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Insights from an invited expert panel using a World Café: Developing a national policy for a human biomonitoring programme

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ABSTRACT

Human biomonitoring (HBM) is a powerful tool for quantifying internal chemical levels via biological samples such as blood and urine. Between 2000 and 2017, global synthetic chemical production doubled from approximately 1.15 billion tonnes to 2.3 billion tonnes, with this trend continuing to increase. There has been an extensive expansion of national HBM programmes to evaluate actual chemical exposures and safeguard their citizens.

A key factor in the development of HBM is to include policymakers and to utilise HBM data for policy impact. This study, part of the HBM4IRE (Human Biomonitoring for Ireland) feasibility study, employed a World Café approach for engaging 25 stakeholders from government agencies, industry, and academia to co-create a national HBM roadmap. Using a critical realist approach and thematic analysis of qualitative data, four key themes emerged from the discussion: (1) targeted HBM for exposure hotspots, (2) mapping HBM to EU and National policy frameworks, (3) monitoring chemical exposures as an early warning system, and (4) aligning HBM with national legislative needs.

Results highlight HBM's critical role in identifying at-risk groups (such as workers in high-exposure industries, children exposed to recycled materials like playground tyres) and validating policy effectiveness (e.g., lead restriction impacts). It also highlighted challenges such as data gaps, high costs, and limited baseline information. Study participants expressed a need for a governance framework, including a national HBM Steering Committee and inter-institutional collaboration, to bridge science-to-policy gaps, offering a scalable model for other nations to enhance chemical risk management, ensure regulatory compliance, and strengthen public health protection.

Overall, stakeholders expressed a high interest and strong willingness in establishing a national HBM programme in Ireland, viewing this as an opportune time for Ireland to implement such a system. The approach adopted for this study could be utilised to engage different stakeholders across an array of relevant topics. Given its valuable outcomes, the HBM4IRE World Café approach has demonstrated that it can serve as a model for other countries to build consensus, identify gaps, and foster stakeholder ownership in establishing long-term and sustainable national HBM programmes.

1. Introduction

People can be exposed to chemicals in occupational and environmental settings, including through the use of consumer products, dietary intake, and dermal or inhalation exposure from chemical pollutants (European Environment Agency, 2025). Chemical exposures are a prominent cause of death and disability worldwide, with approximately 2 million lives and over 53 million disability-adjusted life-years lost in the single year of 2019 due to exposures to selected chemicals (World Health Organisation, 2021). This issue is ever-growing with global chemical production, valued at over US$5 trillion in 2017, expected to double by 2030 due to population dynamics, urbanisation, and economic growth in emerging economies (U.N.E.P., 2019). Chemical manufacturing and chemical products are a major industrial sector in Ireland, accounting for 11.5 % of all industrial production in 2023 (Central Statistics Office, 2024). Against this backdrop, it is important to determine the chemical exposure levels among the general population. Human biomonitoring (HBM) is the direct measurement of chemicals, their metabolites or specific biomarkers in biological materials such as blood, urine or breast milk to assess exposures to chemicals. HBM accurately quantifies internal chemical concentrations from all routes and sources of exposures and, as such, is considered a gold standard and integral component among exposure science and risk assessment methods (Zare Jeddi et al., 2022).

There are several advantages of utilising HBM methods for public health. HBM can be used to accurately assess the exposure burden

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among the general population, sub-populations or specific target sub-populations (such as vulnerable groups) that could have higher exposures than the general population (Vogel et al., 2019). Furthermore, HBM data can act as an early warning indicator for emerging chemicals and risks and lead to important policy interventions or awareness campaigns to help reduce chemical exposure (Ubong et al., 2023), as well as assess the effectiveness and impact of chemical interventions, such as newly introduced regulatory framework, on human exposure to pollutants (Abrams et al., 2006). Several countries, such as Germany (Kolossa-Gehring et al., 2012), Slovenia (Perharic and Vracko, 2012), and the USA (Calafat, 2012), have established national HBM programmes (Judy et al., 2015; Singh et al., 2025a), allowing countries to gauge chemical burden among the population and meet their chemical regulation standards. The European Union has one of the most comprehensive chemical regulations with the regulation on registration, evaluation, authorisation and restriction of chemicals (REACH) (European Commission, 2006), as well as the Classification, Labelling and Packaging (CLP) regulation (European Commission, 2008). The REACH regulation makes industries responsible for the risk management of chemical substances. A major component of REACH is to ensure that human health is protected from chemicals in use in the EU (European Commission, 2006). HBM can make chemical risk assessment easier by providing actual exposure levels, and as such, can help industry ensure that they are meeting the REACH requirements (Boogaard et al., 2011).

To evaluate chemical exposures and address policy needs, there is a necessity to bridge the science-to-policy knowledge gap (Carusi et al., 2022). Science-to-policy involves using high-quality, robust scientific data to support evidence-based decision-making and develop initiatives through co-creation with policymakers. This can improve evidence use, so that data is used for foresight and an early warning indicator, improve data sharing and strengthen collaborative partnerships with academia and for implementation, to enhance the impact of HBM programmes (OECD, 2023).

In this context, World Cafés are now an established qualitative method of explorative data collection through active expert participation in workshop settings. First introduced over two decades ago (Brown and Isaacs, 2005), it has more generally been utilised in the fields of business and organisational management, as well as for patient participatory involvement processes in the fields of nursing and public health (Biondo et al., 2019; MacFarlane et al., 2016). However, it has been increasingly utilised for strategy and policy development more broadly, as the workshop setting is designed to maximise the sharing of expert knowledge through rotating participation at several moderated discussion tables, with each table concentrating on one specific aspect of the overall topic at hand.

From an organisational perspective, to effectively utilise a World Café, timing and duration are some of the most important factors in its successful delivery. Typically organised as a one-day workshop event with introductory sessions to give an overview of the topic to be discussed (sometimes utilising expert panel discussions), they have the advantage of speeding up expert stakeholder engagement (as opposed to one off semi-structured interviews which can be frequently stretched over many months) while also enabling academic and practitioner engagement (Silva and Guenther, 2018). World Cafés differ from traditional qualitative research methods in their distinct methodological design. They organise specific sub-theme research questions into moderated tables, where participants rotate between tables to discuss and ideate on these questions in small groups of expert peers. This enables much richer data collection and sharing of ideas, experiences and perspectives in a non-confrontational and welcoming social environment (Fouché and Light, 2010).

As World Cafés are social processes due to the deliberate group composition changes through several rounds of conversation, the expert participants meet fellow experts (known and unknown to each other) and build a new network of peers as the World Café unfolds, thus enabling the sharing of perspectives, ideas and experience in an iterative process. As conversations emerge and link to previous discussions through the table rotation process, participants establish emerging themes and patterns while also fielding new questions triggered by the different experiences and backgrounds of the new network established. As the World Café's end, generally a large group discussion occurs in which the new network establishes “collective knowledge…visible and actionable” (Brown and Isaacs, 2005).

