20-5	LCD substances	SVOC	target
1-methoxy-4-((4-(4-pentylcyclohexyl) phenyl) ethynyl) benzene	MOPCHPEB	372983-17-0	LCD substances	SVOC	target
1-(4-pentylcyclohexyl)-4-((4-propoxyphenyl) ethynyl) benzene	PCHPROPEB	334826-61-8	LCD substances	SVOC	suspect
1,2-Difluoro-4-[trans-4-(trans-4-ethylcyclohexyl) cyclohexyl]benzene	DFECHB	118164-50-4	LCD substances	SVOC	target

Substance name	Abbreviation	CASnr	Compound group	Analytical method	Target/Suspect
1,2-difluoro-4-[2-fluoro-4-(4-propylphenyl)phenyl]benzene	DFPRPB	248936-60-9	LCD substances	SVOC	target
1,2-Difluoro-4-[trans-4-(trans-4-propylcyclohexyl)cyclohexyl]benzene	DFPRCHB	82832-57-3	LCD substances	SVOC	target
1-Fluoro-4-[4-(4-propylcyclohexyl)cyclohexyl]benzene	FPRCHB	82832-27-7	LCD substances	SVOC	target
trans,trans-4'-(3-Butenyl)-4-(3,4-difluorophenyl)bicyclohexyl	BDFPBCH	155266-68-5	LCD substances	SVOC	target
3,4-Difluoro-1-[4-(trans-4-butylcyclohexyl)cyclohexyl]benzene	DFBUCHB	82832-58-4	LCD substances	SVOC	target
1,2,3-Trifluoro-5-[trans-4-[2-(trans-4-propylcyclohexyl)ethyl]cyclohexyl]benzene	TFPRCHEB	131819-24-4	LCD substances	SVOC	target
1,2-Difluoro-4-[4-(4-pentylcyclohexyl)cyclohexyl]benzene	DFPECHB	118164-51-5	LCD substances	SVOC	target
1,2-Difluoro-4-[trans-4-[2-(trans-4-propylcyclohexyl)-ethyl]cyclohexyl]benzene	DFPRCHEB	117943-37-0	LCD substances	SVOC	target
4-(3-buten-1-yl)-2'-fluoro-4''-propyl[1,1':4',1''-terphenyl]	BFP RTP	915956-24-0	LCD substances	SVOC	suspect
4''-Propyl-2'-fluoro-4-pentyl-1,1':4',1''-terphenyl	PRFPETP	95759-51-6	LCD substances	SVOC	target
3,4-difluoro-4'-[4'-ethyl-1,1'-bi(cyclohexyl)-4-yl]biphenyl	DFEDCHBP	139195-63-4	LCD substances	SVOC	target
3,4,5-trifluoro-4'-[(trans,trans)-4'-propyl[1,1'-bicyclohexyl]-4-yl]biphenyl	TFPRBCHBP	137529-41-0	LCD substances	SVOC	target
3,4-Difluoro-4'-[(trans,trans)-4'-propyl[1,1'-bicyclohexyl]-4-yl]biphenyl	DFPRBCHBP	119990-81-7	LCD substances	SVOC	target
trans,trans-3,4,5-Trifluoro-4'-(4'-pentylbicyclohexyl-4-yl)biphenyl	TFPEBCHBP	137529-43-2	LCD substances	SVOC	target
3,4-Difluoro-4'-[(trans,trans)-4'-pentyl[1,1'-bicyclohexyl]-4-yl]biphenyl	DFPEBCHBP	136609-96-6	LCD substances	SVOC	target
2-Fluoro-4-(trans-4-pentylcyclohexyl)-4'-(trans-4-propylcyclohexyl)biphenyl	FPEPRCHBP	106349-49-9	LCD substances	SVOC	target
2,3-Difluoro-1-methoxy-4-[(trans-4-propylcyclohexyl)methoxy]benzene	DFMOPRCHB	1373116-00-7	LCD substances	SVOC	target
1,4-dibutoxy-2,3-difluorobenzene	DBDFB	1326241-42-2	LCD substances	SVOC	suspect
1,2,3-trifluoro-4-methoxy-5-(4-(4-propylcyclohexyl)cyclohexyl)benzene	TFMOPRCHB	NA	LCD substances	SVOC	suspect
4-[difluoro(2-methyl-3,4,5-trifluorophenoxy)methyl]-3,5-difluoro-4'-propylbiphenyl	TFPOPBP	1690317-23-7	LCD substances	SVOC	suspect
1-ethoxy-2,3-difluoro-4-(4-(4-prop-1-enyl)cyclohexyl)cyclohexylbenzene	EODFPRCHB	NA	LCD substances	SVOC	suspect
1-(4-(4-butylcyclohexyl)cyclohex-1-enyl)-4-ethoxy-2,3-difluorobenzene	BUCH EODFB	NA	LCD substances	SVOC	suspect

