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Cambridge Prisms: Plastics

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Research Article

Cite this article: Deeney M, Yates J, Kadiyala S, Cousin X, Dignac M-F, Wang M, Farrelly T and Green R (2025). Human health evidence in the global treaty to end plastic pollution: a survey of policy perspectives. *Cambridge Prisms: Plastics*, **3**, e8, 1–12
https://doi.org/10.1017/plc.2025.5

Received: 20 November 2024
Revised: 13 February 2025
Accepted: 03 March 2025

Keywords:
plastic pollution; human health; global plastics treaty; life cycle; science-policy interface

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Abstract

Science shows mounting global health risks associated with plastics life cycle pollution. Leveraging evidence and streamlining research to inform policy is critical to safeguarding people and planet. We conducted an electronic survey questionnaire, between 16th April and 16th August 2024, amongst United Nations government delegates developing the Global Plastics Treaty. We explored (1) perceptions and prioritisation of human health evidence, (2) preferred plastic pollution mitigation strategies, and (3) priorities for health research. Responses were collected in Qualtrics and analysed using summary statistics, the Fisher's Exact Test, and thematically mapped to the Policy Cycle Framework. We received 27 survey responses, balanced by gender and career stage, including 23 countries and all World Bank country income classifications and regions, but greater representation from high-income and European countries. Human health was the highest-ranking concern related to plastics risks (Sum of rank scores (SRS) = 54). Most delegates expressed strong conviction in evidence of risks associated with plastics chemicals, polymers, products, microplastics and broader life cycle emissions. Reducing plastics production (SRS = 53) and eliminating chemicals, polymers and products of concern (SRS = 53) were prioritised, even amongst those affiliated with waste management departments or less convinced of health risks. We found the least regard for recycling as a strategy to protect health (SRS = 4–5) and eliminating open burning was the most prioritised downstream measure (SRS = 15). Generating quantitative, causal data on risks across plastics life cycles, identifying emerging health hazards, defining criteria, safe lists and substitutes for chemicals, polymers and products were government delegate priorities for research, alongside tools to track policy impacts on health and greater bilateral communication between scientists and delegations. Health risks of all forms of plastic pollution were a concern for most delegates responding to our survey. We identified key priorities for policy-driven research to strengthen the science-policy interface and support evidence-based plastics policy that protects human health.

Impact statement

Plastic pollution generated, emitted and released across the entire life cycle of plastics, including chemicals present in plastics and nano and micro-sized plastic particles, is posing human health risks to populations worldwide. The Global Plastics Treaty to end plastic pollution remains under negotiation by more than 175 countries in 2025 and has the potential to shape safer and more sustainable global systems that protect people and planet. Whilst previous surveys have sought to understand public perceptions of plastic pollution and necessary global responses, very little documented research has explored the views of United Nations (UN) government delegates negotiating the Global Plastics Treaty. These delegates can play a crucial role in connecting science and policy, fostering cooperation between governments, and advancing evidence-based policy. We conducted a survey amongst UN government delegates to identify their most pressing needs for scientific evidence on health to inform their work. We received responses from 27 UN government delegates with diverse geographic representation (23 countries in six World Bank regions) revealing key priorities for scientific research amongst this group. These priorities included (1) generating quantitative, causal data on health risks across the plastics life cycle; (2) horizon scanning for emerging health hazards; (3) establishing criteria, safe lists and identifying substitutes across plastics chemicals, polymers and products; (4) providing tools to track policy impacts on health; and (5) increasing bilateral communication with policymakers. Our study suggests many government delegates are motivated to engage with scientists to advance their understanding and find safer solutions. We urge independent scientists to respond actively to this opportunity by developing interdisciplinary research agendas driven by these policy priorities, advancing innovative data systems and analyses that can inform policy within critical decision-making windows, and engaging with UN government delegations to strengthen the science-policy interface to end global plastic pollution.

Introduction

Ending plastic pollution is an urgent planetary health imperative, integral to protecting global human health and the well-being of future generations (UNGA, 2021). Existing policy, regulation and industry initiatives are limited (Lau et al., 2020), and will be entirely insufficient if plastics production and waste triples, as envisaged by 2060 (OECD, 2022). Leveraging evidence of the human health implications of plastics, and ensuring it is available, accessible and appropriate for policy uptake, could drive more ambitious policy that safeguards people and planet.

