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epa Research

Human Biomonitoring for Ireland – The HBM4IRE Study

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Lead organisation: University College Dublin

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Rialtas na hÉireann
Government of Ireland

Environmental Protection Agency

The EPA is responsible for protecting and improving the environment as a valuable asset for the people of Ireland. We are committed to protecting people and the environment from the harmful effects of radiation and pollution.

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2. Office of Environmental Enforcement
3. Office of Evidence and Assessment
4. Office of Radiation Protection and Environmental Monitoring
5. Office of Communications and Corporate Services

The EPA is assisted by advisory committees who meet regularly to discuss issues of concern and provide advice to the Board.

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What did this research aim to address?

People are regularly exposed to chemicals through air, water, food, consumer products, and their surrounding environment. Despite stringent EU regulations, concerns about the cumulative impact of chemical exposure persist. Effective monitoring is crucial for assessing the extent of human exposure and evaluating the effectiveness of existing policies.

The HBM4IRE project aims to bridge this gap by assessing the feasibility of establishing a national Human Biomonitoring (HBM) programme in Ireland. HBM is a powerful tool that measures chemicals in biological samples (e.g. blood, urine), providing data on actual human exposure levels from all sources and pathways and offering a more comprehensive risk assessment approach.

This research is crucial for policymakers, regulatory agencies, and public health authorities, as it supports evidence-based decision-making on chemical safety. HBM4IRE plays a key role in aligning Ireland with European initiatives, including the EU Green Deal, the Chemicals Strategy for Sustainability, and the Zero Pollution Action Plan. HBM4IRE adopts an innovative, multi-stakeholder approach, aligning with EU-wide initiatives while tailoring its methodologies to Ireland's specific needs.

What did this research find?

The HBM4IRE project confirmed that Ireland has the capacity to establish a national Human Biomonitoring (HBM) programme, aligning with EU policies like the Green Deal and Zero Pollution Action Plan. The study produced Ireland's first HBM priority chemical list and proposed a cross-sectoral governance framework involving agencies such as the EPA, HSE, and HSA and concerned ministries.

Key Findings:

- Feasibility has been confirmed, as comparable nations, such as Slovenia and Iceland, have national HBM programmes.
- Stakeholder engagement is crucial, with scientific experts, policymakers, regulators and the public emphasising co-creation and data transparency.
- HBM data will strengthen risk assessments, inform regulations, and identify vulnerable groups.
- Ireland can leverage EU-wide initiatives, such as PARC and the WHO HBM Working Group, for expertise and data comparability.
- Sustained funding and policy commitment are essential for success.
- Data-sharing and public trust need to be carefully managed.

HBM4IRE provides a solid foundation for an Irish HBM programme, ensuring evidence-based policymaking, enhanced public health protections, and integration with European biomonitoring efforts. Now is the opportune time for Ireland to act and establish this critical initiative.

How can the research findings be used?

HBM4IRE outlines a comprehensive framework for establishing a national Human Biomonitoring (HBM) programme in Ireland. Study recommendations include the creation of a National HBM Steering Committee, composed of stakeholders from various sectors (e.g., EPA, HSE, HSA, academic/research institutions), to coordinate and oversee the programme's development and ensure that priorities align with chemical safety regulations and public health objectives. Study recommendations also provide the first chemical and biomarker priority list for Ireland for an HBM programme. Additionally, securing long-term funding and leveraging international collaborations, such as the Partnership for the Assessment of Risks from Chemicals (PARC) and WHO HBM Working Group, will be critical for the success and sustainability of the programme.

The study aims to achieve significant environmental outcomes by providing robust data on environmental chemical exposures. This data can guide policy decisions regarding chemical safety, occupational health, and environmental regulations and support the development of evidence-based policies and initiatives aimed at reducing chemical risk. Furthermore, the study's outputs will contribute to raising awareness of chemical safety among the general public. Future ambitions will include addressing emerging contaminants, longitudinal exposure trends, and vulnerable subgroups to enhance the programme's effectiveness.

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Human Biomonitoring for Ireland – The HBM4IRE Study

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Prepared for the Environmental Protection Agency

by

University College Dublin

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This report is based on research carried out/data from March 2023 to January 2025. More recent data may have become available since the research was completed.

The EPA Research Programme addresses the need for research in Ireland to inform policymakers and other stakeholders on a range of questions in relation to environmental protection. These reports are intended as contributions to the necessary debate on the protection of the environment.

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Executive Summary

The Human Biomonitoring for Ireland (HBM4IRE) project evaluated the feasibility of establishing a national human biomonitoring (HBM) programme in Ireland to assess chemical exposures and inform strategies for managing chemical risks. The urgency for such a programme is emphasised by the estimations of vastly increased chemical production worldwide and numerous initiatives in Ireland and the EU. The European Green Deal, the EU Zero Pollution Action Plan and the Chemicals Strategy for Sustainability all emphasise the need to have indicator information on chemical pollution and evaluate progress towards ambitious targets to protect human health and the environment.

HBM has been identified as the “gold standard” for chemical risk assessment, analysing levels of chemicals in biological samples (e.g. urine/blood) to measure the systemic availability of chemicals from all exposure sources and routes. HBM offers robust data on chemicals and their breakdown products, including their exposure levels and aggregate and cumulative internal doses. HBM is a well-established method for assessing total exposures to a chemical from various sources, evaluating changes over time within a population and regional/population differences, and identifying potential “hotspots” of chemical exposures and highly exposed or vulnerable groups. HBM is an incredibly valuable tool, as it provides reliable exposure information for performing robust and integral exposure and risk assessments. HBM contributes to the health policymaking process by providing a quantifiable measure of the range and magnitude of exposures in a population, which provides evidence for prioritising actions and measures, as well as evaluating the effectiveness of policy measures. HBM has also been widely adopted in many developed countries through national programmes, which have demonstrated their value in understanding chemical exposure. Over the past decade, major advancements in HBM have been made through EU-wide initiatives to harmonise protocols, analysis, interpretation and communication in HBM studies. These efforts also play a crucial role in assessing the effectiveness of environmental and chemical legislation in reducing exposure to regulated and restricted chemicals.

Ireland has already demonstrated its capacity to participate in such initiatives through its involvement in the DEMOCOPHES (Demonstration of a Study to Coordinate and Perform Human Biomonitoring on a European Scale) project.

HBM4IRE incorporated scientific analysis and review, national and international expert stakeholder engagement, and public input to evaluate the criteria for a national programme. Study results demonstrated that national HBM programmes are available worldwide, including in countries with similar or smaller population sizes (i.e. Slovenia, Iceland) and that national expertise and resources exist to conduct such studies. Furthermore, analysis has demonstrated the enormous value of such programmes. HBM4IRE provided the first HBM chemical priority lists for Ireland, a proposed governance structure and an implementation framework. Furthermore, HBM4IRE demonstrated need to map national resources, expertise and infrastructure for such a programme to incorporate a cross-department/agency committee and the importance of co-creation for such an initiative to have the greatest possibility of success, maximise its impact and ensure sustainability.

HBM4IRE recommendations include:

- establishing a national HBM Steering Committee with cross-sectoral collaboration to foster co-creation, strengthen inter-institutional partnerships and enhance resource sharing;
- aligning national priorities with policy requirements to maximise the use of HBM data in informing policy decisions;
- leveraging international expertise, resources and assistance to support the initial steps of establishing a national HBM programme and to ensure the quality and comparability of national studies with those conducted across Europe;
- developing national capacity through education and training, including the integration of HBM principles into multidisciplinary subjects at third-level education;
- promoting discovery and innovation in HBM through dedicated research and development initiatives.

It is an opportune time for the establishment of an Irish national HBM programme, as extraordinary progress has been made in Europe for HBM studies, and Ireland can leverage this substantial progress and resources for the Irish programme. Ireland has already demonstrated its readiness for such an ambition through its collaboration with the Partnership for the Assessment of Risks from Chemicals initiative, which will provide access to expertise from over 29 countries, more than 200 institutions and over 1000 contributors, and with the World Health Organization European Environment and Health Process Partnerships on the HBM Working Group, both of which will bolster Ireland's ability to implement an effective HBM programme.

1 Introduction

1.1 Chemical Prioritisation

Chemicals offer numerous beneficial applications, yet the release of hazardous, toxic or restricted substances at various stages of their lifecycles can pose significant risks to both human health and the environment. The World Health Organization (WHO) has indicated a significant surge in global chemical production by 2050, nearly quadrupling from 2010 levels (WHO, 2021). Currently, more than 350,000 chemicals and chemical mixtures are registered for production and use globally, a figure that is up to three times higher than earlier estimates, with considerable variation across different countries and regions (Wang *et al*., 2020). More than 100,000 chemicals are available on the European market (ECHA, 2020). According to the European Commission's 2020 Chemicals Strategy for Sustainability, global chemical sales reached €3347 billion in 2018. Europe, as the second-largest producer, contributed 16.9% of these sales, although its share has halved over the past 20 years and is expected to drop further by 2030, placing Europe third globally (European Commission, 2020). Notably, chemical pollution is now acknowledged as one of the "planetary boundaries" – critical environmental thresholds that must be respected to ensure humans' safe existence. This type of pollution also exacerbates challenges associated with other planetary boundaries, including climate change and the integrity of the biosphere. To address these challenges of chemical pollution, the European Commission has adopted numerous initiatives and action plans, including the European Green Deal, the EU Zero Pollution Action Plan and the Chemicals Strategy for Sustainability. All these initiatives aim to create a toxic-free environment to ensure that chemicals are safe for human health and the environment and to ensure the protection of the public and the environment. To ensure that we are achieving this progress, it is essential that there are robust monitoring and outlook mechanisms for the early detection of emerging issues. We are exposed to a wide range of chemicals through various pathways, including air, water, food, soil and the surrounding environment, as well as under-recognised sources such as personal care products and plastic packaging. Although there are mechanisms for evaluating different routes of exposure, there is a need to understand overall exposures to the human population from all sources and routes, which is essential for evaluating their potential health risks.

1.2 Human Biomonitoring Approach

Human biomonitoring (HBM) involves the analysis of biological samples (e.g. urine, blood) to measure the systemic availability of chemicals from all exposure sources and routes and is widely regarded as the gold standard for assessing chemical exposures (Louro *et al*., 2019). It directly measures the levels of chemicals in the human body, providing more scientifically relevant data for risk assessments than extrapolations from environmental concentrations in soil, air or water (Angerer *et al*., 2007, 2011; Jeddi *et al*., 2022; Nakayama *et al*., 2023). HBM offers robust data on chemicals and their breakdown products, including their exposure levels and aggregate and cumulative internal doses. Moreover, it plays a crucial role in EU-wide early warning and action systems, enabling informed decision-making and proactive measures to safeguard public health and the environment. HBM is a well-established method for assessing total exposures to a chemical from various sources, evaluating changes over time within a population, regional/population differences, and identifying potential "hotspots" of chemical exposures and highly exposed or vulnerable groups. Another notable aspect of HBM is that surveys can reveal increased exposure levels within subgroups, such as individuals working in specific occupational settings, those residing near pollution hotspots or those with unique dietary habits (Lagerqvist *et al*., 2015). HBM also helps to identify population groups that are at greater risk. For instance, children have higher levels of pesticides, such as organophosphates and pyrethroids, in their bodies than adults, as reported by Becker *et al*. (2006). In addition, Koch *et al*. (2007) reported that children not only have a higher uptake of phthalates but oxidise a greater amount of the monoesters to form toxic metabolites.

HBM can be conducted for numerous chemical substances that are the subject of global environmental health discussions, including metals, polycyclic aromatic hydrocarbons (PAHs), phthalates, dioxins, pesticides, aromatic amines, perfluorinated compounds, environmental tobacco smoke and volatile organic compounds (HBM4EU, 2020a; i-HBM Working Group, 2024; WHO, 2023).

HBM is an incredibly valuable tool to support exposure and risk assessments, as it provides reliable exposure information for performing robust and integral exposure and risk assessments. HBM contributes to the policymaking process for health by providing a quantifiable level of the range and magnitude of exposures in a population, which provides evidence for prioritising actions and measures for policymaking, as well as evaluating the effectiveness of policy measures (Joas *et al*., 2012). HBM has also been widely adopted in many developed countries through national programmes (Apel *et al*., 2017).

1.3 International Advancement in Human Biomonitoring Programmes

Over the past decade, significant research has been conducted globally, particularly in Europe, in the field of HBM. One of the first major advancements for HBM was the European Commission-funded COPHES (Consortium to Perform Human Biomonitoring on a European Scale) project, which aimed to create harmonised HBM protocols for better data comparison (Becker *et al*., 2014; Schindler *et al*., 2014). This was prepared by the ESBIO (Expert Team to Support Human Biomonitoring) consortium. In the twin project DEMOCOPHES (Demonstration of a Study to Coordinate and Perform Human Biomonitoring on a European Scale), these protocols were tested in the first EU-wide pilot study (Schwedler *et al*., 2017). These initiatives were crucial steps towards generating consistent and validated data on chemical exposure across Europe and, through the pilot study, demonstrated the utilisation of HBM data as a policy tool (Joas *et al*., 2012).

The lessons learnt and practical demonstration from COPHES and DEMOCOPHES were advanced upon when establishing the Human Biomonitoring for Europe (HBM4EU) project (www.hbm4eu.eu) (2017–2022), which was a collaborative effort involving 30 countries and 120 institutions, including the European Environment Agency and the European Commission, with ambitions to enhance HBM knowledge and provide evidence on citizens' chemical exposure and potential health impacts to inform policy decisions. HBM4EU formed a bridge between science and policy (Ganzleben *et al*., 2017). As part of the initiative, the HBM4EU consortium undertook a chemical prioritisation exercise to identify key chemicals of concern, conducted harmonised HBM studies across countries and developed public dissemination materials. These collective studies demonstrated the importance of producing comparable HBM datasets on the population's chemical exposures, demonstrating the effectiveness of using HBM as a policy tool.

The substantial gains of the HBM4EU initiative will progress even further for the next-generation chemical risk assessment to protect human health and the environment through the Partnership for the Assessment of Risk from Chemicals (PARC) initiative (PARC, 2024), launched in May 2022. PARC builds on the work done in the HBM4EU project (Kolossa-Gehring *et al*. 2023), which aligns with the EU Chemicals Strategy for Sustainability and the European Green Deal's "zero pollution" goal by providing new data, knowledge, methods, tools, expertise and networks. This multinational project involves nearly 200 institutions from 29 countries and three EU authorities – namely, the European Chemicals Agency, the European Food Safety Authority (EFSA), and the European Environment Agency. Through these efforts, PARC supports the EU Chemicals Strategy for Sustainability, contributing to the "zero pollution" ambition outlined in the European Green Deal (PARC, 2024).

1.4 Irish Human Biomonitoring Studies

In Ireland, a limited number of studies have been conducted on measuring chemicals in human populations via the HBM approach. A significant study by Cullen *et al*. (2014) examined mercury concentrations in hair samples from 120 mother–child pairs in Ireland, revealing detectable levels in 79.2% of mothers and 62.5% of children, with arithmetic mean levels of 0.262 µg/g and 0.149 µg/g, respectively. Mercury was notably higher among individuals with

greater fish consumption. The Food Safety Authority of Ireland makes recommendations on fish intake, especially among vulnerable groups (e.g. pregnant women) (FSAI, 2025a). Another research project by Cullen *et al*. (2017) within the DEMOCOPHES pilot project detected phthalate metabolites in all individuals sampled, with higher concentrations observed in participants from lower educational backgrounds and those exposed to polyvinyl chloride, fast food and personal care products.

Further exploration of environmental contaminants in Ireland has highlighted the prevalence of persistent organic pollutants. For example, Wemken *et al*. (2020) analysed breast milk samples from 92 mothers and detected various brominated flame retardants, with BDE-209 accounting for 65% of the total polybrominated diphenyl ether (PBDE) concentration. Similarly, Pratt *et al*. (2012) investigated the impact of the 2008 dioxin incident in Ireland on concentrations of polychlorinated dibenzo-p-dioxins (PCDDs), polychlorinated dibenzofurans (PCDFs) and polychlorinated biphenyls (PCBs) in pooled breast milk samples from 109 first-time mothers, collected in 2010. A comparison with similar data from 2002 showed generally lower concentrations of PCDD/Fs and dioxin-like PCBs in the 2010 samples, confirming a declining trend in the levels of these contaminants. The mean combined PCDD/F and PCB WHO toxic equivalents in the 2010 breast milk samples was 9.66 pg/g fat, which was slightly lower than in international reports. Pratt *et al*. (2012) confirmed a declining trend in the levels of these contaminants but noted a slight increase in PCDFs from 2002 to 2010.

Recent HBM efforts in Ireland have expanded to include emerging pollutants such as per- and polyfluoroalkyl substances (PFAS), analysed in breast milk samples by Abdallah *et al*. (2020). The study measured concentrations of 10 PFAS in 92 breast milk samples from 16 pools in Ireland. Four PFAS were detected: perfluorooctanoic acid (PFOA), perfluoro-n-non-anoic acid (PFNA), perfluoro-1-hexanesulfonate (PFHxS), and perfluorooctane sulfonate (PFOS). PFOA was the most prevalent, detected in all samples, with a median concentration of 0.10 ng/mL (Abdallah *et al*., 2020). Rooney *et al*. (2022) found gender differences and regional variations in urinary metal concentrations in the Irish population. Women had higher levels of arsenic, cadmium, chromium, copper, lead and selenium but lower mercury levels than men. Compared with European data, Irish levels of aluminium, cadmium, chromium and lead were slightly elevated, while arsenic, copper, manganese and selenium levels were lower.

Numerous national pesticide studies have utilised HBM strategies, predominantly focusing on glyphosate exposures. Initially, these studies focused on workers' exposures (Connolly *et al*., 2017, 2018), finding low-level occupational exposures among amenity horticulturists and that task duration affected exposure levels. Further environmental exposure studies (Connolly *et al*., 2018, 2022) found low-level environmental exposure to glyphosate. Connolly *et al*. (2022) investigated glyphosate and its main breakdown product (i.e. aminomethylphosphonic acid (AMPA)) among farm and non-farm families, with AMPA quantifiable in 61% of samples and glyphosate in 32%. Exposure levels were found to be below health-based guidance values, and these findings contributed to regulatory risk assessments (EFSA, 2023).

These studies demonstrate that Ireland has the capability for executing HBM studies, and further investigation is required to establish whether Ireland could establish a continuing HBM surveillance programme as part of a framework for having indicators of chemical pollution and to inform policy.

1.5 Aim and Objectives

The Human Biomonitoring for Ireland (HBM4IRE) project's overall aim was to evaluate the criteria required to develop a national HBM surveillance programme for Ireland to contribute to monitoring environmental chemical exposures.

The objectives of HBM4IRE were:

- To undertake a comprehensive literature review of HBM national programmes, which also contributed to identifying and prioritising chemicals that are a burden to the environment and human health and identifying the state of the art in national HBM programmes.
- To develop and report from a national survey seeking input from policymakers, regulators and the general public to nominate the chemicals and substance groups of concern for inclusion on a national chemical priority list.

- To develop a chemical priority list along with a biomarkers list that identifies chemical priorities in relation to the Irish context while aligning with EU priorities.
- To engage with stakeholders throughout the project's lifetime to contribute to evaluating the feasibility of the HBM4IRE programme. Additionally, to conduct and report from the stakeholder forum, including hosting a World Café, to identify emerging subthemes for initiating a national HBM programme, inter alia the prospects and challenges, including practical/logistical, financial and scientific benefits/shortcomings.
- To provide recommendations for the long-term goals of developing a national HBM programme, including stakeholder commitments and requirements.

2 Methodology

2.1 Human Biomonitoring Mapping

The first step was to conduct a systematic and strategic review of national HBM programmes worldwide to evaluate the criteria required for a national HBM programme and determine priority chemicals.

The search for national HBM programmes combined database searches, grey literature reviews, information available on government websites and informal consultations with a few experts. We conducted an extensive literature review using Google Scholar with keywords such as “national human biomonitoring programme”, “HBM programme” + [country name] and “human biomonitoring national programmes”. This yielded scattered records, including peer-reviewed articles mainly focusing on HBM study results. To obtain the desired information, we supplemented database results with grey literature from official websites of established programmes (e.g. NHANES (United States National Health and Nutrition Examination Survey), the German Environmental Survey and surveys in Czechia and Canada) and EU initiatives like HBM4EU and PARC. Informal consultations with researchers in Belgium, Slovenia and Iceland provided unpublished insights and verified operational details (e.g. funding mechanisms, cohort design).

The factors reviewed for each programme included the chemical groups or specific chemicals analysed, the strategy or criteria for selecting these chemicals, the methods of measurement and sample sizes, the collection protocols and cohort characteristics, the supporting funding agencies, the impact of HBM findings on policy, and the availability and implementation of quality assurance (QA) and quality control (QC) measures in testing laboratories.

2.2 Chemical Prioritisation

The chemical prioritisation methodology involved a multi-step approach designed to identify and prioritise chemicals based on both international best practices and the perception of people living in Ireland.