Each country's HBM programmes are slightly different, due to variation in HBM programme developement and implementation capacity, public concerns, country-specific (emerging/legacy) pollutants, and practical policy considerations (Singh et al., 2025a). Therefore, gathering the perspectives of all stakeholders, including governmental, academic, and industrial groups, should precede understanding the limitations in current policies and how HBM can be applied. To develop a national HBM programme in Ireland, it is essential to acknowledge national health concerns and situations. Ireland has a high chemical, agricultural and pharmaceutical production (Central Statistics Office, 2024), so chemicals involved in these industries should be highlighted. To scrutinise and understand the stakeholders' interests and the policy impact of the HBM programme, a stakeholder forum was held. Despite growing international experience with HBM, there exists only a limited understanding of how HBM can be strategically aligned with national priorities, existing infrastructure, and regulatory frameworks and more importantly, how the relevant stakeholders view it. Moreover, there is a need to explore how inclusive stakeholder engagement can guide the development of a science-to-policy pathway for HBM in Ireland. To the best of the authors' knowledge, a World Café format has never been utilised to leverage co-creation as a strategy for the development of national strategies for a HBM programme. Participatory formats such as the World Café can be leveraged to co-create national strategies for HBM implementation. To address these gaps, this study is guided by the following research questions:

1. What are the key policy, scientific, and infrastructural needs for establishing a national HBM programme in Ireland? Furthermore, what are the key challenges?
2. How can stakeholder engagement through a World Café approach facilitate the co-creation of a national HBM roadmap?
3. How can HBM data be mapped to both EU and Irish policy questions to ensure relevance and long-term sustainability?

2. Methodology

2.1. Research paradigm

A critical realist approach, which views reality as objective but shaped by social and human factors, combined with the World Café approach, can be a highly impactful paradigm, enabling the exploration of complex societal issues (Lawani, 2021). As a research paradigm, critical realism, where World Cafés are utilised as the primary data gathering mechanism, involves a dialogic participatory process. This involves gathering expert peers to establish a new network at the event, facilitating purposeful conversations to ideate and expound upon the underlying mechanisms and structures that shape the phenomenon in focus. The World Café, which should offer an informal and welcoming environment that enables all perspectives and experiences to be shared, allows for these conversations to develop and enable collaboration, cross-pollination of ideas and collective intelligence (McGrath et al., 2023).

2.2. World Café design and delivery

This qualitative study utilised a World Café approach as part of the Human Biomonitoring for Ireland (HBM4IRE) project to facilitate an in-depth stakeholder discussion with the specific aim of informing the development of national and European Union (EU)-level HBM policy frameworks. Notably, five key themes were pre-identified through iterative consultations with an established network of HBM researchers, policymakers, and scientists involved in HBM research globally, including from Germany and Belgium. Five themes identified were: Policy, Chemical Priorities for Ireland, Funding Mechanism, Synergies, and Communication and Engagement. This study focuses exclusively on the Policy theme, which examined the role of HBM in addressing policy needs, such as legislative initiatives and risk assessment frameworks. A primary prompt question, supported by targeted sub-prompt questions (Supplementary Table S1), was developed for the theme "Policy" through a collaborative brainstorming session among the research team to ensure alignment with the study's objectives.

The World Café was conducted on 11 October 2024 at University College Dublin with a series of expert talks designed to provide background, stimulate thinking, and contextualise the discussions. Invited international experts delivered a series of presentations covering key aspects of human biomonitoring, including recent scientific advancements, HBM programme design, ethical considerations, and real-world examples from national and regional contexts. The session concluded with a panel discussion involving all speakers, which set the stage for the World Café (UCD, 2024). This approach was selected because of its participatory, dialogic structure, which fosters collaborative knowledge generation through structured but flexible discussions.

The session was attended by 25 stakeholders, invited from an initial pool of approximately 60 experts, to ensure representation from diverse sectors. The recruitment process aimed to secure participation from at least half of the invitees, achieving a robust sample size suitable for qualitative exploration. Stakeholders were selected using purposive sampling to ensure broad representation from departments and agencies central to Ireland's policy and regulatory landscape for human biomonitoring and chemical management. Representatives from key government departments such as the Department of the Environment, Climate and Communications (DECC), the Department of Health, and the Department of Agriculture, Food and the Marine were included, as these entities play pivotal roles in policymaking. The Health Service Executive (HSE) was involved due to its responsibility for public health, while the Environmental Protection Agency (EPA), as the national regulatory body overseeing chemical pollution control and environmental surveillance, contributed essential regulatory perspectives. Together with experts from academia, research institutions (national and international), and industry, these stakeholders ensured a comprehensive and policy-relevant discussion on how HBM can address national and EU policy needs.

Participants were organised into groups of five, each assigned to a dedicated table facilitated by five trained moderators (research team members) to promote equitable participation and maintain focus on the discussion prompts. A structured approach was adopted to ensure a diversity of expertise at each table during the World Café discussions. Specifically, each group was thoughtfully composed to include one representative each from industry, government agencies like the Food Safety Authority of Ireland, the Environmental Protection Agency, and a national or international HBM expert, thereby fostering a rich and interdisciplinary dialogue (Fig. 1). Time allocated to each group per table for discussion was 15 minutes. Notably, the policy theme was the focus of one of the five tables, and each group of five participants discussed this theme for approximately 15 minutes per round.

World Café discussions were audio-recorded with participants' informed consent, which covered participation, recording, and anonymised data use, adhering to ethical standards. Verbatim transcriptions of the 'Policy' theme discussions were prepared to facilitate analysis.