Substance name	Abbreviation	CASnr	Compound group	Analytical method	Target/Suspect
1-butoxy-2,3-difluoro-4-(4-methylphenyl)benzene	BODFMPB	1443311-78-1	LCD substances	SVOC	suspect
1-[2-[4-(trans-4-Ethylcyclohexyl)phenyl]ethynyl]-4-propylbenzene	ECHMPB	100558-65-4	LCD substances	SVOC	suspect
4-Methoxy-4'-(trans-4-propylcyclohexyl)-1,1'-biphenyl	MOPRCHBP	111158-10-2	LCD substances	SVOC	suspect
3,4-difluoro-4'-propyl-1,1'-Biphenyl	DFPRBP	118164-49-1	LCD substances	SVOC	suspect
3,4-difluoro-4'-[4'-butyl-1,1'-bi(cyclohexyl)-4-yl]biphenyl	DFBCHBP	119990-82-8	LCD substances	SVOC	suspect
4-[difluoro(2-methyl-3,4,5-trifluorophenoxy)methyl]-3,5-difluoro-4'-propylbiphenyl		NA	LCD substances	SVOC	suspect
Polybromotrifluoroetylen oljer	BTFEPO	598-73-2	FRs, additives, and related substances	SVOC	suspect
Polychlorotrifluoroethylene	CTFEPO	9002-83-9	FRs, additives and metabolites	SVOC	target
Bis(2-ethylhexyl) phosphate	DEHPO	298-07-7	FRs, additives and metabolites	OPFR metabolites	target
Dibutyl phosphate	DBP	107-66-4	FRs, additives and metabolites	OPFR metabolites	target
Diphenyl phosphate	DPPO	838-85-7	FRs, additives and metabolites	OPFR metabolites	target
Bis(1,3-dichloro-2-propyl) phosphate	BDCPP	72236-72-7	FRs, additives and metabolites	OPFR metabolites	target
Bis(2-butoxyethyl) phosphate	BBOEP	14260-97-0	FRs, additives and metabolites	OPFR metabolites	target
Bis(2-chloroethyl) phosphate	BCEP	3040-56-0	FRs, additives and metabolites	OPFR metabolites	target
Bis(2-chloro-1-methylethyl) hydrogen phosphate	BCPP	789440-10-4	FRs, additives and metabolites	OPFR metabolites	target
Monomethyl phthalate	MMP	4376-18-5	FRs, additives and metabolites	FTAL met	target
Monoethyl phthalate	MEP	2306-33-4	FRs, additives and metabolites	FTAL met	target
Mono-iso-butyl phthalate	MIBP	30833-53-5	FRs, additives and metabolites	FTAL met	target
Mono-n-butyl phthalate	MBP	131-70-4	FRs, additives and metabolites	FTAL met	target
Monobenzyl phthalate	MBZP	2528-16-7	FRs, additives and metabolites	FTAL met	target
Mono(2-ethylhexyl) phthalate	MEHP	4376-20-9	FRs, additives and metabolites	FTAL met	target