Initially, the chemicals recognised as high priority at the EU level were mapped from two significant European initiatives: HBM4EU and PARC. Next, national HBM programmes were analysed for their prioritised chemicals (section 2.1), and these were consolidated into an initial list of groups and individual chemicals/biomarkers. These chemicals were ranked by frequency of appearance in priority lists, scoring 2 for EU-specific initiatives (HBM4EU and PARC priority lists), 1 for EU countries and 0.5 for non-EU countries. Ireland shares similar regulatory frameworks, environmental conditions and public health priorities with other EU countries, making chemicals highlighted in EU initiatives highly relevant.

2.3 National Survey

A national survey was developed to incorporate public perception using a modified version of the HBM4EU social survey (HBM4EU, 2018), which was circulated via SurveyMonkey. Information collected included demographics, chemical awareness, hazard perception and input on prioritisation. The national survey was designed to capture the insights (level of awareness and perception) of people who are working on or associated with chemical management and also the general public who are not working on or associated with chemical management. The aggregate score for a chemical was estimated using Equation 2.1.

$$\{C_i\} = \sum_{i=1}^{5} p_i hs_i; \tag{2.1}$$

In Equation 2.1, p_i is the proportion of people who responded for a perceived level of harmfulness *hs*. Notably, the perceived level of harmfulness was measured by five categories: “seriously harmful”, “moderately harmful”, “slightly harmful”, “not harmful at all” and “don’t know how harmful it is”, with allocated scores of 3, 2, 1, 0 and 0, respectively (with “not harmful at all” and “don’t know how harmful it is” both being assigned a score of 0).

The final step involved synthesising the results of the survey and the chemicals listed in the HBM

programmes to create a comprehensive shortlist of the top 10 groups of priority chemicals for Ireland's national HBM programme. This shortlist incorporates chemicals selected by the public, ensuring that Ireland's HBM efforts address both societal concerns and the HBM programme's recommended priorities.

Additionally, for each of the chemical groups, priority biomarkers were identified based on their frequency of appearance in HBM4EU, PARC and national HBM programme lists. Each chemical's biomarker priority list, along with the analytical methods, matrix for analyses and guidance values, were also studied.

2.4 Stakeholder Forum

A stakeholder forum was hosted with the ambition of a two-way knowledge transfer between the national research group, the international HBM experts and national experts and was divided into two separate sessions: a morning session of presentations from the international experts, including a panel discussion with the audience, followed by a World Café. Presentation topics included an overview of EU-wide HBM initiatives, real-world examples of how HBM data can influence policy decisions, HBM logistics, laboratory requirements for biomarker analysis and ethical considerations in HBM studies. The expert presentation has been uploaded to the University College Dublin website: https://www.ucd.ie/phpss/research/hbm4ire/.

2.4.1 World Café approach

The World Café was organised based on the seven integrated design principles suggested by the originators of the World Café format, namely (1) setting up the context; (2) creating a hospitable space for

Figure 2.1. Five themes discussed at a World Café involving cross-sectoral stakeholders (government, ministries, HBM experts) and covering HBM policy alignment, Ireland-specific chemical priorities, public engagement, economic sustainability and interdepartmental collaboration.

the participants; (3) exploring questions that matter; (4) encouraging everyone's contribution; (5) cross-pollinating and connecting diverse perspectives; (6) listening together for patterns, insights and more profound questions; and (7) harvesting and sharing collective discoveries as recommended in Brown and Isaacs (2005). In our study, five thematic stations were set up, each focusing on a "key question" or "theme" for the HBM4IRE project, and each facilitated by a moderator (Figure 2.1). Participants rotated through the stations (i.e. 15 minutes per station), discussing specific questions related to each theme, which enabled them to contribute insights across all topics and collectively address the policy needs, funding, chemical prioritisation, challenges and opportunities for establishing a national HBM programme in Ireland.

3 Results

3.1 Mapping of the Human Biomonitoring Programme

A comprehensive review of national HBM programmes from various countries was undertaken to identify the key features of well-established, nationwide initiatives. Thirteen countries – namely the United States, Canada, China, Sweden, Germany, France, Belgium, Czechia, Norway, South Korea, Slovenia, Iceland and New Zealand – were selected based on predefined criteria outlined in the study. The review assessed several aspects of these programmes, including starting year, frequency of monitoring, inclusion of vulnerable groups, chemicals analysed, sample size and availability of QA/QC protocols and biobanks based on the information available on the public domain (CDC, 2024; Health Canada, n.d.; National Institute of Public Health, Prague, 2023; National Institute of Public Health, Slovenia, 2024; Norwegian Institute of Public Health, 2023) as well as personal communications. These programmes provided valuable insights into best practices and strategies for successful implementation. The findings are summarised in Table 3.1.

Building on the review findings, a framework for establishing a national HBM programme in Ireland has been developed under this study. The framework outlines the essential components and steps required to design a structured, sustainable and impactful programme. Figure 3.1 provides a detailed overview of the framework, highlighting the critical elements necessary for ensuring the programme's effectiveness and long-term success.

3.1.1 Setting up a human biomonitoring programme

National HBM programmes have been established worldwide to assess chemical exposures in populations and inform health risk assessments (Choi *et al*., 2015). The first step in establishing an HBM programme in a country is advocating for and securing policymaker support through demonstrating public health benefits and aligning programme priorities with national needs. Participation in international initiatives like PARC and HBM4EU can provide political incentives, expertise, capacity-building opportunities and cost-sharing benefits. Engagement with the health sector and citizen awareness campaigns can encourage policymakers to make actionable commitments (Figure 3.1).

It has been recognised that integrating HBM into legislation has also been pivotal for the establishment of national programmes. For instance, Slovenia's Act on Chemicals (No. 110/03) facilitated its first HBM survey in 2007, while the Flemish Decree on Preventive Health Care (2003) incorporated HBM into policy. Similarly, France's HBM programme is supported by the Grenelle Law for the environment (2009) and is included in national environmental health plans. Such legislative initiatives ensure alignment with multi-level governance and reinforce HBM's policy relevance.

3.1.2 Methodology and matrix selection

The development of a national HBM programme involves multi-phase studies to evaluate exposure to pollutants, establish reference values, and identify geographical differences in and groups vulnerable to exposure (Choi *et al*., 2015; Perharič and Vracko, 2012).

These programmes involve the careful selection of biomarkers, matrices and analytical methods. Blood, urine, serum and plasma are commonly used matrices, with liquid chromatography–tandem mass spectrometry (LC-MS/MS) and gas chromatography–mass spectrometry analysis being commonly used. Non-invasive matrices like saliva, hair and breast milk are also being explored to facilitate easier sampling (Esteban and Castaño, 2009); however, their use is neither harmonised nor standardised yet. While study designs vary between countries, advancements in harmonised protocols for the methodology, guidance values and applicable human matrices are available via HBM4EU and PARC resources. These openly available resources outline EU-wide standards and practices, offering evidence-based frameworks that

Table 3.1. Review of national HBM programmes

No.	Country	Starting year	Frequency of monitoring	Leading public/ research institutes	Inclusion of vulnerable groups?	Chemicals analysed in recent cycles	Selection method	Criteria for selection	Sample size, cohort and collection method	Sample collection protocol	Biobank
1	United States: NHANES	1999	Biennial	National Center for Environmental Health at the Centers for Disease Control and Prevention	Yes	Heavy metals, PFAS, PAHs, VOCs, pesticides, flame retardants, phthalates, PCBs, etc.	Participatory approach	Health effects, exposure data, public health priorities	~10,000 individuals; stratified multistage probability sampling, MECs used for collection	Face-to-face and computer-assisted interviews, home interviews, physical exams, blood and urine sampling	NHANES Biospecimen programme
2	Canada: Canadian Health Measures Survey	2007	Every 2–3 years	Led by Statistics Canada in partnership with Health Canada and the Public Health Agency of Canada	Yes	Metals, PFAS, pesticides, VOCs, flame retardants, PCBs, phthalates, bisphenols and PAHs	Formal and informal consultation	Public health impact, feasibility, data gaps	~5800 individuals; nationally representative samples, cross-sectional survey – representative of approximately 96–97% of the Canadian population	Personal interview in the respondent's home, followed by a visit to temporary examination centres at MECs	Public Health Agency of Canada's National Microbiology Laboratory
3	China: China National Human Biomonitoring	2017–2018	Every 3 years (2-year survey cycle followed by a 3-year gap before the next cycle begins)	National Institution of Environmental Health under the Chinese Center for Disease Control and Prevention	Yes; sampling ensures representation by sex (male/female), six age groups and geographical diversity (31 provinces, 152 sites)	Heavy metals, phthalates, PFAS, PAHs, benzene metabolites and environmental phenols	Expert panel review	Health and environmental impact, emerging threats	~22,000 individuals; representative sampling, including urban and rural populations, longitudinal cohort tracked across cycles for dynamic epidemiological data	MECs; includes free physical exams and incentives for participants	Centralised facilities

Table 3.1. Continued

No.	Country	Starting year	Frequency of monitoring	Leading public/ research institutes	Inclusion of vulnerable groups?	Chemicals analysed in recent cycles	Selection method	Criteria for selection	Sample size, cohort and collection method	Sample collection protocol	Biobank
4	Sweden: Swedish HBM programme	1993	Riksmaten (dietary surveys); occur approximately every 10 years (e.g. 2010–2011 and 2023)	Swedish Environmental Protection Agency under the Ministry of the Environment	Riksmaten (focus on general population), longitudinal cohorts like the SELMA study focus on prenatal/child exposure	Heavy metals, phthalates, flame retardants, pesticides, PFAS, UV filters, organochlorines and brominated compounds	Prioritised by the Toxicological Council using HBM data; reported to SamTox	Exposure trends, regulatory impact, policy needs	Register-based random samples collected by Statistics Sweden (Statistiska centralbyrån); stratified based on the level of education achieved at household level. ~1000/ age group in dietary survey; 300/age group for blood and urine	Centralised sample analysis in specialised labs	Managed by universities/ research institutes (e.g. Karolinska Institute)
5a	Germany: German Environmental Surveys (GerES)	1985	Every 4–5 years	German Environment Agency, coordination by the Ministry for the Environment and funding/ oversight by HBM Commission expert advisory body	Yes; population-representative sampling (GerES). Vulnerable groups inferred through demographic stratification	More than 130 substances, i.e. heavy metals, flame retardants, phthalates, pesticides, PFAS, UV filters, chlorinated/ brominated POPs	Expert review, need for policy advice	Environmental and health relevance, regulatory needs (e.g. EU chemical policies), risk assessment priorities (Federal Institute for Risk Assessment)	~1500–5000 participants; population-representative sampling across regions	Home visits and centralised examination centres, HBM and ambient monitoring	GerES
5b	German Environmental Specimen Bank (ESB)	1985	Every year	German Environment Agency (UBA), coordination by the Ministry for the Environment (BMUKN) and funding/ oversight by HBM Commission expert advisory body	Students aged 20–29 years in defined peripheral conditions	Continuous according to needs	In agreement between BMUKN and UBA	Exposure trends, regulatory impact, policy needs	500/year	By standard operating procedures in mobile lab	ESB, rigorous pre-analytical steps (storage at –150°C) for time-trend reliability

Table 3.1. Continued

No.	Country	Starting year	Frequency of monitoring	Leading public/ research institutes	Inclusion of vulnerable groups?	Chemicals analysed in recent cycles	Selection method	Criteria for selection	Sample size, cohort and collection method	Sample collection protocol	Biobank
6	France: French National Biomonitoring Programme: (1) Esteban health study on the environment, a nation-wide cross-sectional survey; and (2) the ELFE birth cohort (longitudinal study from childhood)	2007	Periodic cycles aligned with PNSEs	Funded by the Ministry of Health and coordinated by the national public health agency, Santé Publique France	Yes (children, women of childbearing age)	PFAS, pesticides, PAHs, PCBs, bisphenols, VOCs, phthalates and glycol ethers	Delphi method, validated by government agencies and PNSEs' "emerging risk" group	Health risks (e.g. carcinogenicity, endocrine disruption), exposure prevalence, policy relevance (aligned with PNSE goals)	Esteban: 2503 adults + 1104 children, ELFE: 18,000+ children (longitudinal biospecimens). Occupational studies under PST 3 (specific cohorts)	MECs with certified containers, temperature-controlled transport	Samples stored in national biobanks (e.g. ELFE cohort biobank). PNSE4's PEPR programme (2021–2025) funds infrastructure for large-scale biomonitoring storage
7	Belgium: Flemish Environment and Health Survey (FLEHS)	2001	Every 5 years	Flemish Institute for Technological Research (VITO)	Yes (children, pregnant women)	PFAS, phthalates, flame retardants, metals, VOCs, PCBs and bisphenols	Regional survey in Flanders	Public health concerns, regional environmental trends	~1500–3000 participants; stratified random sampling of the Flemish population	MECs and home visits for sample collection	Regional biobank
8	Czechia	1994	Periodic (originally annual; now reduced to once every several years due to funding constraints)	National Institute of Public Health, National Centre for Toxic Compounds (Ministry of the Environment and Masaryk University)	Yes	Heavy metals, pesticides, PCBs, PFAS, phthalates, PAHs and VOCs	Alignment with National Portfolio of Actions (Ostrava Declaration 2017), guided by the Stockholm Convention and EU regulations, and expert consultations	Health risks (e.g. toxicity, persistence). International obligations	~2000–4000 participants; cohorts representative of national demographics	Standardised methods, subcontracted external lab	Biobank for future use, managed by RECETOX Research Infrastructure (national roadmap project)

Table 3.1. Continued

No.	Country	Starting year	Frequency of monitoring	Leading public/ research institutes	Inclusion of vulnerable groups?	Chemicals analysed in recent cycles	Selection method	Criteria for selection	Sample size, cohort and collection method	Sample collection protocol	Biobank
9	Norway	1999 (MoBa)	Continuous	Norwegian Institute of Public Health	Yes (pregnant women, children)	Heavy metals, phthalates, PFAS, PCBs, pesticides, parabens, flame retardants, bisphenols	Longitudinal cohort study	Long-term health effects of chemical exposure	~114,500 children, ~95,200 mothers; biological samples from maternity units	Longitudinal tracking with follow-up and standardised biobanking	Centralised biobank
10	South Korea	2009	Every 3 years	National Institute of Environmental Research	Yes	PFAS, phthalates, PAHs, metals, VOCs, phenols, flame retardants	National survey	Exposure trends, health impact	~6000 participants; nationally representative cohorts	MECs and mobile units for sample collection	Centralised facilities
11	Slovenia	2007	Phase-based	National Institute of Public Health	Yes (children, pregnant women)	Heavy metals, PFAS, phthalates, POPs, bisphenols, parabens and pesticides	Regional monitoring	Public health needs, risk assessment priorities	Regionally representative cohorts focused on high-risk areas	Health centres with certified equipment for collection and storage	National biobank
12	New Zealand	2022	Proposed annual	Institute of Environmental Science and Research	Yes (children, elderly people, indigenous groups)	Metals, PFAS, phthalates, VOCs, pesticides, emerging contaminants	Stakeholder consultations	Emerging contaminants, risk trends	Small-scale pilot study targeting priority cohorts	Study with proposed MECs and regional collection	Planned

Table 3.1. Continued

No.	Country	Starting year	Frequency of monitoring	Leading public/ research institutes	Inclusion of vulnerable groups?	Chemicals analysed in recent cycles	Selection method	Criteria for selection	Sample size, cohort and collection method	Sample collection protocol	Biobank
13	Iceland[a]	Diet survey since 1939; HBM added in 2019–21[b]	Periodic (every few years, aligned with national diet survey)	Public funding: Ministry of Health, University of Iceland and, for the last cycle, HBM4EU (Horizon)	Not specified	Cadmium, PAHs and bisphenols, acrylamides, mycotoxins, pesticides (glyphosate, AMPA, chlorpyrifos, phytoestrogens, neonicotinoids, etc.), PFAS	Cadmium, PAHs and bisphenols were HBM4EU priorities; others were included due to national interest and lack of prior relevant data in Iceland	No formal criteria; chemicals were newly analysed and chosen based on national relevance and availability of HBM4EU-approved labs	As per the HBM4EU protocols: 200 participants from the national diet survey; urine, serum and whole blood; and REDCap questionnaire added	Linked with diet survey sampling, two phone interviews, bio-sample collection post interview. Urine, serum and EDTA blood samples were transferred to cryo vials and kept frozen	Samples were biobanked and kept at –80°C.

[a]Information received based on private communications.

[b]Iceland's National dietary survey has been conducted since 1939 to assess the nutritional value of the nation's food intake. Human biomonitoring was added to the last survey (2019–2021) for the first time.

EDTA, ethylenediaminetetraacetic acid; MEC, mobile examination centre; MoBa, Norwegian Mother, Father and Child Cohort study; PEPR, Priority Research Programmes and Equipment; PNSE, national environmental health plans (France); POP, persistent organic pollutant; PST, primary, secondary, tertiary; REDCap, Research Electronic Data Capture; SELMA, Swedish Environmental Longitudinal, Mother and Child, Asthma and Allergy; No, number; VOC, volatile organic compound.

Source: adapted from Singh *et al.* (2025a).

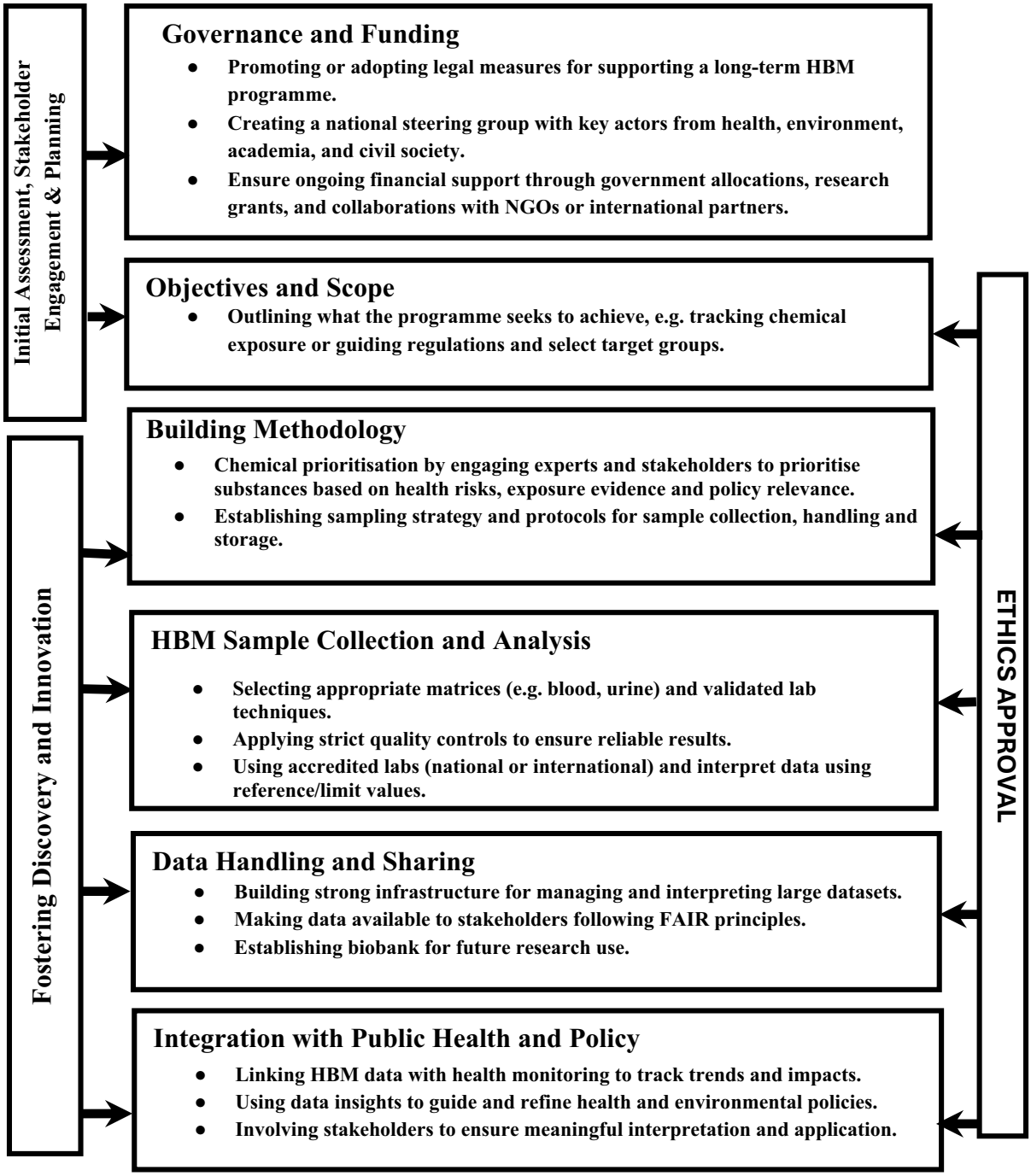

Figure 3.1. Framework for establishing a national HBM programme. Source: adapted from Singh *et al.* (2025a).

support harmonised methodologies and reference values for HBM across European countries.