2.3. Qualitative data analysis

Data were analysed using thematic analysis, adapted from Braun and Clarke's (2006), six-phase framework, which provided a systematic approach to identifying patterns and sub-themes (Chen et al., 2022). The transcription of the World Café discussion was first generated manually by each of the moderators and then finalised. To identify the emergent sub-themes arising from the transcription, we employed a two-phase critical friend analysis. Notably, in this study, two researchers within

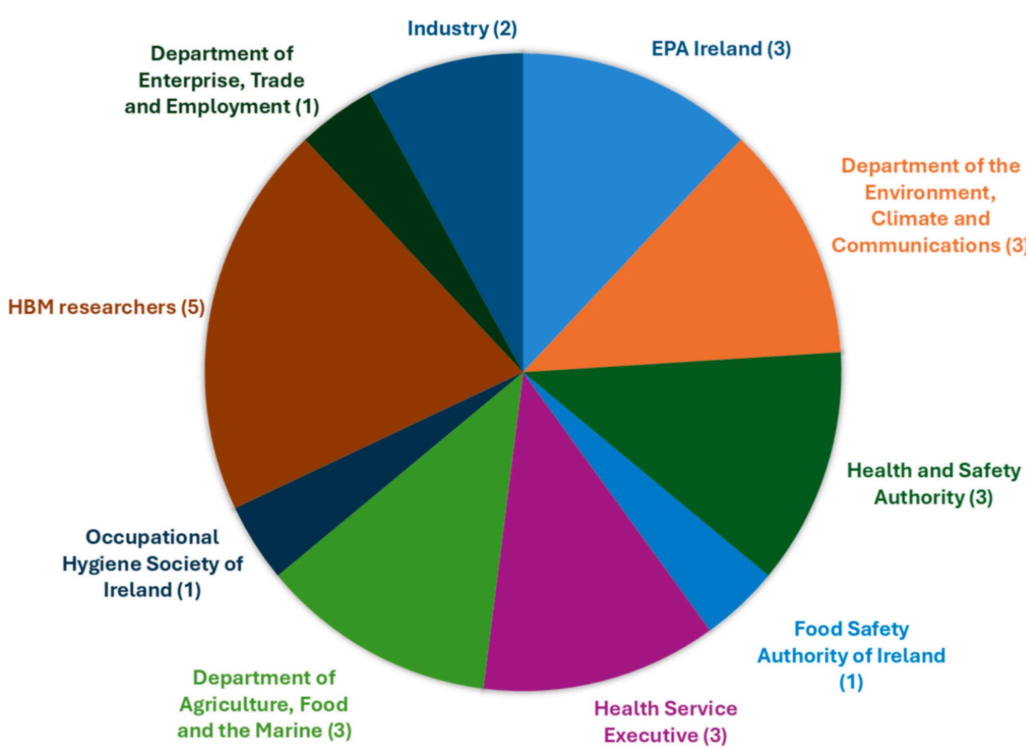

Fig. 1. Distribution of participants by institutional affiliation at the HBM4IRE World Café event (number of participants), highlighting the diverse engagement of stakeholders from government agencies, research institutions, and industry.

the research team (RS and SL) acted as the primary coders, while three additional team members (AC, DD, and CB) served as critical friends. The critical friend process involved these three members, who were not directly involved in the initial coding. Their role was to critically review, challenge, and refine the interpretations and coding decisions made by the two primary coders. This reflexive dialogue encouraged the coders to justify their analytical choices and consider alternative interpretations, thereby enhancing the trustworthiness and transparency of the analysis.

Phase 1 involved the identification of emergent sub-themes. For this, two coders conducted a rigorous review of the transcription to gain familiarity with the content. This was followed by the identification of emergent sub-themes, ensuring that each theme was discussed by multiple participants across at least two to three groups, thereby capturing recurring and widely shared perspectives. Two of the research team members (or coders) carried out this process independently to enhance reliability. Once the initial emergent sub-themes were identified, the critical friends process essential for robust qualitative analysis was initiated (Feldman et al., 2008; Baskerville and Goldblatt, 2009; Kember et al., 1997), with the first critical friend meeting was held with all the wider research team members to review, brainstorm, refine, and finalise the emergent sub-themes through consensus (two researchers as coders, with three researchers as critical friends).

Phase 2 focused on identifying specific codes for each of the finalised emergent sub-themes. For this step, the same two coders independently conducted a critical friend analysis, immersing themselves once again in the transcriptions to generate quotes for each of the emergent sub-themes and reduce interpretive bias. One coder used NVivo software (Version 2022) to systematically identify the quotes and organise the data, while the other performed manual coding to ensure comprehensive coverage of all the insights and identify the relevant quotes. NVivo facilitated quote identification for one researcher, while a manual review ensured that no critical insights were missed. After the individual coding was completed, the two coders convened for a second critical friend meeting to compare their respective code sets. Duplicate codes were removed, and the remaining codes were retained based on mutual agreement. Afterwards, all research team members reconvened for the third critical friend meeting to decide how the quotes should be organised, given their large number. It was agreed that the quotes would be categorised into three groups: (1) best or preferred quotes that would shape the manuscript's narrative, (2) supporting quotes to substantiate the findings, and (3) less relevant quotes for contextual background.

Illustrative quotes were then jointly selected by the same two coders in the fourth critical friend analysis meeting and categorised into three: preferred or favourite quotes that shaped the manuscript's narrative, supporting quotes that substantiated the findings, and less relevant but contextual quotes that provided additional background. Duplicate or redundant quotes were eliminated, and the coders ensured the selection of quotes.

After finalising the quotes (at coders' end), the fifth and the final critical friend analysis meeting was organised with the wider research team, where the quotes corresponding to each emergent sub-theme were compared and consolidated in three categories: (1) primary or preferred quotes (forming the "overview of the idea"), (2) supporting quotes, and (3) less relevant but contextual quotes. The quotations presented in the Results section were those that most clearly articulated the collective viewpoints expressed by participants across multiple tables, effectively summarising the dominant idea supporting each sub-theme. This was done through iterative team discussions and brainstorming sessions within the wider research team, with discrepancies resolved via consensus to produce a coherent set of quotes reflecting stakeholder perspectives. Each sub-theme is presented in the Results section with representative quotes embedded in the text. A comprehensive compilation of all participant quotations for these sub-themes is provided in Supplementary Table S2 *(Illustrative quotations corresponding to Sub-Themes 1–4 from World Café discussions)*. An overview of the entire methodology employed by this research study can be seen in Fig. 2.