Substance name	Abbreviation	CASnr	Compound group	Analytical method	Target/Suspect
Mono(2-ethyl-5-hydroxyhexyl) phthalate	MEHHP	40321-99-1	FRs, additives and metabolites	FTAL met	target
Kortere halogenerte alkaner vSCCPs (C6-C9)	VSCCP	NA	CPs and related substances	BCA og PCA	target
Bromo-cloro parafiner og olefiner (C12-C30)		NA	CPs and related substances	BCA og PCA	suspect
SCCP - metabolitter		NA	CPs and related substances	BCA og PCA	suspect
MCCP - metabolitter		NA	CPs and related substances	BCA og PCA	suspect
LCCP - metabolitter		NA	CPs and related substances	BCA og PCA	suspect
SCCP			CPs and related substances	BCA og PCA	
MCCP			CPs and related substances	BCA og PCA	
Long-chain chlorinated paraffins (C18-C28)	LCCP	85535-86-0	CPs and related substances	BCA og PCA	target
Dibromobisphenol A	DBBPA	29426-78-6	FRs, additives and metabolites	Halogenated bisphenols	suspect
diiodo-BPA	DIBPA	NA	FRs, additives and metabolites	Halogenated bisphenols	suspect
dehalogenated TBBPA and related compounds	DeBrTBBPA*	NA	FRs, additives and metabolites	Halogenated bisphenols	suspect
Dekabromodifenyl-debrominerte versjoner Benzene, 1,1'-(1,2-ethanediyl)bis-, brominated	DBDPDB	1092834-40-6	FRs, additives and metabolites	BFRs	suspect
2,2',4-Tribromodiphenyl ether	BDE17	147217-75-2	FRs, additives and metabolites	PBDEs	target
2,4,4'-Tribromodiphenyl ether	BDE28	41318-75-6	FRs, additives and metabolites	PBDEs	target
2,2',4,4'-Tetrabromodiphenyl ether	BDE47	5436-43-1	FRs, additives and metabolites	PBDEs	target
2,2',4,5'-Tetrabromodiphenyl ether	BDE49	243982-82-3	FRs, additives and metabolites	PBDEs	target
2,3',4,4'-Tetrabromodiphenyl ether	BDE66	189084-61-5	FRs, additives and metabolites	PBDEs	target
2,3',4',6-Tetrabromodiphenyl ether	BDE71	189084-62-6	FRs, additives and metabolites	PBDEs	target
3,3',4,4'-Tetrabromodiphenyl ether	BDE77	93703-48-1	FRs, additives and metabolites	PBDEs	target
2,2',3,4,4'-Pentabromodiphenyl ether	BDE85	182346-21-0	FRs, additives and metabolites	PBDEs	target

Substance name	Abbreviation	CASnr	Compound group	Analytical method	Target/Suspect
2,2',4,4',5-Pentabromodiphenyl ether	BDE99	60348-60-9	FRs, additives and metabolites	PBDEs	target
2,2',4,4',6-Pentabromodiphenyl ether	BDE100	189084-64-8	FRs, additives and metabolites	PBDEs	target
2,3',4,4',6-Pentabromodiphenyl ether	BDE119	189084-66-0	FRs, additives and metabolites	PBDEs	target
3,3',4,4',5-Pentabromodiphenyl ether	BDE126	366791-32-4	FRs, additives and metabolites	PBDEs	target
2,2',3,4,4',5'-Hexabromodiphenyl ether	BDE138	182677-30-1	FRs, additives and metabolites	PBDEs	target
2,2',4,4',5,5'-Hexabromodiphenyl ether	BDE153	68631-49-2	FRs, additives and metabolites	PBDEs	target
2,2',4,4',5,6'-Hexabromodiphenyl ether	BDE154	207122-15-4	FRs, additives and metabolites	PBDEs	target
1,2,3,4-Tetrabromo-5-(3,4-dibromophenoxy)benzene	BDE156	405237-85-6	FRs, additives and metabolites	PBDEs	target
2,2',3,4,4',5',6-Heptabromodiphenyl ether	BDE183	207122-16-5	FRs, additives and metabolites	PBDEs	target
2,2',3,4,4',6,6'-Heptabromodiphenyl ether	BDE184	117948-63-7	FRs, additives and metabolites	PBDEs	target
2,3,3',4,4',5',6-Heptabromodiphenyl ether	BDE191	446255-30-7	FRs, additives and metabolites	PBDEs	target
2,2',3,3',4,4',5,6'-Octabromodiphenyl ether	BDE196	446255-39-6	FRs, additives and metabolites	PBDEs	target
2,2',3,3',4,4',6,6'-Octabromodiphenyl ether	BDE197	117964-21-3	FRs, additives and metabolites	PBDEs	target
1,1'-Oxybis[2,3,5,6-tetrabromobenzene]	BDE202	67797-09-5	FRs, additives and metabolites	PBDEs	target
2,2',3,3',4,4',5,5',6-Nonabromodiphenyl ether	BDE206	63387-28-0	FRs, additives and metabolites	PBDEs	target
2,2',3,3',4,4',5,6,6'-Nonabromodiphenyl ether	BDE207	437701-79-6	FRs, additives and metabolites	PBDEs	target
Decabromodiphenyl ether	BDE209	1163-19-5	FRs, additives and metabolites	PBDEs	target
Cyclo-di-BADGE	CDBADGE	20583-87-3	BP derivatives	Bisphenols	target
4,4'-(1,3-Dimethylbutylidene)bis[phenol]	DMBUBP	6807-17-6	BP derivatives	Bisphenols	target
Bisphenol A dicyanate	BPADC	1156-51-0	BP derivatives	Bisphenols	target
4,4'-Isopropylidenebis(2-allylphenol)	DABPA	1745-89-7	BP derivatives	Bisphenols	target
4,4'-isopropylidenedi-2,6-xylol	TMBPA	5613-46-7	BP derivatives	Bisphenols	target
4,4'-((Propane-2,2-diylbis(4,1-phenylene))bis(oxy))dianiline	APPPPA	13080-86-9	BP derivatives	Bisphenols	target