3.1.3 Participant recruitment and sample collection

Effective recruitment strengthens HBM studies, requiring tailored strategies that consider target populations and resources. The approach to participant recruitment must be carefully designed along with results reporting, ensuring transparency through the consent process (Haines *et al*., 2011). These strategies can help overcome participation biases, which include a lack of trust, perceived benefits, complex study designs and complicated questionnaires (Morrens *et al*., 2017). Lessons from pilot studies, such as DEMOCOPHES, highlight the need for thorough planning, clear exclusion criteria

and consistent follow-up to maximise response rates. Offering incentives such as financial rewards, personal health results or expense reimbursements can improve participation but must align with national and international ethical guidelines (Halpern, 2011; Halpern *et al*., 2021). Participation and contributions were encouraged across several countries, with monetary incentives provided in specific locations for HBM studies. These included Cyprus (€60 per participant), Israel (a voucher worth ~€13), the Netherlands (€35, facilitated by the recruitment service) and Denmark (a gift card worth ~€80) (Matisāne *et al*., 2022).

Additionally, any travel expenses related to onsite events, such as those in Denmark, were reimbursed. However, providing incentives may introduce potential disadvantages, such as disproportionately attracting certain groups, limiting the representativeness of the sample (Resnik, 2015). However, this consequence could also be interpreted as a positive outcome, as it may attract more people who are disproportionately represented (i.e. low socio-economic status) to participate, and such recruitment can be challenging for HBM studies.

Sample collection strategies can vary across programmes, and standardising sample collection across different sites in HBM programmes is a significant challenge. Samples can be collected at various venues, including during home visits, at participants' workplaces or kindergartens, or in designated examination centres such as town halls, schools or clinics. In some cases, less common set-ups like mobile labs are used to reach participants in remote or underserved areas (Fiddicke *et al*., 2021a). Each option, however, imposes some level of burden, such as time spent or travel effort. To address this, it is advisable to offer participants flexible alternatives, allowing them to choose between being visited at home or visiting a nearby examination centre. Germany has developed a mobile epidemiological laboratory (epiLab) for the German Environmental Specimen Bank. This innovative approach includes reception, examination and laboratory areas, all designed to ensure highly standardised sampling conditions. The mobile set-up allows for consistent collection methods regardless of location, making it a valuable tool for enhancing the reliability and comparability of HBM data (Lermen *et al*., 2014). Similarly, NHANES, conducted by the Centers for Disease Control and Prevention, uses mobile examination centres to collect data from participants across the United States. These mobile centres travel around the country and are equipped with the tools and equipment necessary for health checks and laboratory tests, including sample collection; however, other countries also utilise local hospitals or clinics to obtain samples within regions.

3.1.4 Funding and financial sustainability

Economic sustainability of HBM programmes can be achieved by integrating them into existing health surveys, reducing costs through shared infrastructure. Many countries reduce the cost of these programmes by implementing them alongside a previously established programme. In Ireland, the Healthy Ireland Survey collects information from the general public and, for many years, conducted in-person interviews; the inclusion of HBM in this initiative would be a consideration (Government of Ireland, 2023). Diverse funding sources, including community involvement, are essential. By leveraging global insights and aligning strategies with national contexts, countries can establish sustainable HBM programmes that protect public health and inform environmental policies.

3.1.5 Ethical compliance in human biomonitoring

Ethical compliance and data protection are critical in HBM studies to safeguard participants' rights, privacy and well-being. Each study must be reviewed and approved by an ethics board, which assesses key aspects such as the respectful selection of the study population, recruitment and information provision procedures, sampling methods, data analysis and data protection measures. Ethical considerations must also extend to personal data feedback, ensuring that participants receive appropriate and clear communication about their data while maintaining confidentiality.

All HBM studies must align with national ethical regulations and the EU General Data Protection Regulation (Regulation (EU) 2016/679). Ethical approval requires detailed project descriptions, information materials and informed consent templates that explicitly outline participant rights, data handling procedures and potential risks. Data must be pseudonymised at the individual level and anonymised

where appropriate, but additional measures are needed to ensure privacy beyond pseudonymisation, such as strict access controls, secure storage systems and predefined data-sharing protocols.

The handling of incidental findings, biobanking and the secondary use of data and samples are crucial ethical concerns that must be explicitly addressed in study protocols. Clear guidelines should be established for managing unexpected health-related discoveries, ensuring that participants are informed of relevant findings in a responsible and non-alarming manner. Furthermore, policies on long-term data and sample storage, as well as potential future research uses, should be defined and communicated transparently.

Given that the ethics approval process can take weeks or months, early engagement with ethics committees and data protection authorities is strongly recommended. Ethics compliance in the HBM4EU project involved training partners on new standards, ensuring valid ethics approvals and managing consent variations. Standardised templates and an interactive database facilitated transparency and sustainability (Knudsen *et al*., 2023).

During the stakeholder forum, specific concerns were raised regarding data access and confidential handling to ensure participant privacy. These concerns highlight the importance of robust governance mechanisms, such as tiered access to sensitive data, clear data ownership policies and accountability frameworks for those handling personal information. Addressing these issues strengthens trust in HBM research and ensures adherence to the highest ethical standards.

3.1.6 Data management and dissemination in human biomonitoring

Efficient data management and dissemination are critical components of HBM programmes. Robust data infrastructure is essential for securely handling and interpreting the large datasets generated during HBM surveys. Ensuring data accessibility for researchers, policymakers and the public while safeguarding confidentiality fosters transparency and trust. Adhering to the findable, accessible, interoperable and reusable (FAIR) principles ensures that HBM data is openly available and usable for ongoing research. In addition, establishing a national biobank for storing biological samples will further strengthen the HBM framework, enabling long-term research and supporting evidence-based decision-making on public health and environmental policies.

3.2 Chemical Prioritisation

As one of the major objectives of the HBM4IRE project, chemical prioritisation was conducted based on the cumulative scores of chemicals listed under HBM4IRE, PARC and national HBM programmes, as well as on chemicals prioritised through the national survey. We did not perform independent hazard assessments for chemical prioritisation. Instead, we relied on chemicals already prioritised under the EU framework, PARC, and other national and international initiatives. The priority chemicals under these programmes have undergone rigorous hazard assessments and evaluations, ensuring that our prioritisation aligns with well-established scientific and regulatory standards (Ougier *et al*., 2021). This approach allowed us to build on existing expertise and focus our efforts on addressing the chemicals most relevant for Ireland.

3.2.1 Demographic profile of the national survey participants

The survey was completed by 218 participants; however, a few of the participants did not answer all the questions. The geographical distribution of responses to the HBM4IRE national survey closely aligns with Ireland's population demographics, with 42% of responses coming from County Dublin, the most populous region, home to over 38% of the population. Counties such as Galway (6.09%) and Wexford (6.60%) also demonstrated significant engagement, contributing to a regionally diverse dataset (Figure 3.2). The survey captured a diverse demographic cohort, encompassing a range of residential, educational and professional backgrounds. In terms of residence, the majority of respondents were from urban areas (62.44%), with a significant portion representing rural areas (37.56%). This distribution ensures inclusivity and offers insights into both urban and rural perspectives on chemical-related concerns.

The duration of residence in Ireland varied among the respondents, with a significant majority having lived in Ireland for extended periods. Over half (54.31%)

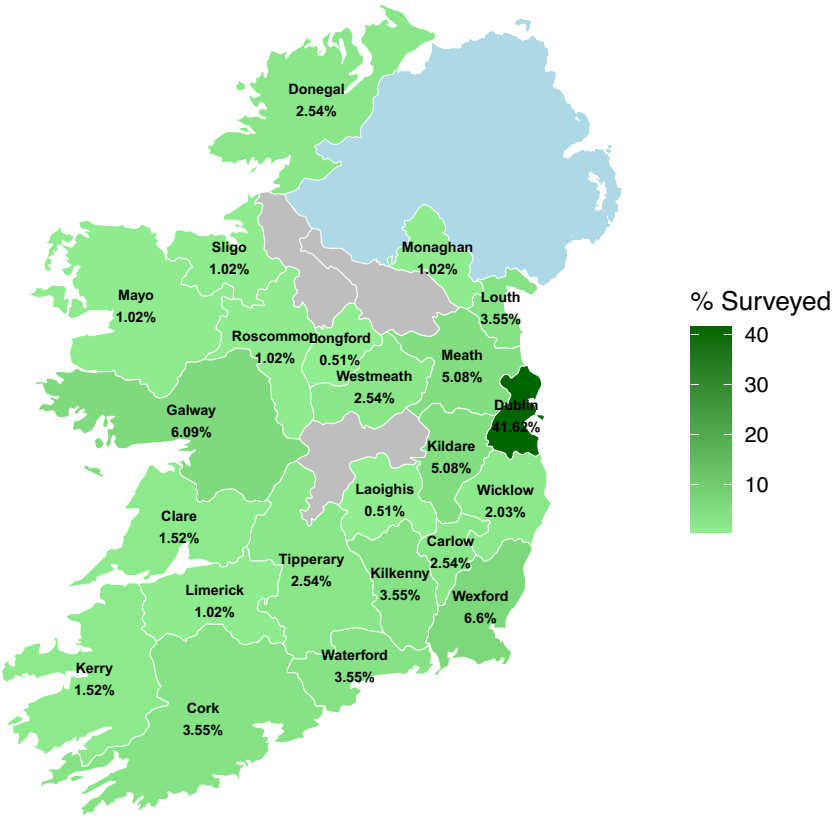

Figure 3.2. Geographical spread of national survey respondents. Note that the survey was not conducted for Northern Ireland (represented in light blue in the map). Grey represents the counties in Ireland where no survey responses were received. Source: adapted from Singh *et al*. (2025b).

reported living in Ireland all their lives, while 27.92% indicated having resided in the country for more than 10 years. Smaller proportions had been in Ireland for shorter durations, with 7.11% reporting residence for less than a year, the same amount for between 1 and 5 years and 3.55% for 6–10 years. This predominantly long-term resident population contributes generational perspectives and deep-rooted experiences to the survey findings (Figure 3.3).

The respondents exhibited a high level of educational attainment, with the majority having completed higher education. Specifically, 38.96% held a bachelor's degree, 32.99% had a master's degree and 16.75% possessed a doctoral degree. A smaller proportion reported qualifications in vocational training (3.05%) or post-leaving certificate programmes (2.54%). This elevated educational profile indicates that the respondents were well-positioned to offer informed and nuanced perspectives on their perception of chemicals addressed in the survey, thereby enhancing the credibility and reliability of the data collected.

Regarding employment status, most respondents were government employees (55.33%), followed by those working in semi-state bodies (11.68%) and private employment (16.24%). Smaller groups included self-employed individuals (5.08%) and students (4.57%). Occupationally, a large proportion of participants were engaged in professional, scientific and technical activities (43.15%), followed by human health and social work activities (19.80%). Other notable occupational sectors included administrative support services (6.09%) and information and communication (5.58%). This broad representation across sectors highlights diverse professional insights into chemical management.

A significant proportion of respondents (35.53%) reported being involved in chemical management as

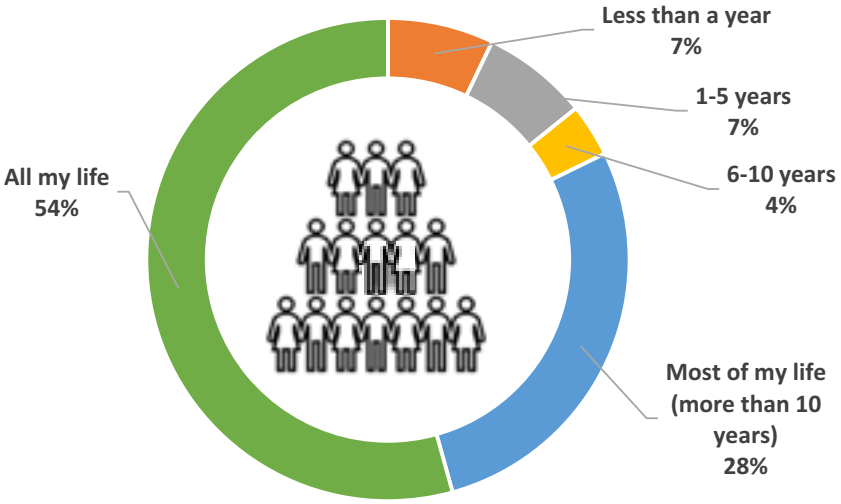

Figure 3.3. Distribution of respondents based on the duration of their residence in Ireland. Source: adapted from Singh *et al*. (2025b).

part of their work duties. Among these, most were affiliated with regulatory bodies (34.67%) or engaged in laboratory management (16.00%). Smaller groups participated in policymaking (14.67%), research and development (6.67%) and other related roles (Figure 3.4).

In terms of concern about chemical usage and exposure, responses varied. While 19.80% reported being extremely concerned, the majority (42.64%) expressed moderate concern, with 26.90% being somewhat concerned. Smaller proportions were slightly concerned (7.61%) or not concerned at all (3.05%). These results suggest that, while awareness exists, perceptions of chemical risks differ across the population. Figure 3.5 depicts the level of concern among survey respondents regarding chemical usage and exposure, with the majority expressing moderate to extreme concern. Figure 3.6 illustrates the most important issues related to chemical exposure as identified by survey respondents, highlighting concerns about food contamination, water quality, air pollution and consumer products.

3.2.2 Scoring of chemicals based on the national survey

The results from the national survey on chemical groups reflect varying levels of concern and awareness among participants, highlighting how different chemicals are perceived in terms of their potential impacts on human health and the environment. Several chemical groups stood out as particularly concerning to respondents, particularly the heavy metals, including lead (2.52), arsenic (2.48), mercury and mercury compounds (2.39). Pesticides (2.35) were also among the groups receiving the highest scores. Several chemicals, including perchlorate and other anions (0.82), quaternary ammonium compounds (0.78) and the aniline family (0.90), scored the lowest, indicating that the majority of participants either have little concern about or limited awareness of these substances. Although they are prioritised under the HBM4IRE list, these chemicals are less likely to be discussed in public health campaigns or regulatory initiatives in Ireland and across the EU, which may contribute to the lower levels of concern associated with them among respondents (Figure 3.7).

3.2.3 Mapping of chemical groups prioritised across HBM4IRE, PARC and national human biomonitoring programmes worldwide

This study also examined the chemical groups prioritised by various countries under their respective national HBM programmes and the EU-wide HBM initiatives – HBM4EU and PARC. The comparative analysis across countries – spanning the United States, Canada, China, Sweden, Germany, France, Belgium, Czechia, Norway, South Korea, Slovenia, New Zealand – and EU-wide HBM initiatives HBM4IRE and PARC highlights both shared concerns about chemicals and distinct national differences in prioritising the chemicals (Figure 3.8).

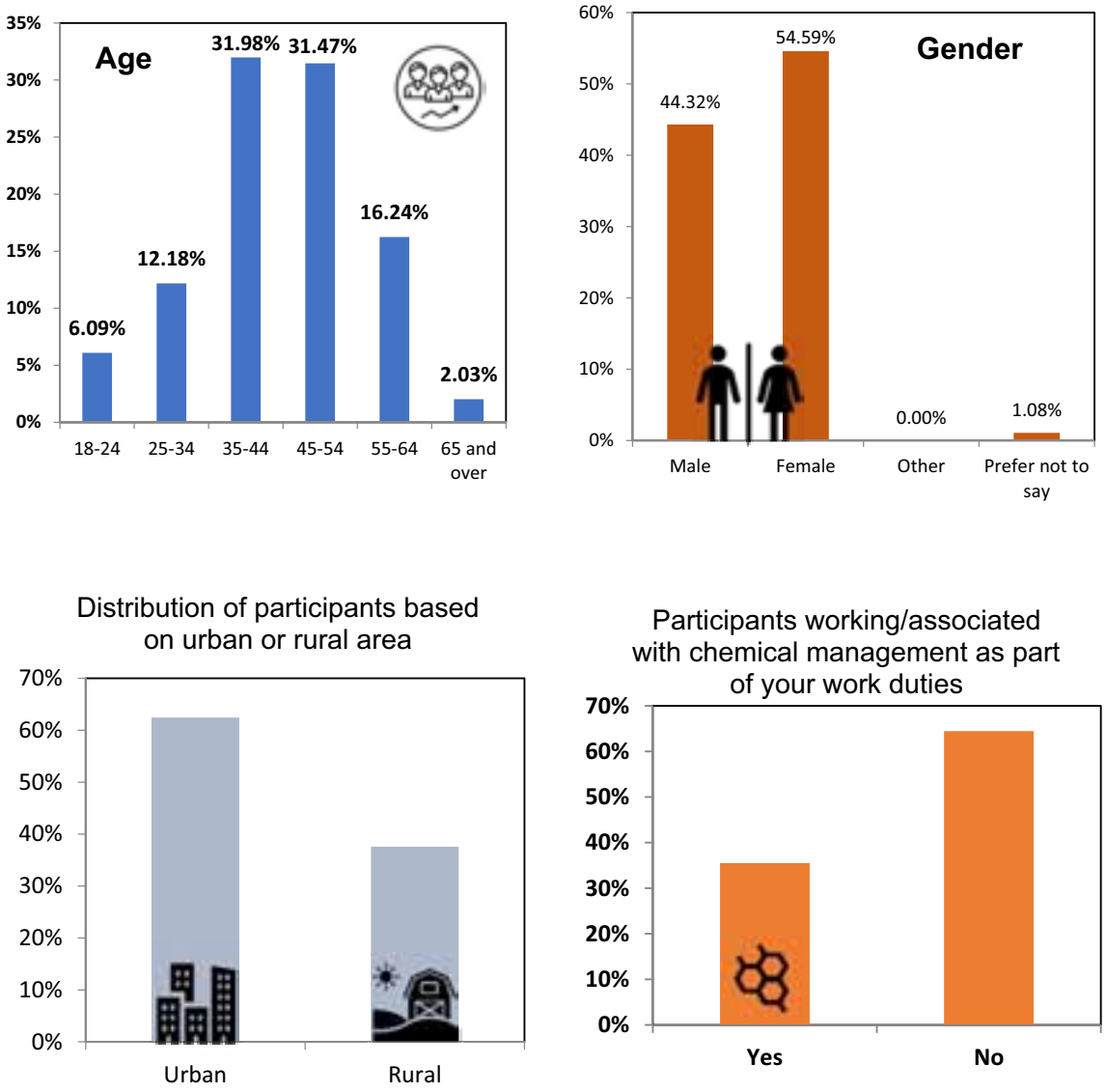

Figure 3.4. Demographic profile of HBM4IRE national survey participants categorised by age, gender, urban or rural residence, and involvement in chemical management. Source: adapted from Singh *et al.* (2025b).

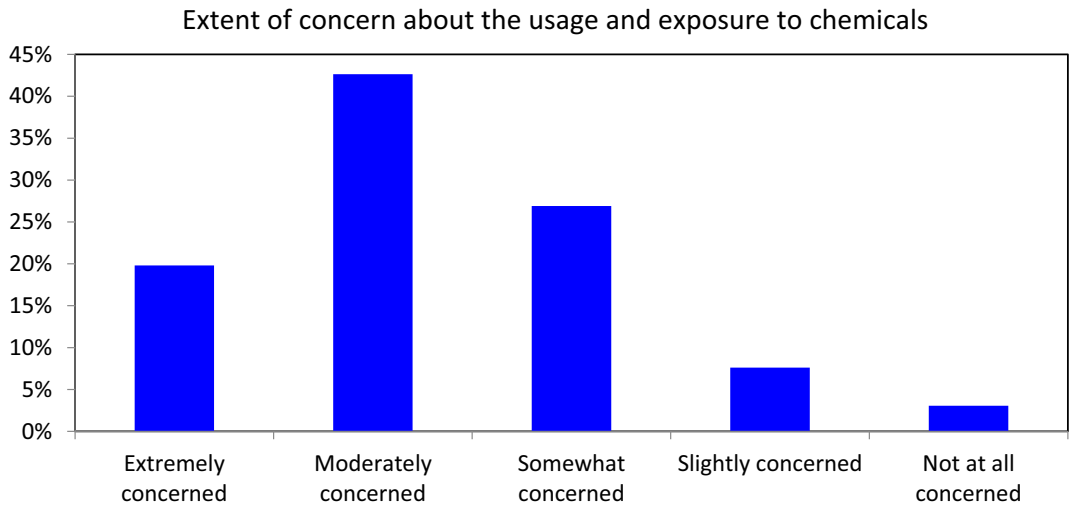

Figure 3.5. Public concern about chemical usage and exposure in the HBM4IRE national survey. Source: adapted from Singh *et al.* (2025b).