2.4. Ethics

Ethical approval for the entire study was obtained from the UCD

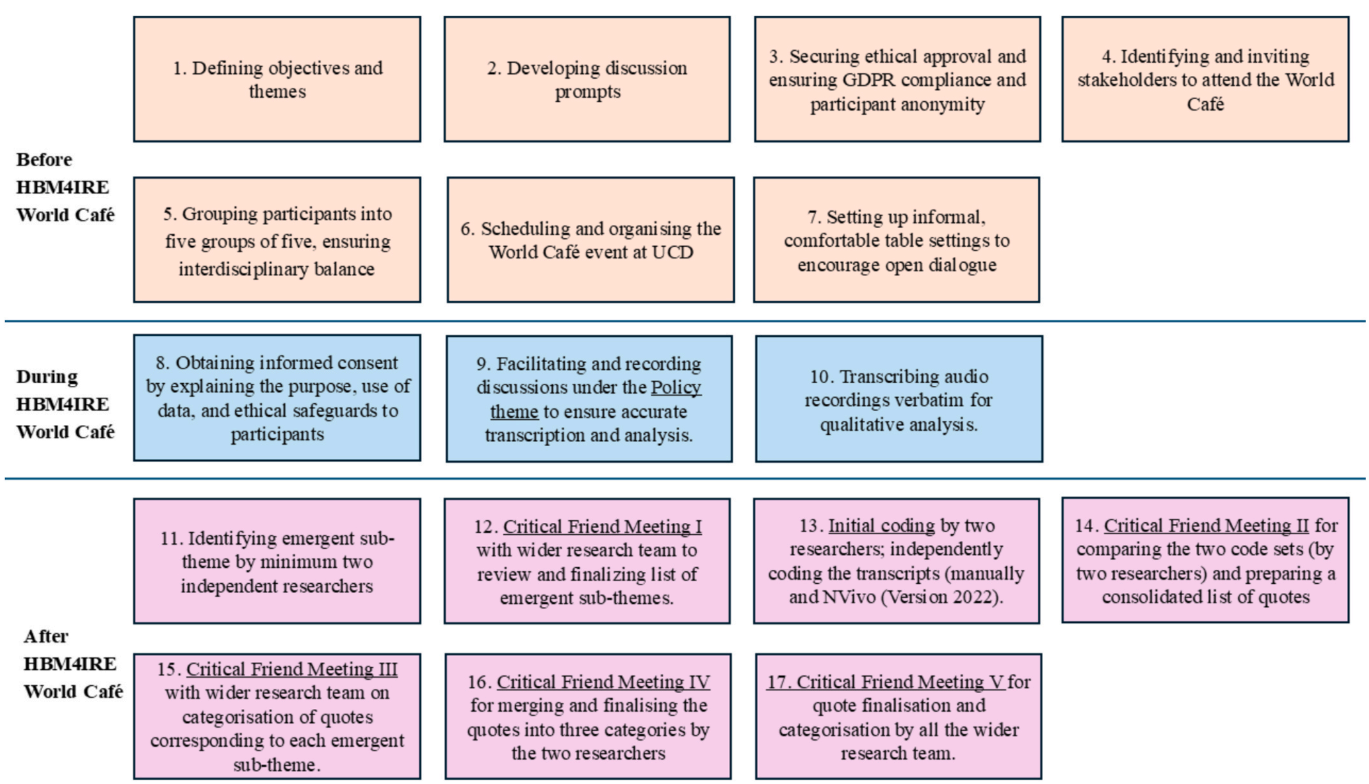

Fig. 2. Stepwise methodology adopted in the study.

Ethics Committee, and all data were anonymised to comply with General Data Protection Regulation (GDPR) guidelines and institutional ethical standards, ensuring participant confidentiality and transparency. For conducting the World Café, ethics approval was obtained from the UCD ethics committee (dated 8 October 2024; LS-LR-24–251-Singh). Trustworthiness was enhanced through several quality assurance measures, including independent coding to reduce bias, critical friend process, reflexive team discussions to validate interpretations, and the World Café's inclusive design, which mitigated the risk of dominant voices influencing the outcomes.

3. Results

The analysis of stakeholder discussions within the World Café concentrated on the policy theme of HBM and revealed a compelling narrative on its necessity and challenges. Results are structured around four interconnected themes central to leveraging HBM for evidence-based policymaking: (1) The urgent need for targeted HBM to address exposure hotspots, at-risk occupations and at-risk cohorts, which is often hindered by fragmented governance. (2) The significant potential for HBM to inform EU-level policy and legislation (e.g., REACH, ECHA activities). (3) The fundamental utility of HBM as a quantitative tool for monitoring exposures, tracking trends, validating policy effectiveness, and identifying emerging risks; and (4) the specific opportunities and barriers for utilising HBM to answer Irish policy questions. These findings articulate a clear demand for HBM integration into policy frameworks to protect public and occupational health effectively.

1 Targeted HBM for exposure hotspots / at-risk occupations / at-risk cohorts

Targeted HBM emerged as a crucial strategy for addressing chemical exposures in specific contexts, such as hotspots, high-risk populations and vulnerable groups. Stakeholders articulated a narrative of urgency, complexity, and opportunity, emphasising the need for localised HBM data, integrated policy frameworks, and transparency to protect communities and workers.

Stakeholders emphasised the need for targeted HBM to identify and address exposure hotspots such as geographic or demographic areas with elevated contamination levels. One stakeholder stressed the dual role of population-wide data in defining hotspots and the urgency of actionable recommendations for affected communities. However, fragmented governance structures often hinder coordinated responses:

"I think also dealing with hotspots is an important point. On the one hand, you need population data to know what a hotspot is. And on the other hand, you need urgently to give recommendations if people live in a hotspot and have higher exposures."

This quote explicitly addresses the dual need of data-driven identification of hotspots and the adequate provision of actionable recommendations to protect the affected populations. The stakeholder's reference to Germany and countries with a well-established HBM programme highlights a systemic issue of shifting responsibility across different levels of Government, potentially causing delays in effective interventions and increasing risks to communities living near contaminated areas, such as regions with historical pollution or industrial zones. To overcome this issue, a strategic approach for creating a well-coordinated governance structure is required.

"Speaking from a government department that implements policy on chemicals, we're working under international EU and then down to national level, we implement the directives. It's a good point, some of the monitoring that I've been on, sort of Europe-wide, chemicals of concern, some might be very specific to an island or even to an area, it doesn't need to be the same chemicals of concern nationally even, does it? It could be very specific to a local, even an incident or something, a local problem."

This insight highlights the importance of tailoring HBM efforts to specific geographical or incident-based contexts, rather than relying on generalised national or international standards. For instance, a chemical spill or industrial activity in a localised area may pose unique exposure risks that require targeted monitoring to identify and address the specific chemicals of concern, ensuring that interventions are relevant and effective.

Stakeholders also articulated that the workers in high-exposure industries (e.g., manufacturing units, waste management) were identified as a vulnerable cohort often overlooked in regulations and policies. A participant criticised the lack of transparency and corporate accountability in occupational HBM programmes:

"One issue policy needs is to improve the protection of workers in occupational settings by human biomonitoring. There are only a few companies that do human biomonitoring, and they don't publish the data."

This quote highlights the significance of occupational HBM programmes in monitoring workplace exposures and safeguarding workers' health. However, problems associated with current workplace exposure monitoring, including a small number of organisations using HBM and a lack of published results, are acknowledged as crucial aspects that a new HBM policy should address.

Stakeholders raised important concerns about the unintended consequences of material circularity, particularly when hazardous substances embedded in waste streams are reintroduced into the environment or consumer products through reuse and recycling. This issue has been widely studied, especially in relation to chemicals used in plastics, which can re-enter the value chain through recycling and cause harm throughout their entire life cycle (Alaranta and Turunen, 2021; Hahladakis et al., 2018; King et al., 2006). One participant pointed out the example of waste tyres reused in playgrounds or synthetic sports pitches, cautioning that such materials may expose children to polycyclic aromatic hydrocarbons (PAHs), which are known to be carcinogenic and persistent in the environment. Similarly, in the context of waste electrical and electronic equipment (typically referred to as WEEE), stakeholders flagged that persistent substances such as per- and polyfluoroalkyl substances (PFAS) may be reincorporated into the material chain without sufficient regulation or monitoring.