Substance name	Abbreviation	CASnr	Compound group	Analytical method	Target/Suspect
4,4'-(4,4'-Isopropylidenediphenoxy)bispthalic dianhydride	BPADAH	38103-06-9	BP derivatives	Bisphenols	target
Bisphenol A diacrylate	BPADAC	4491-03-6	BP derivatives	Bisphenols	suspect
Bisphenol A dimethacrylate	BPADMAC	3253-39-2	BP derivatives	Bisphenols	target
Bisphenol A diglycidyl ether diacrylate	BPAGEAC	4687-94-9	BP derivatives	Bisphenols	target
Bisphenol A glycerolate dimethacrylate	BPAGMAC	1565-94-2	BP derivatives	Bisphenols	target
4,4'-(1-Methylethylidene)bis[2,6-bis[(dimethylamino)methyl]phenol	MEDMAMP	16224-36-5	BP derivatives	Bisphenols	suspect
4,4'-methylenedi-2,6-xylenol	XYLENOL	5384-21-4	BP derivatives	Bisphenols	target
4,4'-Methylenebis(2,6-dimethylphenyl cyanate)	MBDMPC	101657-77-6	BP derivatives	Bisphenols	target
2,2'-Methylenebis[6-(1,1-dimethylethyl)-4-methylphenol]	AO246	119-47-1	BP derivatives	Bisphenols	target
4,4'-(2-Ethyl-1,1-hexanediyl)diphenol	EHEDDP	74462-02-5	BP derivatives	Bisphenols	target
bis(4-(4-aminophenoxy)phenyl)sulfone	BAPOPS	13080-89-2	BP derivatives	Bisphenols	target
2,2'-diallyl-4,4'-sulfonyldiphenol	DASDP	41481-66-7	BP derivatives	Bisphenols	target
4-(4-Isopropoxyphenylsulfonyl)phenol	4IPPSP	95235-30-6	BP derivatives	Bisphenols	target
4,4'-thiodiphenol	44TDP	2664-63-3	BP derivatives	Bisphenols	target
4,4'-Cyclohexylidenebis[2-methylphenol]	SHEBMP	2362-14-3	BP derivatives	Bisphenols	target
2,2'-[Cyclohexylidenebis(4,1-phenyleneoxymethylene)]bis[oxirane]	SHEPOMO	13446-84-9	BP derivatives	Bisphenols	suspect
4,4'-Butylidenebis[2-(1,1-dimethylethyl)-5-methylphenol]	BBM	85-60-9	BP derivatives	Bisphenols	target
p,p'-(2-pyridylmethylene)bisphenol	DDPM	603-41-8	BP derivatives	Bisphenols	target
1,1'-(chlorophenylmethylene)bis[4-methoxybenzene]	CPMMOB	40615-36-9	BP derivatives	Bisphenols	target
Tris(4-hydroxyphenyl)ethane	T4HPE	27955-94-8	BP derivatives	Bisphenols	target
Bisphenol A	BPA	80-05-7	BP derivatives	Bisphenols	target
2,4'-Bisphenol A	BPA24	837-08-1	BP derivatives	Bisphenols	target
4,4'-Bisphenol S	BPS	80-09-1	BP derivatives	Bisphenols	target
2,4 Bisphenol S	BPS24	5397-34-2	BP derivatives	Bisphenols	target
Dibromoaldrin	DBALD	20389-65-5	FRs, additives and metabolites	Dechloranes	target
Dechlorane 602	DDC_DBF	31107-44-5	FRs, additives and metabolites	Dechloranes	target
Dechlorane 603	DDC_ANT	13560-92-4	FRs, additives and metabolites	Dechloranes	target
Dechlorane 604	HCTBPH	34571-16-9	FRs, additives and metabolites	Dechloranes	target