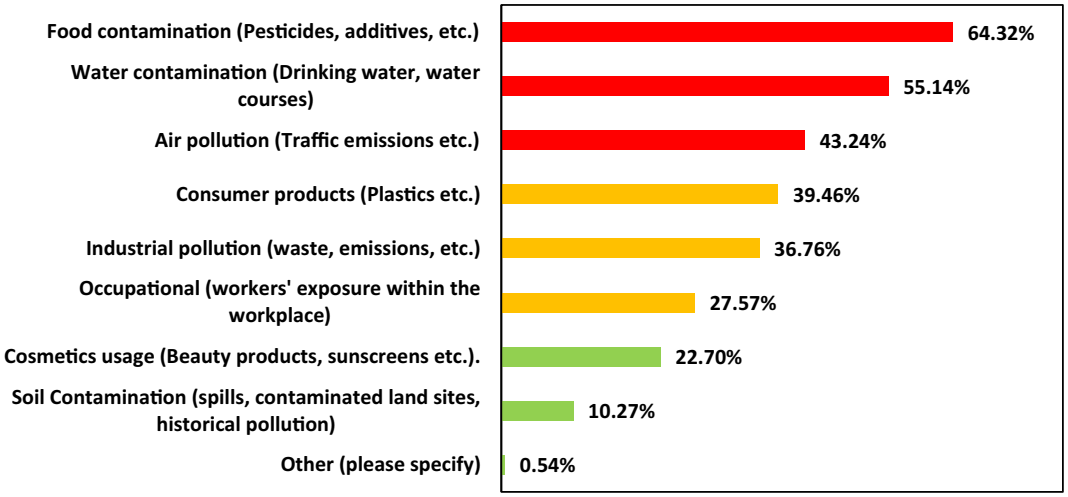

Figure 3.6. Public concerns about chemical exposure in the HBM4IRE national survey. Source: adapted from Singh *et al.* (2025b).

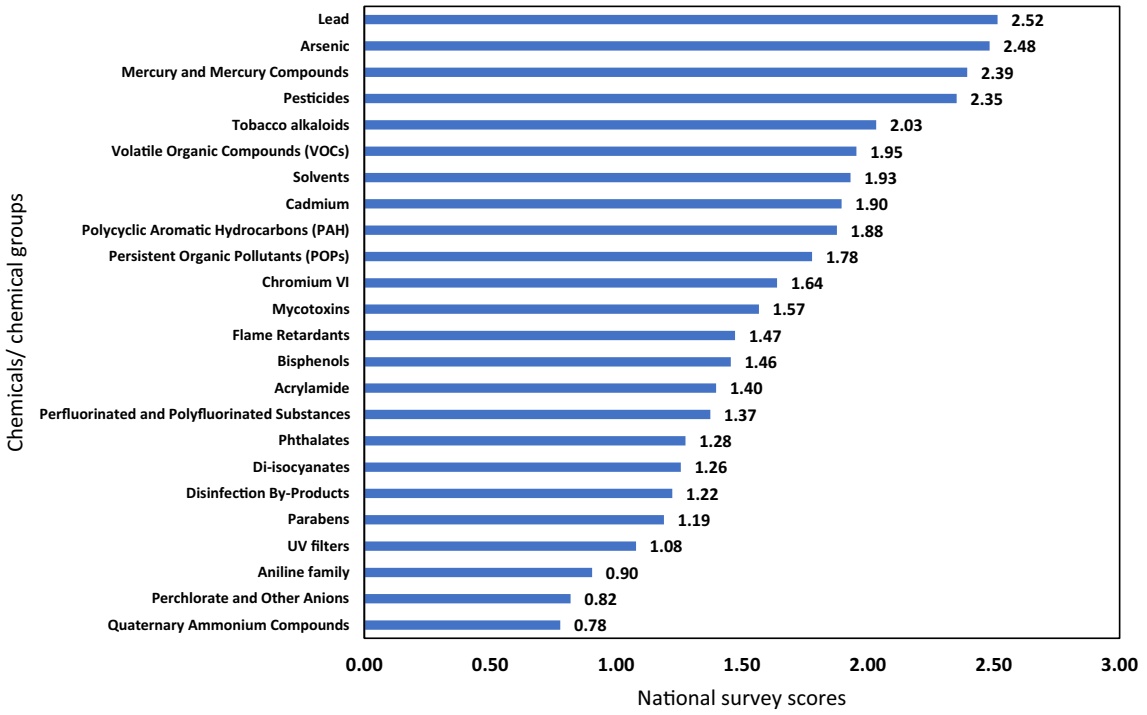

Figure 3.7. Scoring of chemicals based on the HBM4IRE national survey. Source: reproduced from Singh *et al.* (2025c); licensed under CC BY-NC-ND (http://creativecommons.org/licenses/by-nc-nd/4.0/).

The highest cumulative scores were observed for lead, cadmium and plasticisers, each scoring 11.5. These chemicals are consistently prioritised across all the countries reviewed in the study and in both the HBM4EU and PARC initiatives, suggesting a broad recognition of their significant health risks, particularly regarding developmental toxicity, neurological damage and environmental persistence.

Mercury, another chemical with a high cumulative score of 10.0, follows close behind. Bisphenols, with a cumulative score of 10.5, are also frequently monitored chemicals, indicating global concern about their health and environmental implications. Substances like pesticides (8.5), flame retardants (9.0), and PFAS (9.0) also rank highly, highlighting their potential for widespread exposure through food, water and

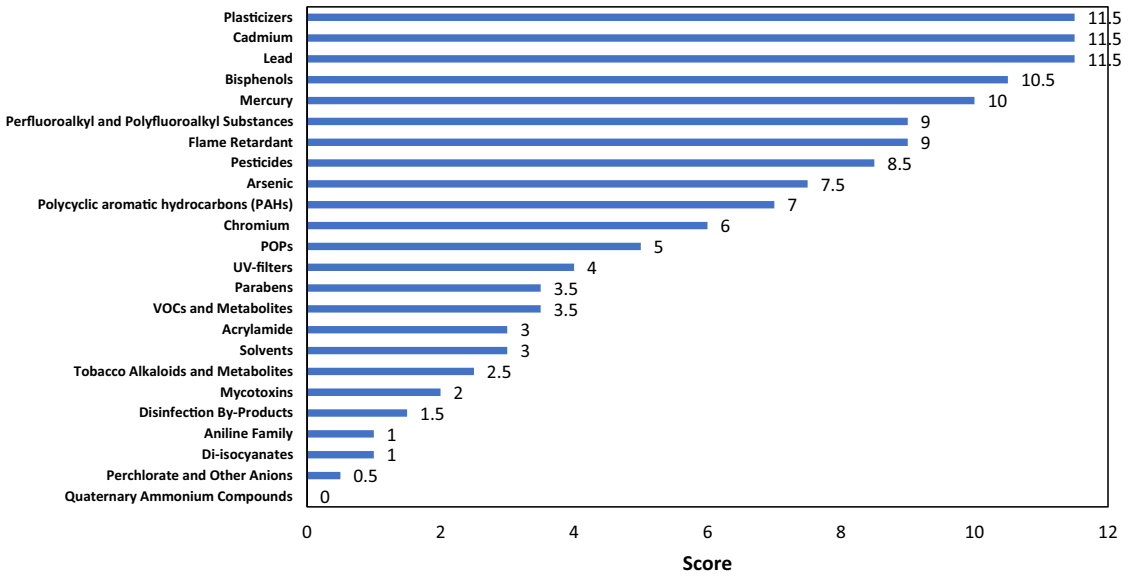

Figure 3.8. Scoring of chemicals based on the HBM4EU, PARC and national HBM programmes. Source: reproduced from Singh *et al.* (2025c); licensed under CC BY-NC-ND (http://creativecommons.org/licenses/by-nc-nd/4.0/).

consumer products. Chemicals such as PAHs and arsenic (both scoring 7.0–7.5) are of particular concern due to their environmental persistence and carcinogenic potential.

3.2.4 Final aggregate score analysis

The inclusion of national survey scores in the chemical prioritisation process provides an essential perspective on the role of public perception and awareness in shaping the prioritisation of chemical groups in HBM programmes. The cumulative scores integrate both the extent of chemical monitoring in HBM across the globe and the national survey scores, offering a comprehensive measure of each chemical group's prioritisation. The highest cumulative scores are observed for lead (14.02), cadmium (13.40), plasticisers (12.78) and mercury (12.39), all of which consistently feature high monitoring coverage across countries and elevated national survey scores. This indicates a direct correlation between societal concern and global HBM efforts. The top priority chemicals after assessing the total scores are presented in Figure 3.9.

However, certain chemical groups demonstrate disparities between global HBM programmes and national survey scores. For example, persistent organic pollutants (POPs) (6.78) and chromium (7.64) exhibit moderate cumulative scores despite being extensively monitored, possibly due to lower societal awareness. Conversely, chemicals like arsenic, which has a relatively high social survey score, achieve higher cumulative rankings, highlighting the influence of public concern in driving prioritisation. The analysis highlights that national survey scores considerably contribute to cumulative scores, especially for chemical groups where public awareness aligns with scientific evidence of health risks. This interplay suggests that addressing societal perceptions through awareness campaigns can enhance the prioritisation of under-monitored but harmful chemicals. In short, the social survey scores amplify the importance of chemicals already prioritised in HBM programmes, while also serving as a tool to spotlight less frequently monitored chemical groups that warrant further scientific and regulatory attention. This dual approach ensures that both technical and societal dimensions are adequately integrated into chemical monitoring strategies.

3.2.5 Selection of biomarkers under each priority chemical group

In this study, the priority individual chemicals or biomarkers were identified based on their inclusion in key HBM programmes, as well as in the HBM4EU

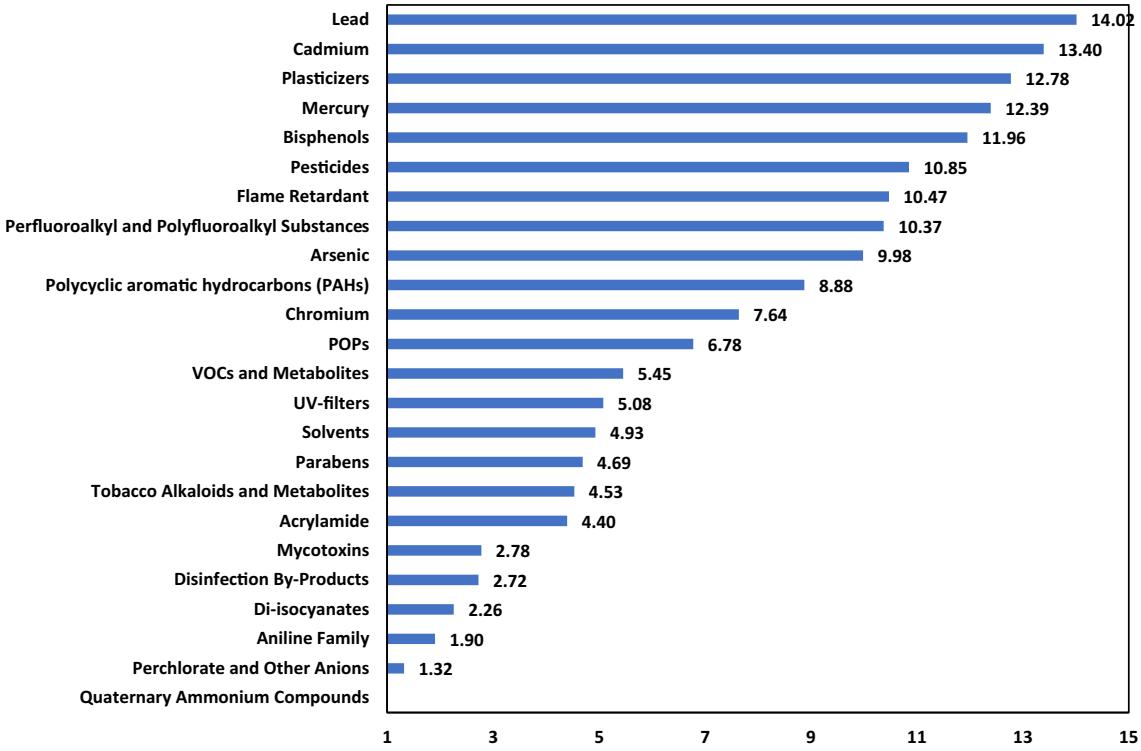

Figure 3.9. Final prioritisation of chemicals based on cumulative score in the HBM4IRE study. Source: reproduced from Singh *et al.* (2025c); licensed under CC BY-NC-ND (http://creativecommons.org/licenses/by-nc-nd/4.0/).

and PARC initiatives. The identified biomarkers are systematically presented in Figure 3.10, which organises the chemicals based on their priority level, as derived from the cumulative scoring based on their appearance in the reviewed HBM programmes (excluding Norway and Iceland[1]).

For example, in the case of bisphenols, seven priority chemicals/biomarkers were selected, with bisphenol A (BPA) ranking first with an overall score of 11.5. Other bisphenols of priority include bisphenol F (BPF), bisphenol S (BPS) and bisphenol B (BPB), with decreasing scores based on their environmental persistence, exposure levels and associated health concerns. The complete list includes a range of bisphenols, such as bisphenol AF, bisphenol AP and bisphenol Z, all of which are widely used in various industrial applications but give rise to varying degrees of concern regarding their toxicity and biomonitoring feasibility. Similarly, the biomarkers of other chemical groups are selected according to their overall scores, which reflect their relevance in ongoing HBM programmes across the globe, helping to focus monitoring efforts on substances that have the most significant implications for human health. Figure 3.10 provides a comprehensive list of these chemicals, along with their corresponding priority rankings.

It is important to note that the chemicals and biomarkers prioritised in this report represent established biomarkers that can be measured via HBM. Although there is overlap with prioritised chemicals under regulatory frameworks, there are some divergences. For example, the EU Water Framework Directive and the HBM4IRE chemical prioritisation have 15 substances in common under the PFAS group, and, for the remainder, there are variances due to chemicals being of concern for the environment rather than human health, or because there is currently a lack of validated biomarkers for HBM due to analytical challenges or limited exposure data.

1 These countries' chemical priorities were either not openly available or were based on the HBM4EU list.

S/no	Priority PFAS	Overall Score
1	Perfluorooctanoic acid (linear and branched isomers) (PFOA)	10
2	Perfluorooctane sulphonate, Heptadecafluorooctane-1-sulphonic acid (linear and branched isomers) - PFOS	9
3	perfluoro-n-nonanoic acid - PFNA	9
4	perfluoro-1-hexanesulfonate (linear and branched isomers) - PFHxS	8.5
5	perfluoro-n-undecanoic acid - PFU(n)DA (in PARC listed as PFUnDA) (in Czeck Republic, it is perfluoroundecanoic acid (PFUdA))	7.5
6	perfluoro-n-decanoic acid - PFDA	6.5
7	perfluoro-1-butanesulfonate (PFBS)	5
8	Perfluoroctylsulfonamide; Perfluorooctanesulfonic acid amide or 1,1,2,2,3,3,4,4,5,5,6,6,7,7,8,8,8-Heptadecafluoro-1-octanesulfonamide (IUPAC) - FOSA, PFOSA	4.5
9	Perfluoro-n-heptanoic acid (PFHpA)	4.5
10	perfluoro-n-butanoic acid (PFBA)	4
11	perfluoro-n-hexanoic acid (PFHxA)	4
12	Perfluorodeconaoic Acid - PFDoDA	3.5
13	perfluoro-heptanesulfonate (PFHpS)	3.5
14	perfluoro-n-tridecanoic acid - PFTrDA (In Czech Republic it is listed as PFTrA)	2.5
15	N-Ethyl-perfluorooctanesulfonamido acetic acid; N-ethyl-perfluorooctane sulfonamidoacetate or N-ethyl-N-[(1,1,2,2,3,3,4,4,5,5,6,6,7, 7,8,8,8-heptadecafluoro octyl)sulfonyl]- glycine (IUPAC) (-Et-FOSAA, Et PFOSA-AcOH, Et FOSAA)	2.5
16	Ammonium 4,8-dioxa-3Hperfluorononanoate (ammonium 2,2,3 trifluor-3-(1,1,2,2,3,3-hexafluoro-3-trifluormethoxypropoxy), propionate) (ADONA)	2.5
17	perfluoro-n-pentanoic acid PFPeA)	2.5
18	Perfluoroether carbocylic acids for example: Ammonium 2,3,3,3-tetrafluoro-2-(heptafluoropropoxy)propanoate (GenX) (PFECA (GenX))	2.5
19	Perfluorododecanoic acid (PFDoA)	2.5
20	perfluoro-1-decanesulfonate (PFDS)	2
21	3,3,4,4,5,5,6,6,7,7,8,8,8-tridecafluorooctanesulphonic acid, 6:2 fluorotelomer sulfonic acid (6:2 FTSA, H4PFOS, THPFOS)	2
22	3,3,4,4,5,5,6,6,7,7,8,8,9,9,10,10,10-heptadecafluorodecanesulphonic acid, 8:2 fluorotelomer sulfonic acid (8:2 FTSA)	2
23	4:2 fluorotelomer sulfonic acid, 3,3,4,4,5,5,6,6,6-Nonafluoro-1-hexanesulfonic acid (IUPAC) (4:2 FTSA)	2
24	Perfluorodecanoic acid (PFDeA)	2

/no	Priority pasticizers	Overall Score
1	Monoethyl phthalate (MEP)	7.5
2	Monobenzyl phthalate (MBzP)	7.5
3	Mono-n-butyl phthalate (MnBP)	6.5
4	Monoisononyl phthalate (MiNP) (in PARC listed as cx-MiNP) metabolite of DENP	6
5	Mono(2-ethyl-5-oxohexyl) phthalate (MEOHP) (in PARC list mentioned as 5oxo-MEHP)	5.5
6	Mono(2-ethyl-5-hydroxyhexyl) phthalate (MEHHP) (listed as 5OHMEHP in Czech Republic)	5.5
7	Di(2-ethylhexyl) phthalate (DEHP)	5
8	Monocyclohexyl phthalate (MCHP)	5
9	Mono(2-ethylhexyl) phthalate (MEHP)	5
10	Cyclohexane-1,2-dicarboxylic mono hydroxy-isononyl ester (OH-MINCH) (listed as MHNCH in US HBM programme)	5
11	Monoisobutyl phthalate (MiBP)	4.5
12	Mono(2-ethyl-5-carboxypentyl) phthalate (MECPP) (in PARC listed as 5cx-MEPP)	4.5
13	Mono-n-octyl phthalate (MOP) (in PARC listed as MnOP)	4.5
14	Diisononyl phthalate (DiNP)	4
15	Diisononyl cyclohexane-1,2-dicarboxylate (Hexamoll® DINCH®)	3.5
16	Monomethyl phthalate (MMP)	3.5
17	Monohydroxyisononyl phthalate (MHiNP) (in PARC listed as OH-MiNP) - metabolite of DENP	3.5
18	Butyl benzyl phthalate - (BBzP)	3
19	Di-n-butyl phthalate (DnBP)	3
20	Diethyl phthalate (DEP)	3
21	Diisodecyl phthalate (DiDP)	3
22	Di(2-propylheptyl) phthalate (DPHP)	3
23	Mono-(3-carboxypropyl) phthalate (MCPP)	3
24	cis-Cyclohexane-1,2-dicarboxylic mono carboxyisononyl ester (cis-cx-MINCH) (listed as MCOCH in US HBM	3
25	Monoisodecyl phthalate (MiDP) (in PARC listed as cx-MiDP)	2.5
26	Monohydroxyisodecyl phthalate (MHiDP) (in PARC listed as OH-MiDP)	2.5
27	Cyclohexane-1,2-dicarboxylic mono oxo-isononyl ester (oxo-MINCH)	2.5

S/no	Priority flame retardants	Overall Score
1	2,2'4,4'-Tetrabromodiphenyl ether (BDE-47)	5
2	2,2',4,4',5-Pentabromodiphenyl ether (BDE-99)	5
3	2,2',4,4',5,5'-Hexabromodiphenyl ether (BDE-153)	5
4	2,4,4'-Tribromodiphenyl ether (BDE-28)	4
5	2,2',4,4',6-Pentabromodiphenyl ether (BDE-100)	4
6	2,2',4,4',5,6'-Hexabromodiphenyl ether (BDE-154)	4
7	2,2',3,4,4',5',6-Heptabromodiphenyl ether (BDE-183)	4
8	Hexabromocyclododecane (HBCDD)	4
9	2,2',3,3',4,4',5,5',6,6'-decabromodiphenyl ether (BDE-209)	3
10	2,3',4,4'-Tetrabromodiphenyl ether (BDE-66)	2
11	Triphenyl phosphate (TPHP)	2
12	Tris-2-chloroethyl phosphate (TCEP)	2
13	Tris(1-chloro-2-propyl) phosphate (TCIPP)	2
14	Tris(1,3-dichloropropyl)phosphate (TDCIPP)	2
15	Tri-n-butyl phosphate (TNBP)	2
16	Tri(2-butoxyethyl) phosphate (TBOEP)	2
17	1,2-bis(2,4,6-tribromophenoxy)ethane (BTBPE)	2
18	2-ethylhexyl diphenyl phosphate (EHDPP)	2
19	Decabromodiphenylethane (DBDPE)	2
20	Bisphenol A bis(diphenylphosphate) (BPA-BDPP)	2
21	2,4-dibromophenol (DBP)	2
22	Dibromostyrene (DBS)	2

Figure 3.10. Priority biomarkers under major chemical groups based on the HBM4EU, PARC and national HBM programmes mapping exercise.