"That means tyres, for example, the reuse of tyres, now in playgrounds, they're being exposed to PAHs, in synthetic pitches. And the WEEE side is like that as well, with the PFAS going back into the chain again, we're not clear as to… And while I agree there's a need for it, we need to put in place, the policy needs to address exposure then during the whole life cycle, not just from the environmental perspective, it needs to address the policy as a whole."

It is interesting to note that this quote highlights a broader concern identified in our thematic analysis, which is that the fragmented nature of policy approaches fails to consider human exposure risks across the full life cycle of materials and products. While efforts to promote resource efficiency and material recovery are central to circular economy models, stakeholders emphasised that without an integrated chemicals policy, such practices may unintentionally reintroduce environmental health risks in the name of "promoting recycling" and achieving the EU recycling targets.

These discussions highlight the need for a more holistic approach to policy development, even in the waste management sector; one that bridges the current divide between environmental sustainability goals, circularity rate and chemical safety. The lifecycle thinking approach, which is coupled with human biomonitoring data/exposure data, was repeatedly proposed as a critical tool to support evidence-based decisions that prevent hazardous exposures, among the people working in recycling plants and common people in general who are using the consumer products derived from recycled material, such as recycled plastics. Stakeholders called for regulatory innovation that ensures materials re-entering the economy do so under conditions that are safe, transparent, and supported by robust risk assessments.

2 Mapping HBM to answer EU policy questions and legislative

initiatives

A recurring theme among participants was the strategic importance of HBM in aligning scientific evidence with policy and legislative initiatives at the EU level. Participants stressed that while HBM is not always systematically used in regulatory processes, it has potential for bridging the gap between hazard identification and comprehensive risk assessment processes, especially under frameworks such as REACH regulation or the activities under the European Chemicals Agency (ECHA).

One participant highlighted the limitations of current EU-level chemical assessments, emphasising that many of ECHA's evaluations primarily focus on potential hazards rather than contextualised risk assessments. In this regard, HBM is seen as a tool that can provide more detailed, real-world data on human chemical exposure, thereby improving the relevance and reliability of regulatory decisions:

"I think at the European level, I don't know if ECHA use human biomonitoring data, but a lot of the ECHA assessments are hazard assessments, not risk assessments, so they measure the harm it could cause, but not from, I suppose, top level. So it (HBM) could inform better risk assessment decisions."

In addition to regulatory assessments, stakeholders also recognised the importance of HBM in policy evaluation or measuring how effectively a policy is enforced. For instance, HBM was positioned as a unique tool for assessing the long-term effectiveness of past policy interventions. One participant gave the example of lead restrictions, explaining how HBM data can track the actual reduction in population-level exposure over time, thereby validating the health benefits of policy measures. This unique function was also framed as particularly important for identifying the real-world impact of legislation and detecting unintended consequences or emerging risks:

"I think….it's very useful to gather data on whether policies have been successful. For example, lead. Obviously, lead was restricted for health reasons and over time then you can actually see the actual impact. And similarly, for newer substances, it's a very useful research tool as well to see what's coming up as new emerging issues that might not be anticipated from, I suppose, other monitoring."

However, it is crucial to note that the implementation of evidence-based policymaking through HBM has its own challenges. Stakeholders pointed out significant data gaps, particularly the lack of baseline HBM data in several EU countries, including Ireland. This absence restricts both the assessment of policy effectiveness and the comparison of different chemical exposure trends across regions within a nation or across different nations. The case of Ireland was cited as an example of this limitation:

"You have mentioned the word baseline, we don't have a baseline in Ireland. There's a good chance we're like a lot of the rest of Europe, which we don't know because we don't have any data."

3 HBM used as a beneficial mechanism to monitor and control chemical exposures

Stakeholders recognised HBM as an effective evidence-based tool for assessing and managing chemical exposures in populations. The quantitative nature of HBM was highlighted as a key strength, providing robust data on human exposure levels that can inform policy and public health strategies. One stakeholder noted:

"I think it's evidence-based. It's quantitative results of exposures. And it can track trends, so that can help in policy over the years. And inform its data response as well, to inform and assist society, link to our values as a society and how we're going to regulate or promote awareness. All linked back to human health and environment and occupational safety."

This highlights the HBM's role in generating actionable data that aligns with policies and supports regulatory frameworks for human health, environmental protection, and occupational safety.

HBM was also widely recognised for its dual capacity to assess past exposures and anticipate future risks. Its retrospective nature was acknowledged by one stakeholder,

"The nature of it that biomonitoring says is rear-view facing is already there. So something's already happened. I suppose one of the interesting things could be as well, if you're making policy decisions and you think there could be an impact that could be monitored by this to sort of use it to forward look to say that something isn't appearing in the sample, in people as a result of taking certain policy decisions."

This perspective highlights HBM's retrospective function, as it can estimate exposures that have already occurred, providing clear estimates of existing chemicals of concern in the populations. Simultaneously, the stakeholder also emphasises HBM's prospective role, suggesting it can be used to evaluate the effectiveness of policy interventions by monitoring whether specific substances or chemicals are absent in populations following the policy intervention or regulatory actions. This forward-looking application positions HBM as a tool for validating policy decisions, ensuring that implemented measures are preventing the new exposures, and identifying any unintended consequences of policy changes. This has also been addressed by another stakeholder who noted:

"It has a part to play in showing how the effectiveness of policy, I suppose, you know, both on a national level, more international, you know, things are banned or whatever like that, we can see then the levels are tapering off over time. Or if they're not like the example this morning, you know, so it can be really informative in that way. But then also staying a little bit ahead of what's the next emerging contaminant of concern."

The ability to provide long-term data was seen as essential for both validating existing policies and identifying areas where further actions are needed to address persistent or emerging contaminants.

In addition, HBM was seen as a critical research tool for identifying emerging contaminants, particularly for emerging substances that may not be detected through other monitoring methods. Stakeholders highlighted HBM's application in identifying unexpected exposure trends and providing robust, evidence-based data. As one participant noted:

"And similarly, for newer substances, it's a very useful research tool as well to see what's coming up as new emerging issues that might not be anticipated from, I suppose, other monitoring. I think it's evidence-based. It's quantitative results of exposures."

This highlights HBM's role in staying ahead of potential public health threats by detecting novel chemical exposures early.