Substance name	Abbreviation	CASnr	Compound group	Analytical method	Target/Suspect
Dechlorane 601	DDC_BBF	13560-90-2	FRs, additives and metabolites	Dechloranes	target
syn-Dechlorane plus	DDC_PS	135821-03-3	FRs, additives and metabolites	Dechloranes	target
anti-Dechlorane plus	DDC_PA	135821-74-8	FRs, additives and metabolites	Dechloranes	target
α -Hexabromocyclododecane	HBCDA	134237-50-6	FRs, additives and metabolites	new BFRs	target
β -Hexabromocyclododecane	HBCDB	134237-51-7	FRs, additives and metabolites	new BFRs	target
γ -Hexabromocyclododecane	HBCDG	134237-52-8	FRs, additives and metabolites	new BFRs	target
2,4,6-Tribromophenyl allyl ether	ATE	3278-89-5	FRs, additives and metabolites	new BFRs	target
α -Tetrabromoethylcyclohexane	TBECHA	1232836-48-4	FRs, additives and metabolites	new BFRs	target
β -Tetrabromoethylcyclohexane	TBECHB	1232836-49-5	FRs, additives and metabolites	new BFRs	target
g-Tetrabromoethylcyclohexane	TBECHG		FRs, additives and metabolites	new BFRs	target
2-Bromoallyl 2,4,6-tribromophenyl ether	BATE	99717-56-3	FRs, additives and metabolites	new BFRs	target
Pentabromotoluene	PBT	87-83-2	FRs, additives and metabolites	new BFRs	target
Pentabromoethylbenzene	PBEB	85-22-3	FRs, additives and metabolites	new BFRs	target
1,2,3,4,5-Pentabromobenzene	PBBZ	608-90-2	FRs, additives and metabolites	new BFRs	target
1,2,3,4,5,6-Hexabromobenzene	HBBZ	87-82-1	FRs, additives and metabolites	new BFRs	target
2,3-Dibromopropyl 2,4,6-tribromophenyl ether	DPTE	35109-60-5	FRs, additives and metabolites	new BFRs	target
2-Ethylhexyl 2,3,4,5-tetrabromobenzoate	EHTBB	183658-27-7	FRs, additives and metabolites	new BFRs	target
1,2-Bis(2,4,6-tribromophenoxy)ethane	BTBPE	37853-59-1	FRs, additives and metabolites	new BFRs	target
Bis(2-ethylhexyl) tetrabromophthalate	BEHTBP	26040-51-7	FRs, additives and metabolites	new BFRs	target
Decabromodiphenylethane	DBDPE	84852-53-9	FRs, additives and metabolites	new BFRs	target
Pentachlorobenzene	QCB	608-93-5	FRs, additives and metabolites	new BFRs	target