S/no	Priority PAH	Overall Score
1	2-naphthol (or 2-hydroxy-naphthalene) - metabolites of naphthalene	5
2	1-hydroxy-pyrene (metabolite of pyrene) (listed as hydroxypy	5
3	2-hydroxy-fluorene (metabolites of fluorene)	4
4	1-hydroxy-phenanthrene(metabolites of phenanthrene)	4
5	2-hydroxyphenanthrene (metabolites of phenanthrene)	4
6	1-naphthol (or 1-hydroxy-naphthalene) metabolites of naphthalene (listed as 1 hydroxynapthol in France)	3
7	3-hydroxy-fluorene (metabolites of fluorene)	3
8	Fluorene	2
9	Chrysene/Benzo(a)phenanthrene	2
10	Naphthalene	2
11	Pyrene	2
12	Benzene	2
13	Formaldehyde	2
14	3-hydroxyphenanthrene (metabolites of phenanthrene)	2
15	4-hydroxyphenanthrene (metabolites of phenanthrene)	2
16	9-hydroxy-phenanthrene (metabolites of phenanthrene)	2

S/no	Priority Bisphenol	Overall Score
1	4,4'-isopropylidenediphenol (BPA) (Bisphenol A)	11.5
2	4,4'-methylenediphenol (BPF) (Bisphenol F)	9
3	4,4'-sulphonyldiphenol (BPS) (Bisphenol S)	8.5
4	4,4'-(1-methylpropylidene) bisphenol (BPB) (Bisphenol B)	5
5	4,4'-[2,2,2-trifluoro-1-(trifluoromethyl)ethylidene]diphenol	5
6	4,4'-(1-Phenylethylidene) bisphenol (BPAP) (Bisphenol AP)	5
7	4,4'-cyclohexylidene bisphenol (Bisphenol Z)	5
8	4,4'-Ethylidenebisphenol (Bisphenol E)	4
9	4,4'-(1,4-Phenylene diisopropylidene bisphenol (Bisphenol P)	4

S/no	Priority UV filters	Overall Score
1	Benzophenone-3 (BP-3)	2.5
2	3-(4-methylbenzylidene)-camphor (4-MBC)	2
3	Benzophenone (BP)	1
4	Benzophenone-1 (BP-1)	1
5	Benzophenone-2 (BP-2)	1
6	3-4CBHC (metabolites of 4-MBC)	1
7	3-4CBC (metabolites of 4-MBC)	1
8	3-benzylidene camphor (3-BC)	1
9	4-hydroxy-benzophenone (4-HBP)	1
10	4-methyl-benzophenone (4-MBP)	1
11	Octisalate (2-ethylhexyl salicylate, EHS),	1
12	5OH-EHS or 5cx-EPS (metabolite of EHS)	1

S/no	Priority POPs	Overall Score
1	Polychlorinated binenyls (PCB) and its congeners	4
2	DDT (Dichlorodiphenyltrichloroethane)	3
3	HCB (hexachlorobenzene)	3
4	Chlordane	2
5	beta-Hexachlorocyclohexane (Component of HCH)	2
6	Hexachlorocyclohexane (HCH)	1
7	Pentachlorobenzene	1
8	alpha-Hexachlorocyclohexane (Component of HCH)	1
9	gamma-Hexachlorocyclohexane (Component of HCH & lindane)	1

Figure 3.10. Continued

'no	Priority pesticides	Overall Score
1	Glyphosate	4
2	3-phenoxybenzoic acid (3-PBA)	4
3	Cyfluthrin (4-fluoro-3-phenoxybenzoic acid (F-3PBA)	3.5
4	Deltamethrin (metabolite - cis-3-(2,2-Dibromovinyl)-2,2-dimethylcyclopropane carboxylic acid (cis-DBCA))	3.5
5	Aminomethylphosphonic acid (AMPA) metabolite of glyphosate	3
6	Dimethylphosphate (DMP) (Unspecific metabolite of methyl organophosphates, e.g., dimethoate, chlorpyrifos-methyl, azinphos-methyl, malathion, fenthion, phosmet, naled)	2.5
7	Diethylphosphate (DEP) (Unspecific metabolite of ethyl organophosphates e.g., chlorpyrifos, diazinon, ethion, coumaphos, terbufos)	2.5
8	Chlorpyrifos (OP)	2
9	TCPy (3,5,6-trichloro-2-pyridinol) - metabolite of Chlorpyrifos and Triclopyr	2
10	Organochlorine pesticides: aldrin, HCB, DDT/DDE, alachlor...	2
11	Chlorophenols: 4-MCP, 2.4-DCP, 2.5-DCP, 2.6-DCP, 2.3.4-TCP, 2.4.5-TCP, 2.4.6-TCP, PCP, 2.3.4.6-TeCP	2
12	cis-3-(2,2-Dichlorovinyl)-2,2-dimethylcyclopropane carboxylic acid (cis-DCCA) (metabolite of Cis-permethrin, cis-cypermethrin, cis-cyfluthrin)	1.5
13	trans-3-(2,2-Dichlorovinyl)-2,2-dimethylcyclopropane carboxylic acid (trans-DCCA) (metabolite of Trans-permethrin, trans cypermethrin, trans-cyfluthrin)	1.5
14	Dimethylthiophosphate (DMTP) (Unspecific metabolite of methyl organophosphates, e.g. dimethoate, chlorpyrifos-methyl, azinphos-methyl, malathion, fenthion, phosmet, naled)	1.5
15	Diethylthiophosphate (DETP) (Unspecific metabolite of ethyl organophosphates e.g., chlorpyrifos, diazinon, ethion, coumaphos, terbufos)	1.5
16	Diethyldithiophosphate (DEDTP) (Unspecific metabolite of ethyl organophosphates e.g., chlorpyrifos, diazinon, ethion, coumaphos, terbufos)	1.5

S/no	Priority Metals	Overall Score
1	Cadmium	10.5
2	Lead	10.5
3	Mercury	9
4	Arsenic	6.5
5	Manganese	6
6	Selenium	5.5
7	Chromium VI	5
8	Copper	4.5
9	Cobalt	4
10	Nickel	4
11	Zinc	3.5
12	Thallium	3.5
13	Molybdenum	3
14	Tin	3
15	Aluminium	3
16	Antimony	2.5
17	Lithium	2
18	Arsenocholine and Arsenobetaine (organic arsenic compounds)	2
19	Iron	2
20	Uranium	1.5

Figure 3.10. Continued

3.2.6 Thematic analyses of the World Café

After the careful analysis of the World Café discussion via a critical friend process, the major emergent themes were identified. Most of the suggestions are incorporated in the recommendations section of the report (Chapter 7 and Figure 3.11).

3.3 National Programme

The development of a national HBM programme requires the consideration of four main factors, including the management structure, who has primary responsibility for the programme, who will contribute to the financial and resource contributions and the general operational requirements, and, finally, the need for collaboration with scientists/researchers/ chemical regulators to ensure that discoveries and innovations are included to ensure that the national programme also encapsulates novel and emerging chemicals of concern (Figure 3.12). Each of these factors will require planning and design to ensure the efficiency and sustainability of the programme, with

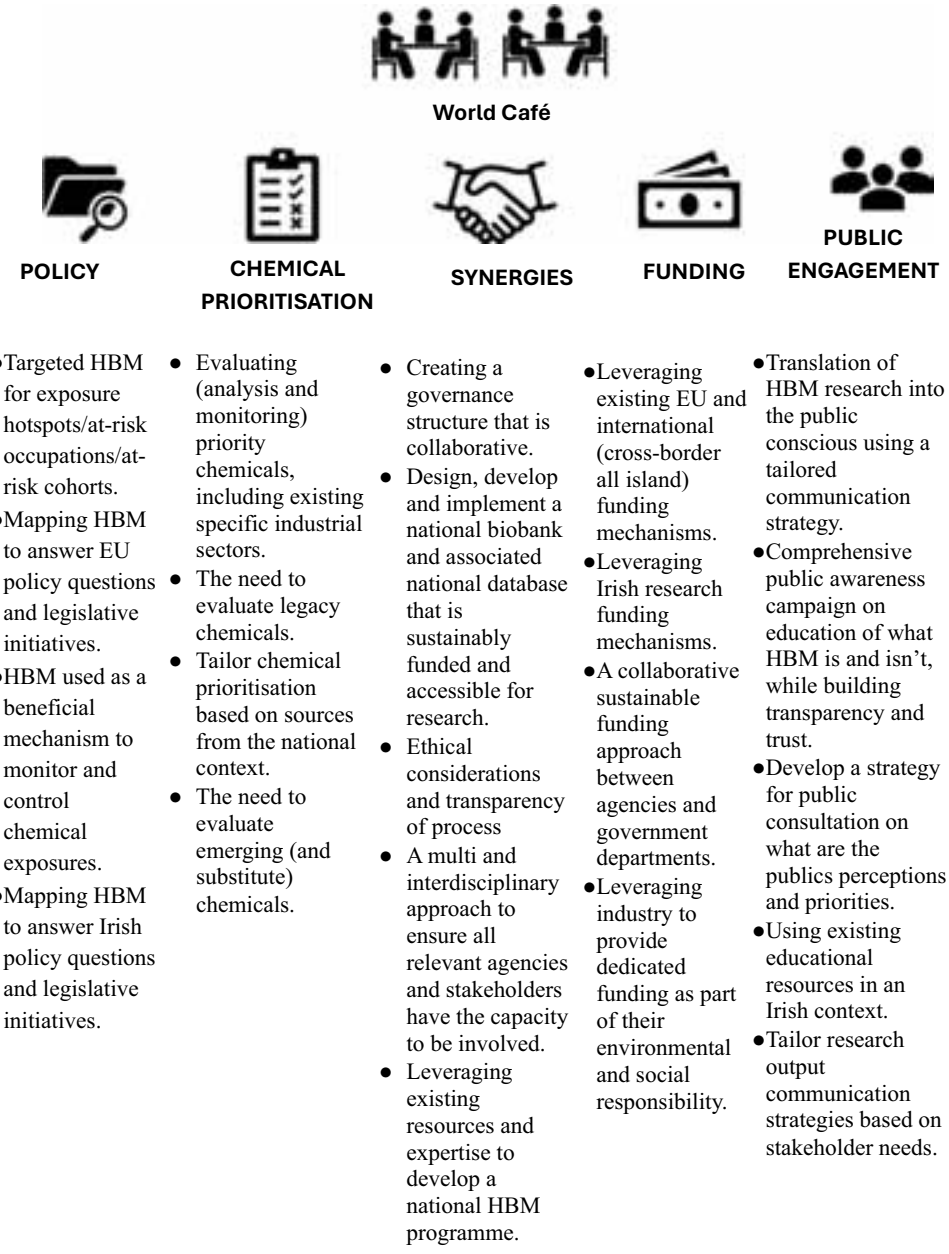

Figure 3.11. Analysis of emergent themes from the World Café session.

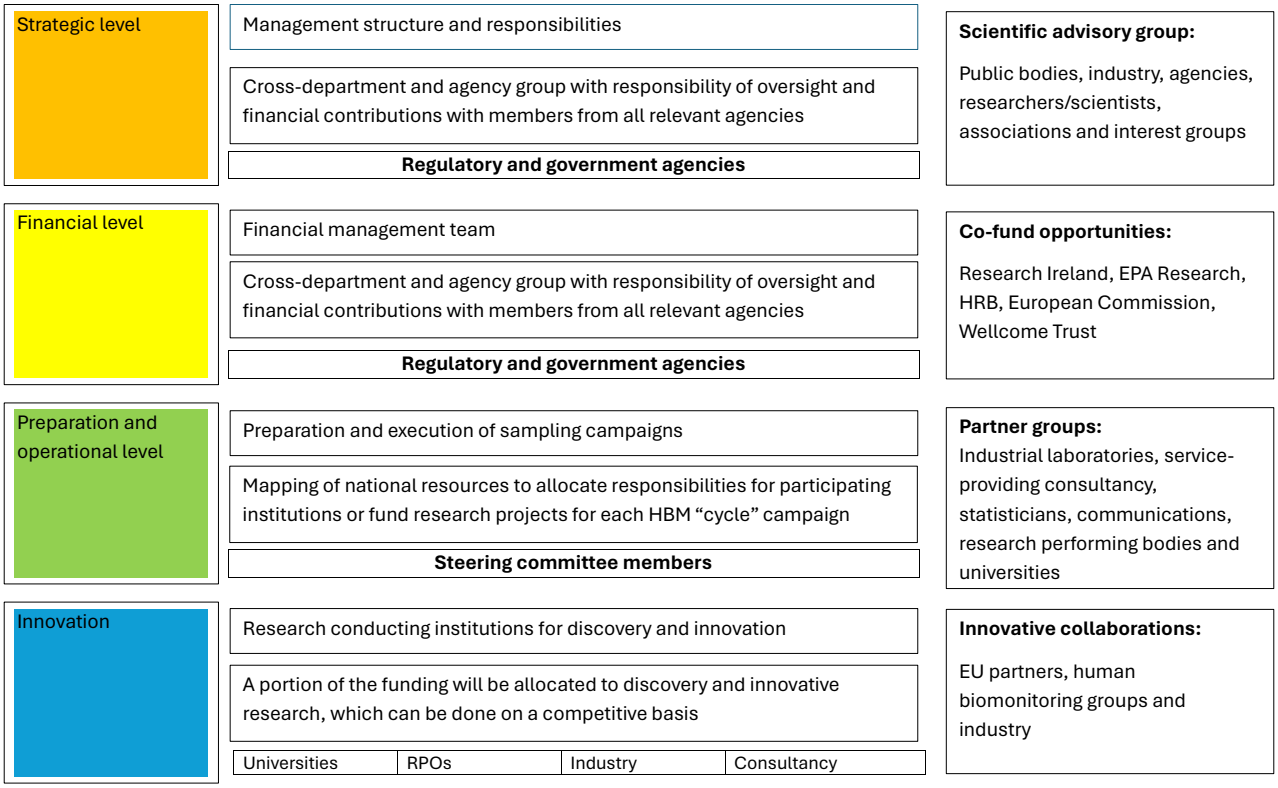

Figure 3.12. The criteria required to ensure the success of a national HBM programme, including criteria, requirements and dedicated groups. HRB, Health Research Board; RPOs, research performing organisations.

further roles, purposes and responsibilities outlined below (Table 3.2).

3.3.1 National human biomonitoring programme criteria

The national HBM programme will need to develop a leadership committee, project coordinators and associated tasks to ensure that communication is included in its development, which all groups should contribute to, as this will ensure a wide distribution of outputs and maximise impacts (i.e. proposed framework structure provided in Table 3.2).

3.3.2 National HBM programme management governance models

From the extensive HBM mapping exercise and consultation with international and national experts, two main methods for developing a governance structure for a national HBM programme were developed. It is important to note that the models suggested in the study are inspired by the existing HBM governance models in other European countries with well-established and sustainable HBM programmes. These models are intended to serve as adaptable starting points for Ireland, contextualised for the country's unique exposure profiles and institutional dynamics. The first proposed model would be the development of a new steering group specifically focused on HBM within the country. The steering committee would comprise members from all relevant agencies and departments, which would allow national discussions on priorities for the country. The need for more multi- and transdisciplinary work is becoming increasingly evident, and such work has been done previously in Ireland with the National Interdepartmental AMR Consultative Committee for Ireland's National Action Plan on Antimicrobial Resistance (Department of Health, 2017). The governing structure should also comprise an external scientific advisory committee to assist with ensuring the integrity of the programme, which is well-informed on cutting-edge scientific developments and provides support to the HBM committee. Once the committee has been established, it would be essential, prior to

Table 3.2. The HBM4IRE governance structure with roles, purposes and responsibilities for the HBM national programme

Governance level/task	Role/committee	Purpose	Key responsibilities	Overall responsibility
HBM4IRE Steering Committee activities				
Leadership	Cross-departmental/ agency committee	Provides overall strategic direction and oversight	Define vision and goals Set research priorities that align with national requirements Approve protocols and resources	Provide leadership and oversight of funding and resources
Funding and resources	Grants and Funding Committee	Secures and oversees research funding	Identify funding opportunities Approve budgets Monitor grant compliance	
Coordination of and advice on research				
Programme coordination	Programme Coordinator	Oversees and monitors project activities	Oversee project timelines Liaise between teams Report to the committee	Ensure the integrity of the programmes and report to the steering committee
Scientific advisory	Scientific Advisory Board	Guides research quality, validity and methodologies	Advise on scientific approaches Facilitate cross-disciplinary links Review proposed studies	
Conduct of HBM studies				
Project coordination	Project Coordinator	Manages day-to-day operations and coordination	Oversee project timelines Oversee timeline for deliverables/ milestones Report to the steering committee	Ensure that research is conducted and data analysed to a high standard and in line with good practice and ethical principles
Ethical oversight	Ethics Review Board	Ensures compliance with ethical standards and protocols	Review ethical implications Approve research protocols Address ethical concerns	
Data and quality control	Data Integrity Committee and Data Management Plan	Oversees data collection, quality and management	Ensure data integrity Manage data storage Develop data-sharing protocols (FAIR)	
Field operations	Fieldwork Coordination Team	Manages logistics for sample collection and fieldwork, utilising well-established protocols	Plan and coordinate fieldwork Ensure participant and worker safety Oversee sample integrity	
Laboratory management	Laboratory Oversight Committee	Ensures laboratory standards and safety compliance and analytical methods have QA/QC protocols	Ensure sample integrity Ensure labs have quality assurance and that analytical methods developed have been through some QA/QC external review	

Table 3.2. Continued

Governance level/task	Role/committee	Purpose	Key responsibilities	Overall responsibility
Data analysis	Data Analysis, Interpretation and FAIR Data Management Team	Analyses and interprets research data	Conduct statistical analyses Report findings to the steering committee To produce these summary results on a public forum	
Communications				
Participant engagement	Develop participant feedback forms	Explains the results and provides suggestions for reducing exposures	Study designers will provide study results in plain English Give suggestions for exposure reduction Provide sources of additional information	Contribute to the development and/or dissemination of study outputs to ensure a broad reach to all stakeholders using differing mechanisms of communication for targeted stakeholders
Reporting and publication	Publications, reports, conference proceedings, funders reports	Manages publications and dissemination of results	Approve publication plans Facilitate peer review Handle public communication	
Community engagement	Community Outreach Committee	Engages with study participants and community stakeholders	Conduct outreach activities Communicate research goals Address community concerns	

the commencement of any work, or allocation of tasks or funding, that a memorandum of understanding be developed and signed by all parties to ensure transparency and that appropriate FAIR data-sharing mechanisms are included (Figure 3.13).

Alternatively, many countries allocate the responsibility for their HBM programme to one division or department, and tasks and responsibilities to other departments, agencies or stakeholders (i.e. environment agencies and departments of health) (Figure 3.14).

It will also be necessary, for public dissemination, to have an ethos for the national HBM programme in order to highlight the benefits for the wider community in contributing to such a programme and to safeguard public health (Figure 3.15).

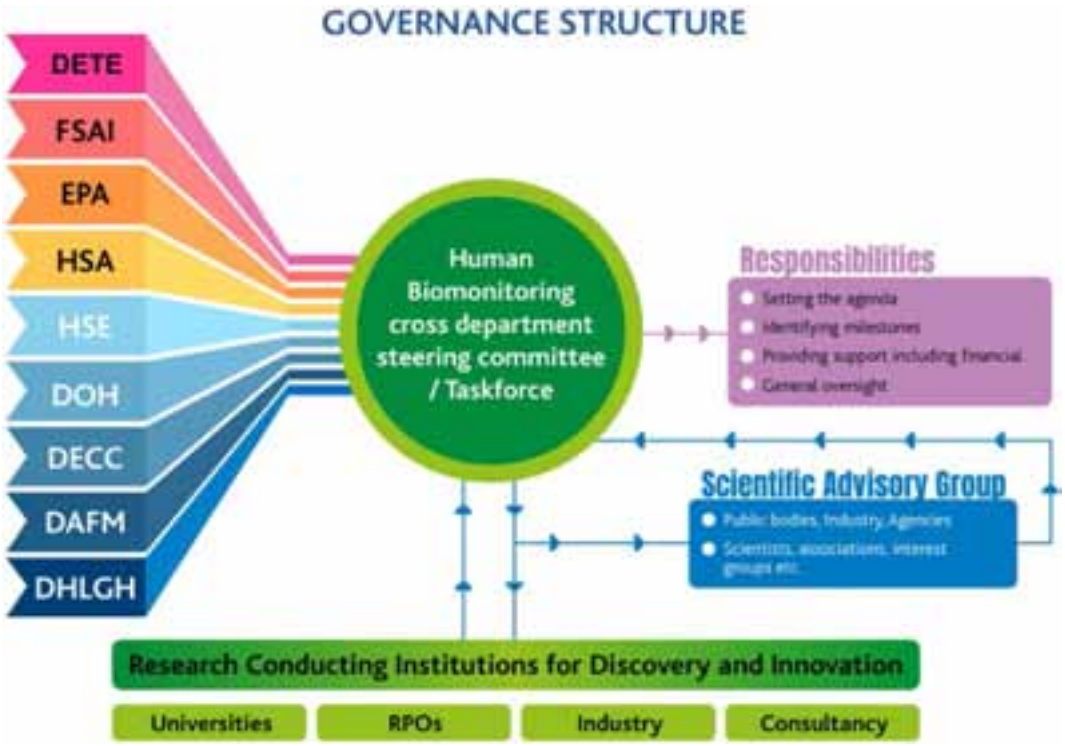

Figure 3.13. The development of a national HBM governing structure for Ireland, which includes developing a national interdepartmental/interagency group with overall responsibility. This is a non-exhaustive list of relevant agencies/departments, and the government has the liberty to decide which would be best-suited. DAFM, Department of Agriculture, Food and the Marine; DECC, Department of the Environment, Climate and Communications; DETE, Department of Enterprise, Trade and Employment; DHLGH, Department of Housing, Local Government and Heritage; DOH, Department of Health; EPA, Environmental Protection Agency; FSAI, Food Safety Authority of Ireland; HSA, Health and Safety Authority; HSE, Health Service Executive; RPO, research-performing organisation.