4 Mapping HBM to answer Irish policy questions and legislative initiatives

Stakeholders highlighted the potential of HBM to address Irish policy questions and support legislative initiatives, particularly in the context of occupational and environmental health. However, they noted a lack of mandatory HBM studies/programmes in Ireland, especially for occupational exposures. One stakeholder reflected on the absence of compulsory biomonitoring for toxic substances like lead, stating:

"Any kind of biomonitoring compulsory in Ireland with regard to occupational exposure? For lead, perhaps? No, I mean, in the laboratory, we would have done solvent monitoring and noise levels. Yeah. Not biomonitoring as such, otherwise. No, but I think in some industrial areas where they're using that level of those types of solvents, whether it is compulsory, there's not enough legislation around that. Just a thought. Yeah, no, I wouldn't know."

This suggests that while some environmental monitoring (e.g., solvent and noise levels) occurs, HBM is still not systematically integrated into occupational health regulations (with the exception of lead), and stakeholders perceive a legislative gap in mandating HBM for high-risk industries.

In addition, stakeholders highlighted the importance of proactive national-level monitoring for emerging contaminants, emphasising the role of Ireland's Public Analysis Laboratories in enabling early detection and response systems. It was emphasised that establishing national standards ahead of EU directives could position Ireland more strategically in European regulatory discussions and decision-making. Stakeholders pointed to the continuous strengthening of occupational exposure limits for metals at the EU level, expressing concern that Ireland currently lacks comprehensive data to contribute effectively to these processes. Without comprehensive national data, Ireland's ability to influence EU decision-making remains limited. The stakeholder described this gap as a missed opportunity, reinforcing the notion that early action and data could not only protect public and occupational health proactively but also enhance Ireland's potential role in shaping future EU directives. These points are noted by a stakeholder:

"But if they do it here in Ireland and our colleagues in the Public Analysis Lab raise a flag that they get in ahead of the curve and say, right, OK, we in Ireland are going to set a standard of what? It's like prevention is better than cure. It would give us probably a better say as well at an EU level, particularly let's say from the occupational exposure with them. Because all of the metals are being reduced for their occupational exposure limits. And I don't think we're having enough of a say in that at the moment because we don't have the data centralised in any way to be able to have valued input at that level."

At a broader policy level, stakeholders identified HBM as a tool to fulfil the Government's fundamental responsibility to protect public health. One participant articulated:

"I suppose for me, before we get into the specific legislation, like what policy needs can be addressed using human biomonitoring, I suppose the answer would be for the government to protect its citizens, you know, and to look after the health of its citizens would be the top sort of policy need."

This statement reflects a consensus that HBM could serve as a critical instrument for evidence-based policymaking, enabling the Irish Government to prioritise citizen health by identifying and mitigating chemicals of concern and their exposure risks. Ireland could enhance its capacity to prevent harm from the chemicals by integrating HBM into national policy frameworks that align with the principle of "*prevention is better than cure*," and address both national and EU-level legislative priorities.

It is interesting to note that stakeholders expressed a strong interest in establishing a national HBM programme in Ireland, viewing it as a critical step towards evidence-based chemical risk assessment and public health protection in Ireland. However, they also emphasised the need for a targeted and strategic approach in its initial phase, particularly in light of the resource-intensive nature of HBM programmes. As a pragmatic starting point, stakeholders recommended focusing on high-risk occupational groups, such as firefighters, especially where environmental exposure data already exists to support or validate the rationale. One stakeholder remarked,

"But they haven't looked at the likes of firefighters exposed. That would be a really good starting point because you already have the measurement in the environment. You know that it's there."

The importance of establishing a starting point and prioritisation was further highlighted in the context of financial constraints, as one stakeholder pointed out:

"I'm in line with a lot of things, but biomonitoring is not cheap. Yeah. So I guess you have to really focus where you apply it, where you might find the most impact of the work you're doing."

The stakeholder highlighted a very crucial point that countries that currently do not have well-established HBM programmes should be mindful and strategic at the initial stages. It is essential to prioritise chemical groups and populations that are most likely to be impacted, ensuring that resources are directed toward areas where HBM can produce the greatest value and inform meaningful policy and technical interventions.

These insights highlight the importance of aligning Ireland's initial HBM efforts with both public health relevance and existing infrastructure to ensure a feasible and impactful national rollout.

4. Discussion

Prior to the World Café exercise conducted as part of this study, five key themes were initially identified to guide the stakeholder discussions: (1) policy, (2) chemical priorities, (3) funding mechanisms, (4) synergies across departments, and (5) communication and public engagement. These themes facilitated rich and diverse conversations, producing a substantial volume of stakeholder insights. However, for the focus of this paper, analysis and consideration, we targeted our analysis specifically on the theme of policy, given its central role in shaping the direction, implementation, and long-term sustainability of HBM initiatives in countries. Policy emerged not only as a cross-cutting issue but also as a foundational enabler for progress across the other identified themes. It is important to highlight that while the overarching theme ("Policy") and prompt questions were designed by the research team to guide discussion, the specific sub-themes and stakeholder quotations emerged inductively from participants' dialogues. Thus, the analytical approach was predominantly bottom-up, grounded in the lived experiences, expertise, and perspectives shared during the World Café discussions.

World Café targeted discussion points on the impact of HBM national programmes on policies and initiatives to safeguard public health, providing policymakers and regulatory bodies with insight and assistance in co-creating requirements for impactful outputs. The key benefits of HBM were highlighted, particularly its ability to generate quantitative, real-world data on internal chemical exposure. HBM relies on direct measurements in human samples rather than on estimates derived from models (Kolossa-Gehring et al., 2012; Zare Jeddi et al., 2022). Unlike traditional exposure assessments based on assumptions and modelled scenarios, HBM accurately reflects the actual body burden of chemicals, capturing cumulative exposure from multiple sources, including air, food, consumer products, and the environment. It also integrates all exposure pathways (oral, dermal, inhalation) (Santonen et al 2017, DeBord et al, 2017). This makes HBM a powerful tool for exposure and risk assessment, offering a scientifically robust foundation for public health decisions and regulatory action. It can provide transparent information to the general public and influence policy processes.

HBM national programmes have already been instrumental in regulating certain chemicals. Early applications, such as the measurement of blood lead levels, revealed widespread exposure in industrialised countries and triggered regulatory actions, including the reduction of lead in gasoline (Creager, 2018). This marked the first significant use of HBM for evaluating policy effectiveness in public health monitoring, leading to the 1977 EU directive on biological screening for lead exposure (Council Directive 77/312/EEC) (Angerer et al., 2007). Although EU-wide HBM activity remained limited for decades, several countries independently launched national HBM programmes such as Germany's Environmental Surveys (GerES, since 1985) (Kolossa-Gehring et al., 2012) and the U.S. National Health and Nutrition Examination Survey or NHANES (since 1999) to monitor population-level exposure to environmental pollutants (Calafat, 2012). These early efforts demonstrated the ongoing role in assessing historical chemical exposures and informing public health policy. Since, these national programmes have gained traction globally. A recent report (Connolly et al, 2025) found a growing number of these programmes worldwide.