Substance name	Abbreviation	CASnr	Compound group	Analytical method	Target/Suspect
Hexachlorobenzene	HCB	118-74-1	FRs, additives and metabolites	new BFRs	target
Vinylidene chloride	DIKLOR	75-35-4	other	S-19 (VOC)	target
cis-1,2-Dichloroethene	ZDCE	156-59-2	other	S-19 (VOC)	target
1,1,1-Trichloroethane	TCE	71-55-6	other	S-19 (VOC)	target
Bromodichloromethane	BDCM	75-27-4	other	S-19 (VOC)	target
Dibromomethane	DBRM	74-95-3	other	S-19 (VOC)	target
cis-1,3-Dichloropropene	CDCPE3	10061-01-5	other	S-19 (VOC)	target
trans-1,3-Dichloropropene	TDCPE3	10061-02-6	other	S-19 (VOC)	target
Tetrachloroethylene	TECE	127-18-4	other	S-19 (VOC)	target
1,1,2-Trichloroethane	TCE2	79-00-5	other	S-19 (VOC)	target
e-Caprolactam	CAPLAC	105-60-2	other	S-19	target
Neodecanoic acid	NEDEA	130776-67-9	other	S-19	target
1,3-Di-o-tolylguanidine	DTGUAN	97-39-2	other	S-19	target
Metformin	METFOR	657-24-9	other	S-19	target
Pyrazole	PYRAZOL	288-13-1	other	S-19	target
Tetrabutylammonium	TBAB	1643-19-2	other	S-19	target
N,N-Dimethyloctadecan-1-amine	DM18D	124-28-7	other	S-19	target
(+)-3-Carene	CAREN	498-15-7	other	S-19 (VOC)	target
6'-(Dibutylamino)-3'-methyl-2'-(phenylamino)spiro[isobenzofuran-1(3H),9-(9H)-xanthen]-3-one	DBMPASBF	89331-94-2	other	S-19	target
Barium 3,5,5-trimethylhexanoate	BTEHA	36211-43-5	other	S-19	suspect

Appendix 2

Analytical methods

EE facilities

SVOCs

Before extraction, a mixture of internal standards was added. Biota, sediment, and sludge samples were homogenised and then extraction was carried out with mixture of acetonitrile and hexane. Hexane layer was separated and concentrated, if necessary. ABN cartridges (for air samples) were extracted with ethyl acetate and concentrated by evaporation in a gentle stream of nitrogen. Dust samples were extracted with acetone. Extracts were concentrated, if necessary. Aqueous samples were extracted with a mixture of dichloromethane and ethyl acetate. Analysis was performed with full-scan GC-HRMS. The instrument used was Thermo Q Exactive GC-Orbitrap-HRAM-MS operated at mass-resolution 60000. Mass-range was adjusted to optimize sensitivity, depending on the sample type. Quantification was made with help of calibration solutions in case of availability of authentic specimens. In case of lack of authentic specimens, the mass-spectra and retention times were estimated based on literature data for related substances. Due to unavoidable ambiguity, only detection/not detection was reported in lack of authentic specimens.

BFRs and CPs

Water samples were filtered, and the filtered sample was extracted using liquid-liquid extraction with cyclohexane/ethyl acetate (1:1). Solid samples (dust, soil, moss and water particles) were dried and homogenized before extraction using accelerated solvent extraction (ASE). A Dionex™ ASE™ 350 system was utilized. An aliquot of the sample was weighed and added to a stainless-steel ASE cell along with a dispersant (Ottawa sand) and added a mixture of isotopically labeled internal standards. Procedural blanks consisted of cells packed with dispersant spiked with internal standards. For the water particle samples, blanks also consisted of a blank filter which had been subjected to filtering of MilliQ-water, dried and grinded along with the samples. Procedural blanks were otherwise treated the same as the samples. Each cell was extracted with acetone/hexane (1:1). Samples were then solvent exchanged to hexane and cleaned using sulphuric acid treatment and an activated silica column. Samples requiring additional cleanup were processed using GPC.

Polybrominated diphenyl ethers (PBDE), other brominated flame retardants (BFRs), polychlorinated biphenyls (PCBs) and dechloranes were quantified on GC-HRMS (Waters Autospec) and/or GC-QToF (Agilent 7200B). Very short, short-, medium- and long chained chlorinated paraffins (vS/S/M/LCCP) and bromo-chloro paraffins and olefins were analysed on GC-HRMS (Waters Autospec) and/or GC-QToF (Agilent 7200B). LCCPs were analyzed with Agilent UHPLC-HR-QTOF-MS operated in negative electrospray mode with acetonitrile and water mixed with TMAC (tetramethyl ammonium chloride).