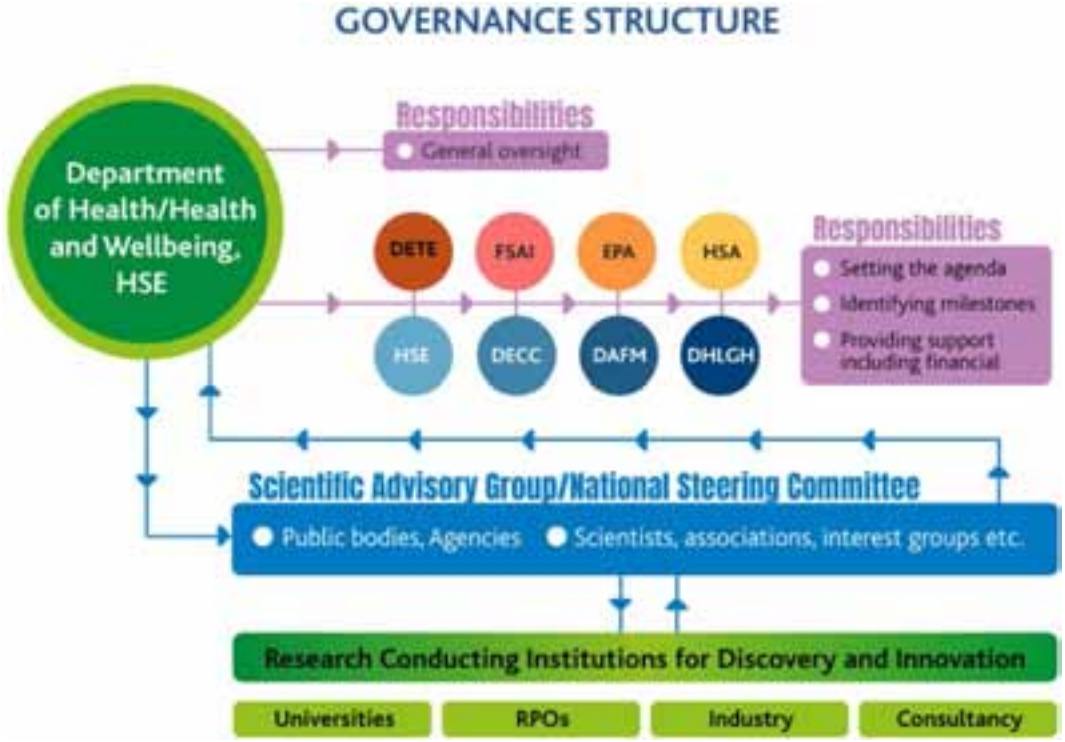

Figure 3.14. The development of a national HBM governing structure for Ireland in which the Department of Health would have overall responsibility. This is a non-exhaustive list of relevant agencies/ departments. DAFM, Department of Agriculture, Food and the Marine; DECC, Department of the Environment, Climate and Communications; DETE, Department of Enterprise, Trade and Employment; DHLGH, Department of Housing, Local Government and Heritage; EPA, Environmental Protection Agency; FSAI, Food Safety Authority of Ireland; HSA, Health and Safety Authority; HSE, Health Service Executive; RPO, research-performing organisations.

Figure 3.15. PROTECT: the ethos of the national HBM programme for Ireland is to protect and safeguard the population.

4 Discussion

4.1 Governance Framework

The HBM4IRE project has provided a framework for the development of a national governance for the establishment of a national HBM programme. The inclusion of an interdepartmental committee, similar to the approach adopted for Ireland's National Action Plan on Antimicrobial Resistance (Department of Health, 2017), alongside a scientific advisory committee, would ensure sharing of expertise, resources and infrastructure for this endeavour. The national framework structure can include suggestions provided in this report, and the European Joint Programme HBM4EU has developed a phased approach to project management with six phases, from phase 0, "scoping and planning", to phase 6, "communication and dissemination", which could be adopted as a national phased approach (Fiddicke *et al*., 2021).

4.2 Chemical Prioritisation

4.2.1 Top 10 priority chemicals and their biomarkers

The identification of the top 10 chemicals in the HBM4IRE project marks the first milestone in the country's efforts to establish a comprehensive and evolving national HBM programme. This list of priority chemicals, developed through a combination of national surveys and chemical priority rankings from the HBM4EU and PARC initiatives, along with the chemicals prioritised by 12 countries' HBM programmes, reflects the intersection of global knowledge, national priorities and emerging public health concerns. It is important to note that the five heavy metals that secured a place in the top 10 chemicals have been grouped together as a category of metals. This grouping is based on the fact that all these metals can be analysed using multi-analysis methods. Other chemicals and their biomarkers are grouped separately.

The details on the method of analysis, guidance values, preferred matrices for analysis and other important aspects of chemical analysis are mentioned in various HBM4EU communication materials and other related websites like the International Society of Exposure Science i-HBM Working Group Human Biomonitoring Health-Based Guidance Value Dashboard (ISES, 2022; Umweltbundesamt, n.d.; VITO, 2021). For instance, the substance reports provides comprehensive information on human exposure, health impacts and detection methods (HBM4EU, 2020b to 2020n). The scoping documents outline background information, policy questions and research activities. Additionally, the HBM4EU policy briefs summarise key findings and policy recommendations. Links to each of the substance groups are provided in the reference section of this report (HBM4EU, 2022).

While this is the first iteration of the list of priority chemicals, it should be regularly updated to reflect new research, changing trends in chemical exposure and emerging risks. The establishment of this prioritised list serves as an essential foundation for Ireland's HBM programme, which aims to monitor and assess chemical exposure levels in the population and guide informed policy decisions aimed at mitigating these risks. A more detailed list of prioritised chemicals is available in Appendix 1.

1. Metals (lead, cadmium, mercury, arsenic, chromium VI). Metals are a significant environmental and health concern due to their toxic effects and widespread presence. Lead exposure, primarily from contaminated food and water and old paint, is regulated under various pieces of EU legislation, including the Regulation on the Registration, Evaluation, Authorisation and Restriction of Chemicals (REACH), Classification, Labelling and Packaging of Chemicals (CLP) Regulation, and the Drinking Water Directive. Blood lead levels are the main biomarker for monitoring exposure. Cadmium, found in industrial emissions and tobacco smoke, is linked to kidney damage and cancer, with regulations covering its presence in food, cosmetics and industrial emissions. Urinary cadmium is used to assess cumulative exposure, while blood cadmium indicates recent exposure. Mercury, persistent in the environment, is regulated under the Minamata Convention and various

EU laws, with monitoring focusing on its accumulation in human tissues, using hair, blood and urine as biomarkers. Arsenic, a risk in drinking water and food, particularly rice, is regulated to limit exposure, with urine, hair and nails used for biomonitoring. These metals are subject to strict EU regulations to minimise exposure and protect public health.

2. Plasticisers (phthalates). Phthalates are widely used in plastics but are of concern for their endocrine-disrupting effects. Key restrictions under REACH target phthalates like di(2-ethylhexyl) phthalate (DEHP), dibutyl phthalate (DBP) and benzyl butyl phthalate (BBP) in consumer goods and toys. LC-MS/MS is the preferred biomonitoring method, with urine as the main matrix. In HBM4IRE, metabolites such as monoethyl phthalate and mono-n-butyl phthalate are prioritised due to their common detection and health risks, particularly their reproductive toxicity.

3. Bisphenols. Substances such as BPA are used in plastics and resins but are endocrine disruptors. BPA is classified as a substance of very high concern under REACH and restricted in toys, food packaging and thermal paper. Urine is the primary matrix for biomonitoring, although other bisphenols like BPS and BPF are classified as being of emerging concern due to their toxicity.

4. Pesticides. Ireland's reliance on agriculture increases the potential risk of pesticide residues in soil, water and food, although national and EU monitoring programmes routinely assess (e.g. through the Department of Agriculture, Food and the Marine, the EPA and EFSA) these pathways for regulatory compliance and public health protection. Additionally, the EU's Farm to Fork Strategy aims to cut chemical pesticide use by 50% by 2030. HBM4IRE prioritises pesticides like glyphosate (and its metabolite AMPA), which scored highest in the chemical prioritisation process. Other priorities include 3-phenoxybenzoic acid, cyfluthrin and deltamethrin, which are known for their neurotoxic and endocrine-disrupting effects. Organophosphates like dimethyl phosphate and chlorpyrifos are also highlighted, alongside persistent organochlorines like DDT (dichlorodiphenyltrichloroethane) and hexachlorobenzene, which bioaccumulate in food chains.

5. Flame retardants: These substances, used in consumer goods, persist in the environment and pose health risks. EU policies restrict chemicals like PBDEs and hexabromocyclododecane (HBCDD), yet many remain unregulated. HBM4IRE prioritises BDE-47, BDE-99 and BDE-153, widely found in electronics, and HBCDD, used in polystyrene. Their cumulative scores reflect their health and environmental impacts, with ongoing monitoring needed.

6. PFAS. These are synthetic chemicals found in non-stick cookware, textiles and firefighting foams and are linked to bioaccumulation and health risks like liver damage and immune disruption. EU regulations ban several PFAS, including PFOA and PFOS, while others are under restriction. HBM4IRE focuses on high-priority chemicals like PFOA, PFOS and PFNA, with scores reflecting their widespread presence. Shorter-chain PFAS like perfluorobutanoic acid (PFBA) and perfluoroheptanoic acid (PFHpA) are also monitored due to persistent contamination risks.

7. PAHs. These substances are produced during incomplete combustion and are toxic and carcinogenic. EU policies regulate PAH concentrations in consumer goods and in air. HBM4IRE prioritises metabolites like 2-naphthol (from naphthalene) and 1-hydroxy-pyrene (from pyrene), reflecting high exposure risks. Other key biomarkers, including 2-hydroxy-fluorene and 1-hydroxy-phenanthrene, highlight exposure to industrial and environmental pollution.

8. POPs. These are toxic chemicals that persist in the environment, bioaccumulate through the food chain and pose significant health risks. POPs include substances like DDT, PCBs and dioxins, which are regulated under international agreements like the Stockholm Convention. POPs are linked to cancer, reproductive harm and endocrine disruption. HBM programmes monitor these substances to assess human exposure and guide regulatory actions.

9. Volatile organic compounds (VOCs). These are a group of chemicals that easily evaporate into the air, contributing to air pollution and health issues such as respiratory problems and cancer. Common VOCs include benzene, formaldehyde and toluene, which are found in paints, solvents and vehicle emissions. HBM programmes focus on VOCs to evaluate exposure risks and their impact on human health, especially in indoor environments.

10. UV filters. These are chemicals used in sunscreens, cosmetics and personal care products to protect skin from harmful UV radiation. Common

UV filters include benzophenone 1 and 2, and 3- and 4-methylbenzylidene, which can be absorbed by the skin and may disrupt hormonal systems. HBM monitoring tracks the presence of these chemicals in humans to assess their potential long-term health effects and environmental impact.

4.2.2 Chemicals of emerging concern and legacy chemicals

The establishment of this prioritised list serves as an essential foundation for Ireland's HBM programme, which aims to monitor and assess chemical exposure levels in the population and guide informed policy decisions aimed at mitigating these risks. Even with chemicals that may be restricted or banned, it is important to evaluate their lasting effects and to ensure no recurrence of exposure. Recent research by Kasper-Sonnenberg *et al*. (2025) reported a significant decline in exposure to legacy phthalates such as di-n-butyl phthalate and DEHP in Germany over 35 years (1988–2022), with reductions exceeding 90%. However, rising exposure to substitutes like 1,2-cyclohexane dicarboxyllic acid diisononyl ester (DINCH) and di(2-ethylhexyl) terephthalate (DEHTP), distinct from DEHP, reflects the evolving landscape of chemical risk and time trends. These findings highlight the critical role of HBM in monitoring both legacy and emerging chemicals, as demonstrated by initiatives like HBM4IRE, PARC and other European HBM programmes, to enable comprehensive exposure assessment and effective risk management.

4.2.3 Addressing gaps in awareness among the public

The demographic information for the survey conducted in Ireland reveals a well-educated, professionally diverse participant group, a substantial number of whom are actively involved in chemical management. The high levels of educational background and occupational engagement of participants lend credibility to the survey findings. In addition, the varying levels of concern about chemical exposure indicate the need for tailored awareness initiatives to address public perceptions and promote understanding of chemical safety. This demographic foundation provides a critical context for interpreting the survey results and shaping future strategies in chemical monitoring and management.

Bridging these awareness gaps requires targeted efforts by Ireland's HBM programme, including educational campaigns aimed at raising awareness about the persistence and health impacts of legacy chemicals like POPs and the risks associated with emerging substances like UV filters. Collaborative efforts with international HBM networks can further align priorities and promote shared best practices for addressing these challenges.

4.2.4 Use of multi-analysis methods in human biomonitoring programmes

Although several biomarkers and individual chemicals within each chemical group are prioritised in national HBM programmes and the current study, it is essential to highlight that multiple biomarkers within a chemical group can often be analysed simultaneously. Such approaches, referred to as multi-analysis methods, allow for the simultaneous assessment of multiple biomarkers from a single biological sample. This not only facilitates the comprehensive evaluation of biomarkers within a chemical group but significantly reduces analytical costs, making it a cost-effective solution for large-scale HBM programmes. For example, recent methods allow the simultaneous analysis of multiple flame retardants in human samples, including PBDEs, HBCD and phosphorus-based flame retardants (Huang *et al*., 2017; Shi *et al*., 2013). Svarcova *et al*. (2019) developed methods for analysing the halogenated and phosphorus-based flame retardants in serum. These methods can handle different flame retardants and achieve high recovery rates (71–118%), enabling the analysis of many flame retardants at once and lowering costs by reducing the need for separate tests and by handling smaller sample sizes. Similarly, for phthalates, 16 phthalates and their metabolites, alongside DINCH and five of its metabolites, can be efficiently analysed in urine samples using one multi-analysis technique (Kasper-Sonnenberg, 2025).

By leveraging multi-analysis methods, HBM programmes can achieve more efficient and cost-effective assessments, supporting the broader objective of comprehensive environmental and health monitoring. For toxic metals, pesticides, PFAS and other groups of chemicals, the biomarkers under these groups can also be analysed using multiple methods.

4.3 Building on National and International Expertise

4.3.1 Building on international expertise, resources and infrastructure

Collaboration with global leaders in HBM will ensure the adoption of best practices, strengthen analytical capabilities and align Ireland's HBM efforts with international standards. Learning from HBM4EU and Ireland's collaboration with PARC, as well as the WHO European Environment and Health Process (EHP) Partnerships on the HBM Working Group (Dr Connolly is Ireland's appointed representative), can offer significant opportunities to strengthen Ireland's HBM capabilities by utilising well-established frameworks, methodologies and networks. These initiatives provide access to expert-led training sessions, workshops and technical exchanges, enabling Irish professionals to develop specialised expertise in critical areas such as laboratory quality assurance and control and chemical risk assessment. This collaborative engagement not only enhances the level of national expertise required for HBM but also lays a solid technical foundation that is essential for the sustainability and long-term success of Ireland's HBM programmes.

4.3.2 Coordinating and mapping the expertise, resources and infrastructure

A proactive step towards establishing an HBM programme would be to document the existing HBM capabilities in Ireland, including information on national laboratories (public and private), available equipment, biobanks and the technical expertise within the country, providing a comprehensive overview of Ireland's assets in terms of HBM studies. Encouraging collaboration among academic institutions, research centres and public health organisations can further bridge gaps in knowledge and expertise. Groups in Ireland have taken the first steps to coordinate efforts, including the Food Safety Authority of Ireland's Scientific Committee, which has formed the Total Diet Study and Biomarkers Working Group under the Chemical Safety Subcommittee, which has produced a list of appropriate and feasible biomarkers to support and enhance risk assessment for food safety in Ireland (FSAI, 2025b).

Furthermore, establishing a centre for excellence or a centre for HBM research in Ireland would be a significant step forward; such centres could serve as a focal point for advancing research, promoting collaboration and strengthening the country's capabilities in HBM, ultimately contributing to more effective public health and environmental policies.

Nationally, there is an immense resource in terms of laboratories, expertise and potential resources that could be utilised across the country, and the need to map and identify how these could be utilised collectively was emphasised as an emerging theme of the HBM4IRE World Café. Additionally, forming dedicated working groups to address critical aspects such as sample collection, data management and analysis can streamline the programme's implementation and ensure efficiency.

4.4 National Capacity Building

4.4.1 Enhancing national initiatives to advance human biomonitoring

Many countries throughout the world, such as the United States with the National Health and Nutrition Examination Survey (CDC, 2024) and Iceland with the National Diet Survey of Icelanders (Directorate of Health and Nutrition Research Unit, 2024), established their national HBM programmes in the beginning by coupling them with an already established survey. Similarly, non-EU countries like South Korea (Korea National Survey for Environmental Pollutants in the Human Body) and China (China National Human Biomonitoring) have developed globally important tools. In Ireland, we have the Healthy Ireland Survey, an annual survey that is conducted with a representative sample of the population living in Ireland, which could include an HBM element (Department of Health, 2024). For cohort-specific investigations, there is also the Irish Longitudinal Study on Ageing (Trinity College Dublin, 2019), which is a large-scale, nationally representative longitudinal study on ageing in Ireland, and the 'Growing Up in Ireland' national longitudinal study of children and young people, which, for over 17 years, has followed the progress of children throughout their childhood, into early adulthood and up to the present (Department of Children, Equality, Disability, Integration and Youth, 2024). The inclusion of HBM in such studies would entail collecting quantitative data on the exposures

that participants experience and enhance the dataset for more thorough investigations.

4.4.2 Analytical laboratory quality assurance and quality control

When analytical methods are being developed nationally for the analysis of HBM samples, it is essential to ensure that the analysis of the HBM samples is conducted to the highest levels of precision and accuracy, and it will be essential to prioritise QA and QC in HBM studies. There are external certification systems for the analysis of HBM samples in biological matrices. The German External Quality Assessment Scheme provides certification for occupational and environmental analysis in HBM samples and has participation from approximately 200 laboratories from more than 35 countries regularly participating (G-EQUAS, 2024). The Centre de Toxicologie du Québec in Canada also offers an external QA scheme in which laboratories can participate in evaluating the accuracy and precision of their analytical methods (INSPQ, 2024). There are also opportunities to participate in occasional programmes when they become available, similar to the schemes developed under HBM4EU and PARC, especially for emerging chemicals. If no certification system exists, for example for novel chemicals, then inter-laboratory comparisons can still be made with reliable laboratories to compare results and ensure the accuracy and precision of the testing.

4.4.3 Education and training in human biomonitoring

To ensure that we have the expertise required for a continuous national HBM programme, it would be essential that training be provided at different levels for different stakeholders. This could include university and third-level educational modules and programmes, industry training, “FAIR-ification” of data, and management and incorporation of HBM study results for national policy, as well as communication and dissemination of study results to a wide range of stakeholders.

4.5 Science to Policy

The necessity of bridging the science–policy gap has been emphasised. The science-to-policy initiative means using high-quality, robust scientific data from scientists that policymakers can utilise to support evidence-based decision-making (Kano and Hayashi, 2021; Oliver and Boaz, 2019; Phillips *et al*., 2020). It is important that the advancement of such an initiative be done through co-creation with policymakers, which was the objective of the HBM4IRE stakeholder forum. Meeting future initiatives’ challenges will necessitate a re-examination of the methods by which policies are designed, coordinated, implemented and evaluated, with input from a range of stakeholders; a sentiment that is echoed in the Organisation for Economic Co-operation and Development’s report *Strengthening Policy Development in the Public Sector in Ireland* (OECD, 2023). Such co-creation of future initiatives will ensure the maximisation of the impacts of such initiatives and their contribution to sustainability. The same report reflects on the strengthening of three pillars of policy development in Ireland: evidence, implementation and feasibility, and legitimacy (OECD, 2023).

For evidence, that report specifically stated a need for data to be utilised for foresight in policymaking, which is a huge strength of HBM as a tool for identifying early warning indicators of chemical exposures. Furthermore, it emphasised the importance of improving data sharing and strengthening collaborative partnerships with academia. For implementation, interdepartmental collaboration and user-centred approaches are encouraged to improve the impact of national initiatives, which is also proposed in this report, to develop an HBM steering group with a cross-department/-agency group. The need for public policies to reflect stakeholders’ and citizens’ interests was central to the legitimacy element, which is the focus of national HBM campaigns, to provide data on populations’ chemical exposures to assist with policymaking in order to safeguard the Irish population.