The strategic potential of HBM in supporting EU-level policy and regulatory processes was a recurring theme among stakeholders. Although HBM is not yet systematically integrated into regulatory decision-making, it is increasingly recognised as a crucial bridge between hazard identification and more comprehensive risk assessment frameworks, such as those under EU REACH regulation or others led by the European Chemicals Agency (ECHA). Stakeholders highlighted that current chemical assessments at the EU level often rely heavily on hazard data, without sufficient incorporation of real-world exposure insights. In this context, HBM offers an opportunity to contextualise hazard information with population-based exposure levels, thereby enhancing the relevance and accuracy of regulatory decisions (Zare Jeddi et al., 2022).

Notably, stakeholders highlighted the urgent need for a more holistic approach to policymaking based on lifecycle thinking, supported by HBM exposure data, which was highlighted as essential to making informed, evidence-based decisions that protect both workers and consumers. Tremendous advancements have been made throughout Europe in the last decade on the harmonisation, protocol development and cross-country comparability of HBM programmes, with initiatives such as DEMOCOPHES (Demonstration of a study to coordinate and perform human biomonitoring on a European scale) (Cullen et al., 2017; Cullen et al., 2014; Schindler et al., 2014), European Joint Programme Human Biomonitoring for Europe or HBM4EU which ran from 2017 to 2022 (Gilles et al., 2021; Kolossa-Gehring et al., 2023), and the ongoing Partnership for the Assessment of Risks from Chemicals (PARC) (PARC, 2025).

While the role of HBM at the EU level was acknowledged, the World Café discussions were particularly focused on the missed opportunities for Ireland due to the current lack of a comprehensive, systematic HBM programme. Several participants noted the absence of mandatory HBM in high-risk occupational sectors, such as those involving solvents or metals, indicating a significant legislative and regulatory gap at a national level. Despite some routine monitoring, e.g., solvent and noise levels in laboratories, stakeholders emphasised that Ireland lacks institutionalised mechanisms to conduct HBM of toxic substance exposures in vulnerable worker populations, such as those in industrial zones or emergency response services, such as firefighters. Targeted HBM stands out as an essential approach for tackling chemical exposures in specific contexts, including exposure hotspots, at-risk occupations, and vulnerable populations. Stakeholders have conveyed a compelling narrative highlighting the importance of localised HBM data, cohesive policy frameworks, and greater transparency to protect communities and workers from the health risks posed by chemical exposures across diverse environmental and occupational landscapes.

Many countries with established or emerging HBM programmes have prioritised chemicals of concern based on exposure levels and potential harm. Part of the Flemish HBM programme is focused on persistent organic pollutants (POPs) and polycyclic aromatic hydrocarbons (PAHs), targeting vulnerable groups and leveraging existing policies to guide precise interventions (Reynders et al., 2017). In addition, since 2002, the Flemish HBM programme has targeted environmental hotspots and vulnerable groups to guide policy through HBM (Schoeters et al., 2012). Similarly, Slovenia has directed its HBM programme towards industrial hotspots, such as the Upper Mežica Valley, affected by legacy pollution from a closed lead and zinc mine, the mercury-contaminated town of Idrija, and the Krupa River area polluted with polychlorinated biphenyls (PCBs) from a former factory (Snoj Tratnik et al., 2019). The NHANES programme prioritises high-risk substances like lead, which helped the CDC adopt the blood lead reference value based on NHANES data in 2012 (Centre for Disease Control, 2025). This helped them to identify children with blood lead levels that are much higher than most U.S. children.

In addition to hotspots, HBM data can effectively support occupational risk assessment by providing direct evidence of internal exposure to hazardous substances. An example of this was the HBM4EU (2017–2022) findings, which raised concerns about chemical exposure from recycled materials. Food packaging made from recycled paper and cardboard may contain thousands of substances, with over 250 identified in a single sample. Similarly, brominated flame retardants have been found in recycled plastic products like toys and kitchen utensils, posing exposure risks through food contact or mouthing. Studies across Europe and globally found high contamination rates, including HBCDD, OctaBDE, DecaBDE, and related toxic compounds. The identification of high-risk tasks in sectors like waste and recycling and contaminated land remediation highlights the emerging nature of occupational risks due to chemicals (Cook et al., 2022; Cruvinel et al., 2019; Scheepers et al., 2021).

One of the most significant benefits of HBM highlighted during the World Café discussions was the crucial role HBM can play in tracking exposure trends over time and identifying emerging risks due to HBM's unique ability to provide real-world, quantitative data for both known and emerging chemical exposures. HBM indicators developed under the HBM4EU initiative have demonstrated how they can assist in translating complex exposure data into actionable insights for chemical policy. An example is DiBP,[1] which is restricted and classed as a substance of very high concern (SVHC), and demonstrated a decline in exposure levels among children across Europe when comparing harmonised HBM data (2014 and 2021) with earlier DEMOCOPHES data (2011–2012). Specifically, median (P50) values decreased from 24.5 μg/L to 18.2 μg/L, reflecting the regulatory success of measures targeting DiBP and other potentially hazardous phthalates (Gerofke et al., 2023).

In contrast, the same study demonstrated HBM's potential for forecasting emerging issues. DINCH (1,2-Cyclohexane dicarboxylic acid diisononyl ester), a non-phthalate substitute of DEHP and DiBP, was introduced in the market in 2002. DINCH exhibited a rising average concentration from 5.1 μg/L to 8.7 μg/L, highlighting the need for continuous monitoring via HBM and the need for regulating chemical substitutes (Gerofke et al., 2023). This validates the findings of the World Café discussion, highlighting the crucial role of HBM in assessing the effectiveness of the existing policies while also acting as a proactive approach to assess the emerging issues. The literature illustrates how HBM has evolved from a reactive instrument initially used to address established hazards like lead to a proactive surveillance tool capable of identifying and tracking newer, less-regulated substances such as DINCH. This progression highlights HBM's dual value in confirming the effectiveness of past policy actions and in flagging emerging issues that may warrant regulatory attention.

Ireland has already demonstrated its commitment and ability to conduct HBM studies, from participating in the DEMOCOPHES (Cullen et al., 2017; Cullen et al., 2014; Scheepers et al., 2021), HBM4EU-aligned studies, and involvement with the PARC initiative, which will contribute to the advancement of HBM and the next-generation risk assessment (PARC, 2025). 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 European Environment and Health Process Partnership on Human Biomonitoring (EHP Partnership on HBM) for the WHO European Region (World Health Organisation, 2025), which is a permanent platform for exchange and collaboration in the field of HBM.