CP metabolites and halogenated bisphenols

Water samples were extracted as for BFRs and CPs. The extract was evaporated to dryness, solved in methanol and filtered on a Millipore PVDF-filter (0,1 µm, 5 min, 10000 rpm), before being evaporated to dryness again. Samples were then solved in distilled methanol/water 1:1 (100 µl) and added recovery standards before analysis. Solid samples (dust, soil, and water particles) were extracted using Dionex ASE 350 system with acetone/hexane

(1:1) and distilled methanol 1% formic acid. Extracts were evaporated to dryness in a MiVac system, filtered, diluted and analyzed.

Moss samples, as well as selected samples from the above-mentioned matrices were extracted using SUPRAS. A SUPRAS mixture was made by mixing water (21 mL), 1-hexanol (3 mL) and THF (6mL), vortex mixing (1 min) and centrifuging (30 min, 3500 rpm). The top layer (SUPRAS) was transferred and stored at room temperature. Samples were weighed in a 2 mL Eppendorf-tube, added internal standards and 3 glass balls, SUPRAS (400 ul) and extracted on a shaker (10 min, 2500 rpm), before centrifuging (10 min, 13400 rpm). 200 ul of the top layer was collected and sent to analysis.

Phthalate and OPFR Met

100mL of process water samples were taken into a new glass and added 20µL of labeled internal standards (d10-BBNP, d10-BPP, d8-BCEP and d4-MEP. d4-MIBP, d4-MBzP, d4-MEHP). Samples were passed through precleaned solid phase extraction columns (glass OASIS HLB 200mg), dried and eluted with 5mL of 1% formic acid in methanol. Extracts were evaporated to 200uL and transferred to analytical glass.

OPFRs and phthalate metabolites were analyzed by the following method. 0.05g of dust was homogenized in a Precellys tube with metal beads, 20µL of labeled internal standards, and 1mL of 1% formic acid in acetonitrile. The mixture was processed thrice at 6800 rpm for 20 seconds, followed by centrifugation at 10000 rpm for 10 minutes. 500uL of the supernatant was transferred to analytical glass.

Moss samples were first processed in a Tubemill 100 and 0.4g was taken out for further homogenization and processing in the Precellys similarly to dust samples.

Mouse liver sample (0.05g) was processed using Precellys by adding 20µL of labeled internal standards and 1mL Ammoniumacetate and processed similarly to dust. 0.8mL of supernatant was transferred to 4 mL glass and added 10uL β-Glucuronidase (BG Turbo) and incubated for 12h @ 37C. Sample was centrifuged and added 2mL phosphate buffer and cleaned up on a 3mL Strata-X which was eluted with acetonitrile and ethylacetate. Sample was evaporated and transferred to analytical glass.

All OPFR and phthalate metabolite fractions was prepared with 20µL d4-MOP and 0.5% formic acid in milli-Q water as a buffer and analyzed via LC-Exploris using a Waters C18 column with standard procedures.

Waste water treatment and recipients

Bisphenol derivatives and other (S-19)

Water samples were extracted and cleaned using solid phase extraction (SPE) with Oasis HLB® 6cc columns on a LCtech Freestyle system. Samples with low degree of purification were filtered before extraction and clean-up. All samples were extracted twice, once using an acidic conditioning of the column and once using a basic conditioning of the column. All samples were eluted in distilled methanol and distilled methanol 2% formic acid. The samples were further evaporated to dryness in a MiVac system, solved in methanol/MilliQ-water (1:1) and vortex mixed. In cases where precipitation occurred, the samples were filtered on a Millipore PVDF-filter (0,1 um, 5 min, 10000 rpm). 20 ul of the sample was then diluted with 40 ul methanol/MilliQ-water (1:1) and sent to analysis. Standard addition method was used.

Solid samples were extracted using a SUPRAS mixture made by mixing water (21 mL), 1-hexanol (3 mL) and THF (6mL), vortex mixing (1 min) and centrifuging (30 min, 3500 rpm). The top layer (SUPRAS) was transferred and stored at room temperature. Samples were weighed in a 2 mL Eppendorf-tube, and 3 glass balls, SUPRAS (400 ul) and extracted on a shaker (10 min, 2500 rpm), before centrifuging (10 min, 13400 rpm). 200 ul of the top layer was collected and sent to analysis. The samples were analysed using an Agilent UHPLC-HR-QTOF-MS operated in negative or positive electrospray mode. Quantification was done using standard addition.

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