HBM studies could investigate the socio-economic impacts of chemical exposures, particularly among vulnerable populations. Strengthening collaborations between regulatory agencies, research institutions and institutes, and public health bodies can ensure that Ireland’s HBM programme remains adaptive and

responsive to evolving environmental and public health challenges. Continuous surveillance and periodic reassessments will be key to capturing emerging contaminants and informing evidence-based policy decisions.

The report also focused on how Ireland's public administration could benefit from data-sharing networks through external partnerships and how strengthening data skills across the civil service would allow Ireland to harness the potential of both data- and evidence-based decision-making. Ireland is in an excellent position for data sharing, both internally through the current initiative and externally through national partnerships with the PARC initiative and the WHO EHP Partnerships on HBM. Nationally, we need to build a policy capability infrastructure with the inclusion of cross-government collaboration, which includes frameworks and processes for evidence-based policies.

4.6 Discovery and Innovation for Human Biomonitoring

As it can take extensive research and time before chemicals become a concern, it is a necessity that all HBM programmes incorporate discovery and innovation for the development of new analytical methods for novel and emerging chemicals, for deriving HBM guidance values for chemical compounds, and for evaluating cumulative and aggregated exposures to chemicals.

In particular, the requirement for this aspect of the programme has been identified in studies on regrettable substitutions (i.e. when a chemical with an unknown or unforeseen hazard is used to replace a chemical identified as problematic), such as alternative plasticiser substitutions, and the increasing trend of such emerging compounds makes it essential to ensure that they do not result in adverse effects among the population (Vogel *et al*., 2023).

The inclusion of research and funding will also contribute to educating the next generation of scientists/researchers, which would build national expertise, especially for niche expertise in HBM.

5 Study Limitations and Future Prospects

This study provides valuable insights into Ireland's HBM programme, although a few limitations must be acknowledged. One key limitation is the sample size of the national survey, which included approximately 218 participants. Given Ireland's total population, this sample is not representative of national perception patterns for and public awareness of chemicals of concern. Future surveys could also consider strategies such as questionnaire simplification, adaptive questioning (where respondents see only relevant questions) or breaking the survey into shorter sections to improve completion rates further. In addition, it is important to note that the chemical priority lists established within this study were explicitly evaluated for HBM programmes. Not all substances/chemicals can be analysed using HBM analytical methods; thus, there may be chemicals of national concern not included in the national survey design and the chemicals list, as this study is focused on chemicals that HBM can analyse.

The study mapped priority lists, which relied on a robust review of HBM programmes and initiatives for prioritising the chemicals of concern. However, future periodic assessments should also include evaluation of new and emerging chemicals and their substitutes for inclusion in future HBM programme chemical priority lists. Additionally, categorising chemicals/biomarkers based on their regulatory status (e.g. restricted, emerging or still in use) across EU frameworks such as REACH, the POPs Regulation, the Water Framework Directive and food safety regulations could strengthen policy alignment. While mapping these against HBM-monitored substances was beyond the current scope of this work, dedicated policy research (e.g. via EPA Fast-Track to Policy funding) could systematically clarify exposure-related policy landscapes and identify regulatory gaps.

6 Conclusions

The project's ambition was to evaluate the feasibility of establishing a national HBM programme for Ireland to evaluate chemical exposures among the Irish population and assist with providing indications of chemical pollution. The study evaluated HBM programmes worldwide that have developed or are developing these initiatives with great success from Europe, Asia and the United States. Furthermore, it is currently an optimal time to establish such a programme, as HBM in Europe has made substantial progress over the past decade, especially with EU Horizon initiatives such as HBM4EU and PARC, which have developed harmonised protocols, questionnaires, and public outreach and dissemination material that is openly available for use.

Ireland has already demonstrated its commitment and ability to conduct such studies, from participating in the DEMOCOPHES project to involvement in more recent HBM4EU-aligned projects. Additionally, Ireland has recently joined the PARC initiative, which will contribute to the advancement of HBM and the next-generation risk assessment. Ireland's participation in this initiative requires the nation to contribute, but, more importantly, it provides phenomenal opportunities to access expertise from 28 other countries, over 200 institutions and over 1000 contributors to advance national ambitions. Ireland is also a member of the EHP Partnership on HBM for the WHO European Region (Dr Connolly is the Irish contact person), which is a permanent platform for exchange and collaboration in the field of HBM.

The development of an HBM4IRE national programme is an attainable ambition for Ireland, and would provide quantitative data for assessing total exposures to a chemical from various sources, both known and unknown, for evaluating a population's temporal changes, regional/population differences and "hotspots", and for identifying highly exposed or vulnerable groups. Furthermore, HBM can be used as an early warning system to detect new and emerging chemicals and as a vital tool for evaluating policy action effectiveness.

7 Recommendations

7.1 Recommendations

Developing a national structure approach would connect different domains, linking scientific evidence and risk assessment with the appropriate governance, legislation, capacity-building and regulatory frameworks. The recommendations are based on scientific evidence and input from expert stakeholders obtained during the HBM4IRE forum.

7.1.1 Recommendation 1: Develop a governance framework that works across silos and creates linkages at the local, national and EU levels

- Create a high-level national HBM Steering Committee that acts as a coordination mechanism for the national programmes, with a memorandum of understanding for all the committed parties that includes provision of finance, resources and expertise. Long-term ambitions would be to establish the Centre for Excellence in Human Biomonitoring Research in Ireland, which would significantly advance research, promote collaboration and enhance the country's HBM capabilities.
- Strengthen inter-institutional and inter-departmental collaboration by having relevant members of each contribute to the steering committee, which would support and provide general oversight of progress.
- Decide on the agenda/objectives and the milestones of progress for the committee and how these would contribute to addressing national and EU policy questions in relation to chemical pollution.
- Identify synergies across departments/agencies and map and support the sharing of infrastructure, expertise and good practices to ensure that sufficient support is provided to address local, regional and national requirements and to achieve the initiative's ambition.
- Have the national HBM Steering Committee supported by a national scientific committee with expertise in HBM, chemical regulation, analysis and risk assessment to ensure that QA and state-of-the-art methods are utilised in national campaigns.
- Ensure that the objectives/ambitions are adequately resourced and funded to achieve success and sustainability.

7.1.2 Recommendation 2: Strengthen the use of human biomonitoring data to inform policy

- Develop short-, medium- and long-term goals that match the national legislation priorities that cover chemical and environmental regulation, including REACH, which is covered under the Chemicals Act 2008 as amended, and Irish POPs and mercury regulations, and help deliver the EU priorities under initiatives such as the EU Chemicals Strategy for Sustainability Towards a Toxic-Free Environment, the European Green Deal and the Zero Pollution Action Plan.
- Utilise the chemical prioritisation strategy outlined, including the steps and the initial list, to evaluate the priority chemicals of concern to be included in the national HBM study and ensure that they are reviewed at regular intervals due to continuous changes in chemical use/production and legislation.
- During each "HBM cycle", review the goals and emerging priorities for inclusion of each cycle and for long-term time trend analysis.

7.1.3 Recommendation 3: Utilise international expertise, data and knowledge to advance the national agenda

- Major advancements are being made internationally via the HBM4EU, PARC and the WHO EHP Partnerships on the HBM Working Group; national policy should build on

existing mechanisms and expertise for national programmes.
- Adopt harmonised protocols, such as questionnaires, consent forms and sampling campaign protocols, which have been developed across Europe via the HBM4EU and PARC initiatives, nationally to ensure high-quality studies and comparability across EU Member States. Additionally, a national database compiling all relevant national and international HBM studies should be established. Data management should also adhere to the FAIR principles, ensuring that data is findable, accessible, interoperable and reusable.
- Engage cross-department/-agency support for sharing infrastructure, expertise and good practices to enhance the national programme's economic impact.
- As we progress with developing our national capacity, we should be utilising international expertise/services to complement our national capacities, including utilising internationally recognised and certified analytical laboratories to conduct analysis on biomarkers for national samples, which are not currently established in national laboratories.
- To ensure the highest standards of sample analysis, to ensure that all laboratories involved with the HBM sample analysis will have to undergo external review. This can be in the form of formal certification, if available, or inter-laboratory quality assurance/control (i.e. laboratory comparison).

7.1.4 Recommendation 4: Support education, training, development and data/ knowledge sharing nationally and internationally

- Integrate HBM principles at all levels of academic and professional training, where relevant, including the incorporation of these principles into multidisciplinary subjects (e.g. One Health approach, exposome, public health, environmental assessment).
- Promote public awareness of HBM and the positive outcomes from previous campaigns/ initiatives, which can include public dissemination material already developed by EU initiatives (e.g. HBM4EU, PARC).

7.1.5 Recommendation 5: Integrate the requirements for discovery and innovation in human biomonitoring through research and development

- Incorporate resources for innovation and discovery in HBM, which includes growing capacity within the country, the development of novel analytical methods, the analysis of samples for novel and emerging chemicals and evaluating exposure scenarios (i.e. occupational, environmental, residential).
- Coordinate with scientists to establish/identify emerging issues and novel areas of interest (e.g. investigating novel chemicals of concern, unexplored occupational exposures).

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Appendix 1 Details of the Top 10 Chemicals

A1 Metals (Lead, Cadmium, Mercury, Arsenic, Chromium VI)

Lead, cadmium, mercury, arsenic and chromium VI are significant environmental and health concerns due to their toxic effects and widespread presence. Lead exposure, primarily from contaminated food and water and old paint, is regulated under various EU directives and regulations, including REACH (Regulation (EC) No 1907/2006), the CLP Regulation (Regulation (EC) No 1272/2008) and the Drinking Water Directive (Directive (EU) 2020/2184). Blood lead levels are the main biomarker for monitoring exposure. Exposure to lead mainly occurs through the consumption of food and water, particularly when lead pipes are used. Additional sources include tobacco smoke, household dust contaminated with old paint residues and lead-containing particles released during waste burning. Lead is registered under REACH and classified as a substance of very high concern. It is restricted in Annex XVII and subject to EU harmonised classification under the CLP Regulation. Regulation (EC) No 1881/2006 sets maximum lead levels for food, while Directive 98/24/EC regulates occupational exposure. The Drinking Water Directive limits lead in water to 10 µg/L, and Directive 2008/50/EC sets a 0.5 µg/m³ limit for lead in air. Soil lead levels are regulated by Directive 86/278/EEC, with limits ranging from 50–300 mg/kg in soil to 750–1200 mg/kg in agricultural sludge (HBM4EU, 2022). In Ireland, although leaded petrol has been phased out and regulations around lead-based paints have improved, legacy contamination still poses risks, particularly in older housing stock and in soil. The inclusion of lead in this top 10 list aligns with international efforts to monitor and reduce lead exposure, highlighting the need for continued vigilance, especially in urban areas and communities with historical lead contamination. Blood lead levels are the primary biomarker for monitoring lead exposure; however, additional biomarkers may be required to distinguish between recent and long-term exposure (Barbosa *et al*., 2005). Other biological matrices include urine, bone and saliva, which can also be used for detecting lead (Klotz and Göen, 2017).

Cadmium, found in industrial emissions and tobacco smoke, is linked to kidney damage and cancer, with regulations covering its presence in food, cosmetics and industrial emissions. The manufacture, use and sale of cadmium and its compounds are restricted under REACH, and cadmium is subject to EU classification under the CLP Regulation. Cadmium limits are established for food items under Regulation (EU) 2021/1323, for cosmetics under Regulation (EC) No 1223/2009, and for toys, electrical equipment and batteries through relevant directives. Cadmium is also classified as a priority hazardous substance under the Water Framework Directive (Directive 2000/60/EC), with a drinking water limit of 5 µg/L. The National Emissions reduction Commitments Directive (Directive (EU) 2016/2284) mandates reporting of cadmium emissions, and the Industrial Emissions Directive (Directive 2010/75/EU) regulates industrial cadmium emissions (HBM4EU, 2022). Similarly, occupational exposure limits are set under the Carcinogens and Mutagens Directive (Directive 2004/37/EC). Cadmium is frequently assessed in HBM studies, with whole blood and urine being the preferred biological matrices. Urinary cadmium serves as an indicator of cumulative exposure and cadmium accumulation in the kidneys, whereas blood cadmium levels provide insight into more recent exposure. Chromium is typically measured in urine; however, this method has certain limitations, including the metal's short biological half-life.

The EU and its Member States are parties to the Minamata Convention on Mercury (2017), which aims to reduce mercury emissions and protect human health and the environment. This was transposed into EU law via Regulation (EU) 2017/852. Mercury use is also restricted under REACH and classified under the CLP Regulation. In addition, it is a priority substance under the Water Framework Directive, and the Drinking Water Directive limits its concentration in water to 1 µg/L. The National Emissions reduction Commitments Directive (Directive EU 2016/2284) regulates emissions, while Directive 2010/75/EU sets limits for industrial emissions from waste incineration and wastewater discharges.

Mercury content in fish is regulated under Regulation (EC) No 1881/2006, with specific limits for different species. Regulation (EU) 2017/852 restricts mercury in dental amalgam, while Regulation (EC) No 1223/2009 bans mercury in cosmetics. Directive 2009/48/EC sets limits for mercury in toys, and Directive 2006/66/EC prohibits its use in batteries. The Restriction of Hazardous Substances Directive (Directive 2002/95/EC) bans mercury use in most electrical equipment. An occupational exposure limit for mercury is also set under Directive 2009/161/EU. In Ireland, mercury is of concern due to its presence in industrial emissions, particularly from coal burning, and its accumulation in aquatic food chains, particularly in fish. Monitoring mercury is critical, as it can accumulate in human tissues, leading to neurological damage. The HBM4IRE programme aims to track levels of mercury exposure in the population, with a particular focus on vulnerable groups.

Mercury biomarkers, such as levels in hair, blood and urine, are key for assessing exposure and health risks. Cord blood mercury level indicates prenatal methylmercury exposure (Grandjean *et al*., 2005), while urine level reflects elemental mercury exposure and hair levels reflect dietary methylmercury intake (Horvat *et al*., 2011). Blood analysis can differentiate between elemental and methylmercury exposure based on mercury distribution in red blood cells and plasma.

Arsenic contamination in drinking water and food, particularly rice and seafood, poses a known health risk globally. In Ireland, while the levels of arsenic in drinking water are regulated, the potential for exposure through environmental sources, such as contaminated soil and groundwater, continues to warrant attention. Arsenic's inclusion in the priority list reflects its ongoing public health significance and the need for its consistent monitoring in food and water supplies. Arsenic is registered under REACH with additional restrictions in Annex XVII. It is classified under the CLP Regulation. Maximum arsenic levels in certain foods are set by Regulation (EU) 2015/1006 (e.g. rice waffles at 0.30 µg/kg). The Drinking Water Directive limits arsenic in drinking water to 10 µg/L. Directive (EU) 2016/2284 requires Member States to report arsenic emissions. Directive (EU) 2019/983 sets an occupational exposure limit for arsenic inhalation at 0.01 mg/m³, applicable from July 2023 in copper smelting (HBM4EU, 2022).

Biomonitoring for arsenic exposure primarily utilises urine, hair, nail and blood samples (Horvat *et al*., 2011; Orloff *et al*., 2009). Urine analysis is preferred for recent exposure assessments, with established reference ranges for the US population (Orloff *et al*., 2009). Hair and nail analyses are valuable for chronic exposure evaluation (Orloff *et al*., 2009). Biomarkers include total arsenic in hair, nails, blood and urine, with speciation necessary for accurate risk assessment due to varying toxicity of arsenic compounds (Horvat *et al*., 2011; Pandey *et al*., 2007). These metals are subject to strict EU regulations to minimise exposure and protect public health. Inductively coupled plasma atomic emission spectroscopy is a preferred method of analysis that uses multi-analytes.

A2 Plasticisers (Phthalates)

Phthalates are widely used in plastics but are of concern for their endocrine-disrupting effects. Plasticisers, especially phthalates, are widely used to increase the flexibility of plastics. They are found in numerous consumer products, but many have given rise to health concerns due to their endocrine-disrupting effects, and they are listed as substances of very high concern under REACH. The EU has implemented stringent restrictions on several phthalates due to their reproductive toxicity. DEHP, DBP and BBP were banned in all toys and childcare items in 2005, with diisononyl phthalate, diisodecyl phthalate and di-n-octyl phthalate restricted in mouthable toys (Hilemàn, 2005). By 2017, BBP, DEHP, DBP and diisobutyl phthalate had been further limited to concentrations below 0.1% in consumer products under REACH (Erickson, 2017). In 2018, the EU unanimously approved a broader ban on these phthalates in consumer goods and indoor environments, effective 18 months after adoption (Erickson, 2018). These measures targeted items such as toys, sports equipment and flooring, prioritising public health and child safety.

The approach used for analysing phthalate and DINCH metabolites is LC-MS/MS, a method that delivers the sensitivity necessary for biomonitoring in the general population. This technique enables the simultaneous identification of all key metabolites using a single LC-MS/MS set-up, ensuring both comprehensive detection and analytical efficiency. Although phthalates and DINCH can be analysed in urine, serum and milk,

urine is the preferred matrix for biomonitoring due to its strong correlation with metabolism and elimination (Esteban and Castaño, 2009; Vorkamp *et al*., 2021).

In the HBM4IRE project, specific plasticisers have been prioritised for monitoring based on their frequency of appearance in studies by PARC, HBM4IRE and other national HBM programmes, highlighting their global significance. Among the top priority plasticisers, biomarkers like monoethyl phthalate, monobenzyl phthalate and mono-n-butyl phthalate rank highly due to their common detection in HBM studies. These chemicals are metabolites of other widely used phthalates and are frequently found in products like fragrances and household items. Monoisononyl phthalate and mono(2-ethyl-5-oxohexyl) phthalate are also of concern due to their widespread use in consumer goods and their presence in human samples. Other notable plasticisers such as DEHP and monocyclohexyl phthalate continue to be prioritised due to their toxicity, especially regarding reproductive and developmental health. Additionally, chemicals like cyclohexane-1,2-dicarboxylic monohydroxy-isononyl ester are emerging as concerns in biomonitoring due to their increasing use and persistence.

A3 Bisphenols

Bisphenols are a group of chemicals widely used in the production of plastics, resins and coatings that are of growing concern due to their potential endocrine-disrupting properties. Among the bisphenols, BPA is the most well known; it has been extensively studied for its harmful health effects and is prioritised by various HBM programmes. Bisphenols, including BPA, are not regulated under international conventions but are recognised as endocrine-disrupting chemicals. BPA has been identified as a substance of very high concern under REACH due to its endocrine-disrupting effects and has been restricted in thermal paper since 2016, with further restrictions under consideration. In 2022, the European Chemicals Agency assessed 148 bisphenols, recommending restrictions for over 30 due to hormonal or reprotoxic effects. Bisphenols like BPA and BPS are classified under the CLP Regulation. BPA is prohibited in food packaging for children, with migration limits in food contact plastics, and has been banned in infant bottles since 2011. It is also regulated in toys and medical devices and is under review for inclusion in the Water Framework Directive with a proposed drinking water limit of 0.01 µg/L. Bisphenols are not covered by EU air quality or industrial emissions laws, but an occupational exposure limit for BPA of 2 mg/m³ has been defined under EU directives (HBM4EU, 2022).

Urine was the preferred matrix for studying exposure in the general population. While techniques are available to analyse bisphenols in other HBM matrices, these studies are typically focused on specific populations or research questions. However, urine analysis alone is considered insufficient to evaluate the full toxicokinetics of bisphenols. The selected analytical methods rely on LC-MS/MS, combined with various extraction and clean-up techniques (Vandenberg *et al*., 2014; Vorkamp *et al*., 2021).

Under the HBM4IRE project, BPA is a priority chemical with the cumulative score of 11.5, reflecting its significant presence in HBM studies and its widespread use in products like polycarbonate plastics and epoxy resins. Other bisphenols such as BPF and BPS also emerge as priority chemicals in the study, with overall scores of 9 and 8.5, respectively. These compounds are often used as alternatives to BPA, but concerns about their toxicity and potential for endocrine disruption persist. BPB, bisphenol AF, bisphenol AP and bisphenol Z, each scoring 5, are less frequently detected and prioritised but still pose health risks due to their chemical similarity to BPA and their increasing use in various industrial and consumer products.