Many countries have already successfully conducted HBM studies, demonstrating technical skills and expertise and the ability to implement a population-level human biomonitoring programme. Although Ireland has a limited number of HBM studies, it has conducted assessments of mercury and phthalate exposure in mother–child groups (Cullen et al., 2017; Cullen et al., 2014). More recently, Ireland has conducted HBM studies on pesticides such as glyphosate (Connolly et al., 2018; Connolly et al., 2017; Connolly et al., 2022) and neonicotinoid insecticides (Wrobel et al., 2025). Many nations have prior HBM experience, which can demonstrate their technical and

[1] 'DiBP was restricted under the EU REACH regulation in 2019 and classified as a substance of very high concern (SVHC) under Article 57(f) of Regulation (EC) No 1907/2006.

institutional readiness to support a sustained, nationwide HBM surveillance system to inform chemical risk policy.

However, a challenge can be the costs, resources and expertise required to establish a national programme. The World Café stakeholders shared an understanding that financial and logistical constraints necessitate consideration in the initial phases of the HBM programme. Stakeholders highlighted the high cost of HBM studies and advocated for a strategic and phased national HBM roadmap that focuses initially on sectors with the highest risk and clearest data gaps, to ensure early wins, thus justifying broader investment and programme expansion and generating the most meaningful regulatory impacts. A proactive step towards establishing a HBM programme would be to document the existing HBM capabilities in the country, including information on national laboratories (public and private), available equipment, biobanks and the technical expertise within the country, providing a comprehensive overview of the nation's assets in terms of HBM studies. Over time, such efforts could build the infrastructure necessary to align with international best practices, contribute to future legislative dialogues, and ultimately enhance national capacity to protect public and occupational health.

As highlighted by one stakeholder, an effective response to environmental health risks depends on two critical elements: accurate population-level data to define exposure hotspots and the rapid delivery of actionable recommendations to the affected communities. To overcome such barriers and ensure that HBM data is translated into effective public health policy, there is a pressing need to develop a governance framework that works across institutional silos and creates strong linkages between local, national, and EU levels. To foster this, encouraging collaboration among academic institutions, research centres, and public health organisations can further bridge gaps in knowledge and expertise. A key recommendation is to establish a high-level national Human Biomonitoring Steering Committee, functioning as a coordination mechanism under a memorandum of understanding among committed parties, ensuring the provision of finance, resources, and expertise. This committee would set the groundwork for long-term ambitions such as the creation of a Centre for Excellence for HBM Research in Ireland (Connolly et al, 2025), significantly advancing Ireland's national capacity and collaboration. Strengthening inter-institutional collaboration through active representation of relevant departments will allow for better oversight and alignment of objectives. The committee should also set clear agendas and milestones that address both national and EU chemical pollution policy questions. Identifying and leveraging synergies across departments and agencies, through shared infrastructure, expertise, and good practices, will be essential to supporting efforts at all governance levels. Furthermore, 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. The HBM programme would generate more impactful and utilised data; the co-creation of the programme would ensure uptake by policymakers (OECD, 2023). Finally, for such a framework to be effective and sustainable, it must be underpinned by long-term and adequate resourcing.

It is important to note that while qualitative methods are highly valued for their capacity to generate rich, nuanced insights from a diverse group of experts in a relatively short time, it is also important to acknowledge certain limitations inherent to this approach. First, although the stakeholder group was diverse, the sample size ($n = 25$) may not capture the full range of viewpoints across all sectors, particularly those underrepresented at the event. Second, while the thematic analysis followed a structured ‘critical friend’ approach to minimise bias, the interpretation of qualitative data inherently involves some degree of subjectivity. Third, the study did not incorporate quantitative reliability metrics, as the primary focus was on collaborative, consensus-driven interpretation. Nevertheless, the rigorous triangulation and reflexive discussions used throughout the analysis enhance the overall trustworthiness and credibility of the findings.

In addition, the rapid and interactive nature of the discussions in the World Café meant that stakeholders/participants (experts), although well-informed, were responding in real time without prior access to the questions; thus, responses may have been more intuitive or spontaneous than thoroughly deliberated. Future studies may benefit from providing participants with the key discussion themes or guiding questions in advance, allowing for more reflective and comprehensive inputs. Additionally, the study invited a diverse group of stakeholders involved in policy making in Ireland, but as with many qualitative approaches, the findings are shaped by the composition and perspectives of the participants. In addition, qualitative data, by nature, are interpretive and context-specific, which can limit the generalisability of findings. Future studies could consider inviting different groups (i.e. frontline workers or vulnerable populations) to gain a wider stakeholder input, or providing participants with the key discussion themes or guiding questions in advance to identify whether study results would be consistent and ensure more reflective responses.

Nevertheless, these insights offer an invaluable foundation for further dialogue and more targeted, in-depth investigations in the future. The study findings revealed a strong stakeholder interest in establishing a national HBM programme in Ireland, viewed as essential for enabling evidence-based policy in chemical risk governance. This interest aligns with the outcomes of the HBM4IRE feasibility study (Human Biomonitoring for Ireland), which has already made foundational progress by identifying priority chemicals and proposing an initial governance structure (Singh et al., 2025a; Singh et al 2025b). The HBM4IRE study also suggested that this is an opportune time for Ireland to establish and operationalise HBM in a structured and informed manner (Connolly and Singh, 2025).

5. Conclusions

The HBM4IRE World Café facilitated a two-way knowledge transfer between international and national experts, as well as between national scientists and policymakers. This enabled the provision of a platform for the co-creation and development of a national human biomonitoring programme in order to evaluate chemical exposures among the population while safeguarding the citizens.

Key discussion points included the requirements for the development of a national HBM programme, identifying the objectives of such a programme (i.e., targeted chemicals/population groups), leveraging existing national infrastructure, expertise, and resourcing, and developing a collaborative governing structure to incorporate expertise across silos and groups. This will ensure that best practices are implemented and that the greatest impact is gained from the HBM data through more science-to-policy actions and recommendations.

The HBM4IRE World Café overall demonstrated a willingness and a need for a national HBM programme and provided insightful suggestions for achieving said goal, for greater impact and sustainability. Given its valuable outcomes, the HBM4IRE World Café approach has demonstrated that it can serve as a model for other countries initiating or planning national HBM programmes or studies, offering a participatory and inclusive approach to building consensus, identifying gaps, and promoting stakeholder ownership for long-term sustainability.

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CRediT authorship contribution statement

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Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix A. Supplementary material

Supplementary data to this article can be found online at https://doi.org/10.1016/j.envint.2025.110025.

Data availability

Data is within the manuscript.

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