A4 Pesticides

Due to Ireland's strong reliance on agriculture, there is increased potential for pesticide residues to enter soil, water and food. However, these risks are routinely assessed through national and EU monitoring programmes, including those led by the Department of Agriculture, Food and the Marine (e.g. Pesticides Residues in Food[2]) and the EPA (e.g. Water Quality in Ireland, Chapter 5 on chemical status of surface

2 https://www.pcs.agriculture.gov.ie/media/pesticides/content/foodsafety/pesticideresiduesinfoodfrom2020/2021AnnualReportPesticideResiduesinFood060923.pdf (accessed 5 June 2025).

waters covering PFOS monitoring[3] and Drinking Water Quality in Public Supplies[4]) and EU bodies and laws, such as EFSA (for food), the Water Framework Directive (for surface water) and the Drinking Water Directive (for drinking water), to ensure compliance with regulatory standards and to protect public health. The EU's Farm to Fork Strategy aims to cut chemical pesticide use by 50% by 2030. HBM4IRE prioritises pesticides like glyphosate (and its metabolite AMPA) score the highest due to their environmental persistence. Other priorities include 3-phenoxybenzoic acid, cyfluthrin and deltamethrin, which are known for their neurotoxic and endocrine-disrupting effects. Organophosphates like dimethylphosphate and chlorpyrifos are also highlighted, alongside persistent organochlorines like DDT and hexachlorobenzene, which bioaccumulate in food chains. As such, HBM4IRE has prioritised a range of pesticides and their metabolites, with an emphasis on their prevalence in Irish agricultural practices and the potential for exposure through dietary intake, water contamination and occupational exposure among farmers.

A5 Flame Retardants

Flame retardants are chemicals widely used in various products, including electronics, textiles and furniture, to prevent or delay the spread of fire. However, concerns have been raised about their environmental persistence and potential toxicity, leading to their prioritisation in global HBM programmes, including HBM4IRE.

EU regulations restrict certain flame retardants, such as PBDEs and HBCDD, under the Stockholm Convention. Dechlorane plus is under review for risk management. Many alternative flame retardants are registered under REACH, but several remain unregulated. Most flame retardants lack established safety limits or usage data. Of the 62 flame retardants identified by HBM4EU, only a few are registered under REACH, with many unregistered or listed under the Community Rolling Action Plan due to high use. EFSA is updating its scientific opinions on brominated flame retardants based on new data (HBM4EU, 2022).

Among the priority flame retardants identified, several brominated diphenyl ethers are particularly notable for their inclusion across multiple HBM programmes and HBM4IRE. These chemicals, such as BDE-47, BDE-99 and BDE-153 are highly prioritised as they have been widely used as flame retardants in a variety of consumer goods, leading to their persistence in the environment and accumulation in human tissues. Other notable flame retardants, like BDE-28 and BDE-100, also receive attention due to their widespread use and potential health risks. Their cumulative scores of 4 highlight their relevance in human exposure monitoring efforts. Additionally, HBCDD, which is used in expanded polystyrene and other materials, is listed as a priority flame retardant, with a score of 4 in several HBM programmes, emphasising its significance in biomonitoring efforts.

A6 Perfluoroalkyl and Polyfluoroalkyl Substances

PFAS are synthetic chemicals found in non-stick cookware, water-repellent clothing, textiles and firefighting foams that are linked to bioaccumulation and health risks like liver damage and immune disruption. EU regulations ban several PFAS, including PFOA and PFOS, while others are under restriction. HBM4IRE focuses on high-priority chemicals like PFOA, PFOS and PFNA, with scores reflecting their widespread presence. Shorter-chain PFAS like PFBA and PFHpA are also monitored due to persistent contamination risks. These chemicals are of particular concern due to their environmental persistence, bioaccumulation and potential adverse health effects, such as liver damage, immune system disruption and developmental effects. The prioritisation of PFAS in the HBM4IRE project reflects their widespread presence and potential health risks.

The EU Chemicals Strategy for Sustainability includes actions to reduce PFAS' exposure throughout their lifecycle. Under the Stockholm Convention, PFOS and PFOA are globally banned, and PFHxS is also listed. The POPs Regulation ((EU) 2019/1021) enforces these bans in the EU. REACH restricts several PFAS, including PFOA and PFHxS, and lists

3 https://www.epa.ie/publications/monitoring--assessment/freshwater--marine/water-quality-in-ireland-2016--2021-.php (accessed 5 June 2025).

4 https://www.epa.ie/publications/compliance--enforcement/drinking-water/annual-drinking-water-reports/drinking-water-quality-in-public-supplies-2023.php (accessed 5 June 2025).

others as substances of very high concern. A broad restriction on all PFAS is being prepared, along with specific bans on their use in firefighting foams and textiles. The CLP Regulation requires harmonised classification for several PFAS. HBM values for PFOA and PFOS are set by the German Commission but are not legally binding. Food safety regulations prohibit PFOA in food contact materials, and EFSA has set a tolerable weekly intake level for four PFAS. In cosmetics, several PFAS are banned. PFOS and PFOA are listed as priority hazardous substances in the Water Framework Directive, and over 70 PFAS are covered in the Drinking Water Directive. Several PFAS are classified as hazardous waste under the Waste Framework Directive. The Chemical Agents Directive also covers 10 individual PFAS for occupational safety (HBM4EU, 2022).

Among the priority PFAS, PFOA is the most widely prioritised in the HBM programmes. PFOA, in both its linear and branched forms, has been used in a wide range of industrial applications, contributing to its persistent presence in the environment and HBM samples. Similarly, PFOS and PFNA follow closely behind in the list of HBM priority chemicals. These chemicals, commonly found in firefighting foams and water-repellent products, have been widely prioritised in both EU and non-EU countries. Other notable PFAS in the priority list include PFHxS, perfluoro-n-undecanoic acid and perfluoro-n-decanoic acid, all of which contribute to the ongoing concerns surrounding PFAS contamination. These chemicals are significant contributors to the body of research on PFAS exposure and its potential health impacts. In addition, perfluoro-1-butanesulfonate and other shorter-chain PFAS compounds, such as PFHpA and PFBA, are also prioritised by the HBM programmes and EU initiatives. As Ireland develops its HBM programme, these priority PFAS will remain central to the assessment of environmental and human exposure, and their ongoing monitoring will help inform regulatory actions aimed at reducing the potential risks posed by these persistent pollutants.

A7 Polycyclic Aromatic Hydrocarbons

PAHs are a group of organic compounds containing multiple aromatic rings that are produced during the incomplete combustion of organic matter. PAHs are primarily used in manufacturing processes for dyes, pigments, plastics and pesticides. However, PAHs are of significant concern in vehicle exhaust, particularly from diesel engines, due to their association with respiratory issues, cardiovascular disease and carcinogenic properties. The identification of priority PAHs in the HBM4IRE project reflects their importance in HBM and widespread presence in both environmental and biological samples. The EU has implemented various policies to reduce PAH exposure, including REACH restrictions on extruder oils used in tyre production. PAHs are also limited in rubber and plastic components of certain consumer goods, and the eight carcinogenic PAHs are banned in childcare articles and toys. Anthracene oil and coal tar pitch require authorisation under REACH. Additionally, PAHs are regulated as air pollutants under the Ambient Air Quality Directive and the National Emissions reduction Commitments Directive (HBM4EU, 2022). Urine is the preferred matrix for analysing PAHs due to its ability to minimise contamination risks and provide reliable measurements of hydroxylated metabolites, which are key biomarkers of PAH exposure. High-performance LC-MS/MS is commonly used for these analyses, ensuring sensitivity and accuracy. While parent PAHs have also been monitored in serum, this matrix is less suitable for biomonitoring due to significant inter-individual variability in PAH metabolism and challenges with contamination (Vorkamp *et al*., 2021). Among the top-priority PAHs, 2-naphthol, a metabolite of naphthalene, has the highest cumulative score of 5. Naphthalene and its metabolites, including 1-naphthol, are commonly found in air, tobacco smoke and automotive exhaust. Similarly, 1-hydroxy-pyrene, a metabolite of pyrene, is also a priority PAH with a cumulative score of 5. Pyrene, found in combustion processes, contributes to PAH exposure, and its metabolites play a role in assessing the level of environmental and occupational exposure. Other PAHs with significant priority include 2-hydroxy-fluorene, 1-hydroxyphenanthrene and 2-hydroxyphenanthrene, all of which scored a 4. These metabolites are indicative of exposure to their parent compounds, fluorene and phenanthrene, which are common in industrial and environmental pollution. Their presence in human samples signals potential exposure to carcinogenic PAHs. Several other PAHs, including 3-hydroxy-fluorene, 1-naphthol and 3-hydroxyphenanthrene, are also identified as priority substances.

A8 Persistent Organic Pollutants

POPs are toxic chemicals that persist in the environment, bioaccumulate through the food chain and pose significant health risks. These include substances like DDT, PCBs and dioxins, which are regulated under international agreements like the Stockholm Convention. POPs are linked to cancer, reproductive harm and endocrine disruption. HBM programmes monitor these substances to assess human exposure and guide regulatory actions.

A9 Volatile Organic Compounds

VOCs are a group of chemicals that easily evaporate into the air, contributing to air pollution and health issues such as respiratory problems and cancer. Common VOCs include benzene, formaldehyde and toluene, which are found in paints, solvents and vehicle emissions. HBM programmes focus on VOCs to evaluate their exposure risks and impact on human health, especially in indoor environments.

The EU regulates VOCs through multiple frameworks to minimise their impact on air quality, human health and the environment. The Industrial Emissions Directive and the Solvent Emissions Directive (Directive 1999/13/EC) set emission limits for industrial VOC sources, while Directive 2004/42/CE restricts VOC content in paints and varnishes. The Ambient Air Quality Directive (Directive 2008/50/EC) establishes air quality standards for VOC-related pollutants, and REACH ensures their safe use. Additionally, the Carcinogens, Mutagens or Reprotoxic substances Directive (Directive 2004/37/EC) addresses workplace exposure, the Fuel Quality Directive (Directive 2009/30/EC) regulates VOC emissions from fuels, and the Ecodesign Directive (Directive 2009/125/EC) promotes environmentally friendly products. VOC contamination in water is monitored under the Water Framework Directive. Together, these regulations provide a comprehensive approach to VOC management in the EU.

A10 UV Filters

UV filters are chemicals used in sunscreens, cosmetics and personal care products to protect skin from harmful UV radiation. Common UV filters analysed in HBM programmes are benzophenone-3, also known as oxybenzone, and 3-(4-methylbenzylidene)-camphor, both of which are widely used in sunscreens and personal care products to protect against harmful UV radiation. Benzophenone and its derivatives, including benzophenone-1 and benzophenone-2, are also prevalent in cosmetics, plastics and packaging for their UV-absorbing properties. Consequently, these chemicals have been prioritised in initiatives like HBM4IRE and PARC and several other European HBM programmes.

Several policy measures in the EU regulate benzophenones to mitigate human exposure and manage associated risks across the chemicals, consumer products, environmental and occupational sectors. Under REACH, benzophenones are subject to registration and risk assessment, while the CLP Regulation mandates harmonised classification and labelling. The Cosmetics Regulation (Regulation (EC) No 1223/2009) limits benzophenone-3 concentrations to 6% in sunscreen products and 0.5% in other cosmetic products. Additionally, Regulation 2002/72/EC governs plastic materials in contact with food, although there is no specific consumer product legislation beyond cosmetics. Environmentally, benzophenones may be indirectly covered by the Pregnant Workers Directive (Directive 92/85/EEC), which ensures workplace protections for pregnant employees exposed to hazardous chemicals. While these regulations provide a foundation for managing benzophenones, gaps remain in direct environmental policies and broader consumer product regulations, highlighting the need for further legislative advancements.

This initial list of priority chemicals for the HBM4IRE programme represents a thoughtful synthesis of information from multiple sources, including HBM4EU, the PARC initiative and national HBM programmes worldwide. The list will continue to evolve further and will remain responsive to emerging evidence on chemical exposure and its impacts on public health. By focusing on chemicals with high environmental persistence, bioaccumulation potential and harmful health effects, Ireland will take a proactive approach to safeguarding its population from the risks of chemical exposure.

Abbreviations

AMPA	Aminomethylphosphonic acid
BBP	Benzyl butyl phthalate
BPA	Bisphenol A
BPB	Bisphenol B
BPF	Bisphenol F
BPS	Bisphenol S
CLP	Classification, Labelling and Packaging of Chemicals
COPHES	Consortium to Perform Human Biomonitoring on a European Scale
DBP	Dibutyl phthalate
DDT	Dichlorodiphenyltrichloroethane
DEHP	Di(2-ethylhexyl) phthalate
DEMOCOPHES	Demonstration of a Study to Coordinate and Perform Human Biomonitoring on a European Scale
DINCH	1,2-cyclohexane dicarboxyllic acid diisononyl ester
EHP	European Environment and Health Process
FAIR	Findable, accessible, interoperable and reusable
HBCDD	Hexabromocyclododecane
HBM	Human biomonitoring
HBM4EU	Human Biomonitoring for Europe
HBM4IRE	Human Biomonitoring for Ireland
LC-MS/MS	Liquid chromatography-tandem mass spectrometry
NHANES	National Health and Nutrition Examination Survey
PAH	Polycyclic aromatic hydrocarbon
PARC	Partnership for the Assessment of the Risk from Chemicals
PBDE	Polybrominated diphenyl ether
PCB	Polychlorinated biphenyl
PFAS	Per- and polyfluoroalkyl substances
POPs	Persistent organic pollutants
QA	Quality assurance
QC	Quality control
REACH	Regulation on the Registration, Evaluation, Authorisation and Restriction of Chemicals
VOC	Volatile organic compound
WHO	World Health Organization

An Ghníomhaireacht Um Chaomhnú Comhshaoil

Tá an GCC freagrach as an gcomhshaol a chosaint agus a fheabhsú, mar shócmhainn luachmhar do mhuintir na hÉireann. Táimid tiomanta do dhaoine agus don chomhshaol a chosaint ar thionchar díobhálach na radaíochta agus an truaillithe.

Is féidir obair na Gníomhaireachta a roinnt ina trí phríomhréimse:

Rialáil: Rialáil agus córais chomhlíonta comhshaoil éifeachtacha a chur i bhfeidhm, chun dea-thorthaí comhshaoil a bhaint amach agus díriú orthu siúd nach mbíonn ag cloí leo.

Eolas: Sonraí, eolas agus measúnú ardchaighdeáin, spriocdhírithe agus tráthúil a chur ar fáil i leith an chomhshaoil chun bonn eolais a chur faoin gcinnteoireacht.

Abhcóideacht: Ag obair le daoine eile ar son timpeallachta glaine, táirgiúla agus dea-chosanta agus ar son cleachtas inbhuanaithe i dtaobh an chomhshaoil.

I measc ár gcuid freagrachtaí tá:

Ceadúnú

- Gníomhaíochtaí tionscail, dramhaíola agus stórála peitril ar scála mór;
- Sceitheadh fuíolluisce uirbigh;
- Úsáid shrianta agus scaoileadh rialaithe Orgánach Géinmhodhnaithe;
- Foinsí radaíochta ianúcháin;
- Astaíochtaí gás ceaptha teasa ó thionscal agus ón eitlíocht trí Scéim an AE um Thrádáil Astaíochtaí.

Forfheidhmiú Náisiúnta i leith Cúrsaí Comhshaoil

- Iniúchadh agus cigireacht ar shaoráidí a bhfuil ceadúnas acu ón GCC;
- Cur i bhfeidhm an dea-chleachtais a stiúradh i ngníomhaíochtaí agus i saoráidí rialáilte;
- Maoirseacht a dhéanamh ar fhreagrachtaí an údaráis áitiúil as cosaint an chomhshaoil;
- Caighdeán an uisce óil phoiblí a rialáil agus údaruithe um sceitheadh fuíolluisce uirbigh a fhorfheidhmiú
- Caighdeán an uisce óil phoiblí agus phríobháidigh a mheasúnú agus tuairisciú air;
- Comhordú a dhéanamh ar líonra d'eagraíochtaí seirbhíse poiblí chun tacú le gníomhú i gcoinne coireachta comhshaoil;
- An dlí a chur orthu siúd a bhriseann dlí an chomhshaoil agus a dhéanann dochar don chomhshaol.

Bainistíocht Dramhaíola agus Ceimiceáin sa Chomhshaol

- Rialacháin dramhaíola a chur i bhfeidhm agus a fhorfheidhmiú lena n-áirítear saincheisteanna forfheidhmithe náisiúnta;
- Staitisticí dramhaíola náisiúnta a ullmhú agus a fhoilsiú chomh maith leis an bPlean Náisiúnta um Bainistíocht Dramhaíola Guaisí;
- An Clár Náisiúnta um Chosc Dramhaíola a fhorbairt agus a chur i bhfeidhm;
- Reachtaíocht ar rialú ceimiceán sa timpeallacht a chur i bhfeidhm agus tuairisciú ar an reachtaíocht sin.

Bainistíocht Uisce

- Plé le struchtúir náisiúnta agus réigiúnacha rialachais agus oibriúcháin chun an Chreat-treoir Uisce a chur i bhfeidhm;
- Monatóireacht, measúnú agus tuairisciú a dhéanamh ar chaighdeán aibhneacha, lochanna, uiscí idirchreasa agus cósta, uiscí snámha agus screamhuisce chomh maith le tomhas ar leibhéil uisce agus sreabhadh abhann.

Eolaíocht Aeráide & Athrú Aeráide

- Fardail agus réamh-mheastacháin a fhoilsiú um astaíochtaí gás ceaptha teasa na hÉireann;
- Rúnaíocht a chur ar fáil don Chomhairle Chomhairleach ar Athrú Aeráide agus tacaíocht a thabhairt don Idirphlé Náisiúnta ar Ghníomhú ar son na hAeráide;
- Tacú le gníomhaíochtaí forbartha Náisiúnta, AE agus NA um Eolaíocht agus Beartas Aeráide.

Monatóireacht & Measúnú ar an gComhshaol

- Córais náisiúnta um monatóireacht an chomhshaoil a cheapadh agus a chur i bhfeidhm: teicneolaíocht, bainistíocht sonraí, anailís agus réamhaisnéisiú;
- Tuairiscí ar Staid Thimpeallacht na hÉireann agus ar Tháscairí a chur ar fáil;
- Monatóireacht a dhéanamh ar chaighdeán an aeir agus Treoir an AE i leith Aeir Ghlain don Eoraip a chur i bhfeidhm chomh maith leis an gCoinbhinsiún ar Aerthruailliú Fadraoin Trasteorann, agus an Treoir i leith na Teorann Náisiúnta Astaíochtaí;
- Maoirseacht a dhéanamh ar chur i bhfeidhm na Treorach i leith Torainn Timpeallachta;
- Measúnú a dhéanamh ar thionchar pleananna agus clár beartaithe ar chomhshaol na hÉireann.

Taighde agus Forbairt Comhshaoil

- Comhordú a dhéanamh ar ghníomhaíochtaí taighde comhshaoil agus iad a mhaoiniú chun brú a aithint, bonn eolais a chur faoin mbeartas agus réitigh a chur ar fáil;
- Comhoibriú le gníomhaíocht náisiúnta agus AE um thaighde comhshaoil.

Cosaint Raideolaíoch

- Monatóireacht a dhéanamh ar leibhéil radaíochta agus nochtadh an phobail do radaíocht ianúcháin agus do réimsí leictreamaighnéadacha a mheas;
- Cabhrú le pleananna náisiúnta a fhorbairt le haghaidh éigeandálaí ag eascairt as taismí núicléacha;
- Monatóireacht a dhéanamh ar fhorbairtí thar lear a bhaineann le saoráidí núicléacha agus leis an tsábháilteacht raideolaíochta;
- Sainseirbhísí um chosaint ar an radaíocht a sholáthar, nó maoirsiú a dhéanamh ar sholáthar na seirbhísí sin.

Treoir, Ardú Feasachta agus Faisnéis Inrochtana

- Tuairisciú, comhairle agus treoir neamhspleách, fianaise-bhunaithe a chur ar fáil don Rialtas, don tionscal agus don phobal ar ábhair maidir le cosaint comhshaoil agus raideolaíoch;
- An nasc idir sláinte agus folláine, an geilleagar agus timpeallacht ghlan a chur chun cinn;
- Feasacht comhshaoil a chur chun cinn lena n-áirítear tacú le hiompraíocht um éifeachtúlacht acmhainní agus aistriú aeráide;
- Tástáil radóin a chur chun cinn i dtithe agus in ionaid oibre agus feabhsúchán a mholadh áit is gá.

Comhpháirtíocht agus Líonrú

- Oibriú le gníomhaireachtaí idirnáisiúnta agus náisiúnta, údaráis réigiúnacha agus áitiúla, eagraíochtaí neamhrialtais, comhlachtaí ionadaíocha agus ranna rialtais chun cosaint chomhshaoil agus raideolaíoch a chur ar fáil, chomh maith le taighde, comhordú agus cinnteoireacht bunaithe ar an eolaíocht.

Bainistíocht agus struchtúr na Gníomhaireachta um Chaomhnú Comhshaoil

Tá an GCC á bainistiú ag Bord lánaimseartha, ar a bhfuil Ard-Stiúrthóir agus cúigear Stiúrthóir. Déantar an obair ar fud cúig cinn d'Oifigí:

1. An Oifig um Inbhunaitheacht i leith Cúrsaí Comhshaoil
2. An Oifig Forfheidhmithe i leith Cúrsaí Comhshaoil
3. An Oifig um Fhianaise agus Measúnú
4. An Oifig um Chosaint ar Radaíocht agus Monatóireacht Comhshaoil
5. An Oifig Cumarsáide agus Seirbhísí Corparáideacha

Tugann coistí comhairleacha cabhair don Ghníomhaireacht agus tagann siad le chéile go rialta le plé a dhéanamh ar ábhair imní agus le comhairle a chur ar an mBord.

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