Scientific evidence reveals mounting global health risks associated with plastic pollution and its life cycle emissions (Landrigan et al., 2023). More than 16,000 chemicals have been identified in plastics, and over 4,200 are hazardous because of their persistence, bioaccumulation, mobility and/or toxicity (Wagner et al., 2024). These include endocrine disruptors, carcinogens and mutagens (Wagner et al, 2024) associated with reproductive and developmental disorders, obesity, cancers and other chronic diseases (Landrigan et al., 2023; Symeonides et al., 2024). Microplastics are pervasive in all ecosystems, in many food sources and food systems (SAPEA, 2019), and have been found in various human tissues with early evidence of cell damage (Winiarska et al., 2024), changes to the microbiome (Fournier et al., 2023), inflammatory and immune responses (Landrigan et al., 2023). Greenhouse gases and air pollutants emitted from plastics industries contribute to climate change and respiratory diseases (Deeney et al., 2023; Landrigan et al., 2023). Emissions begin with oil and gas extraction, continue throughout polymer and product production processes, and along the entire plastics life cycle, including from recycling, all forms of waste (mis)management, and the removal of legacy plastics (Seewoo et al., 2024). Plastics accumulation in the environment may exacerbate the risks of flooding (Tearfund, 2023) and infectious disease transmission (Maquart et al., 2022; Ormsby et al., 2024), and can pose risks to food safety and security (FAO, 2021). All people are affected by plastic pollution; but socio-demographic, geographic and even physiological disparities, including being within critical stages of childhood development, result in a disproportionate global burden of disease, poor health and wellbeing (UNGA, 2021; Karasik et al., 2023; Landrigan et al., 2023).

Despite growing evidence of plastics' health risks, environmental concerns appear to have been the primary driver of policy initiatives to date (Global Plastics Policy Centre, 2022; Mederake and Knoblauch, 2019; Nielsen et al., 2023). Reviews of plastics policies and legislation, including more than 100 national plans, product bans and taxes, producer responsibility schemes, and recycling regulations identified only the Zimbabwean ban on polystyrene packaging (2012) (Global Plastics Policy Centre, 2022), Palau's Plastic Bag Use Reduction Act (2017) and the Solomon Islands National Implementation Plan for the Stockholm Convention on Persistent Organic Pollutants (2018) (Farrelly et al., 2020) as explicitly motivated by public health. Environmental concerns were raised twice as often as health concerns in the European Union (EU) parliamentary debate for the adoption of the EU Plastics Strategy and the Single-Use Plastics Directive (Mederake and Knoblauch, 2019). Document analysis revealed these EU policies, and four others including plastic waste amendments to the Basel Convention, were largely informed by scientific evidence (often including evidence published during the year preceding the initiative), but primarily drew on marine litter monitoring data, ecological risk assessment and environmental life cycle assessment (Nielsen et al., 2023).

Since these policies were implemented, much has evolved in science, society and global governance that places greater emphasis on the health implications of plastics. An explosion of research, and the convergence of previously disparate health disciplines, is providing new clarity and syntheses of plastics' manifold health risks (Landrigan et al., 2023). The growing use of One Health (FAO, 2022) and Planetary Health (UNEP, 2024a) approaches explicitly recognises the interdependencies between the environment and human health. Public concern is increasing pressure on policy; a 2024 survey of 19,000+ people in 19 countries found that between 77% and 85% were concerned about the impacts of plastics on their own health, that of their children and loved ones (Greenpeace, 2024). In global governance spheres, plastics' adverse health effects have been recognised as a human rights issue by the United Nations (UN) Special Rapporteur on Toxics and Human Rights (UNGA, 2021). In 2022, the UN adopted the resolution on the human right to a clean, healthy and sustainable environment (UNGA Human Rights Council, 2022), complementing the human right to health (UNGA, 1948). These evolutions may pave the way for health evidence as a more powerful catalyst for change and a core consideration in the next generation of plastics policy.

In March 2022, the UN Environment Assembly (UNEA-5.2) adopted a historic resolution to develop an international, legally binding instrument to end plastic pollution (UNEP, 2022a). The Intergovernmental Negotiating Committee (INC), comprising representatives from 175 national governments, was tasked with developing the framework (UNEP, 2022a). Human health has become a central theme in the ongoing negotiations (Deeney et al., 2022; TESS, 2024), but in order to streamline evidence for policy uptake, a clearer vision of how health evidence is being perceived and used by governments, and their priorities for research to inform policy is needed. While the official standpoint of governments in the INC is relatively well-documented through submissions to the INC web platforms and observer analysis of live negotiations (IISD, 2024), these statements do not necessarily reveal government views and valuation of health evidence. Engaging with government delegates at the individual as well as the organisational level could provide greater insight into priorities for science. These individuals are at the forefront of developing the treaty and they can play a crucial role in connecting science and policy, fostering cooperation between national governments, and advancing evidence-based action within their own governments. As yet, there is no official science-policy interface for the treaty (Syberg et al., 2024), though many stakeholder groups attend the INC as observers and engage with policy informally, including scientists, civil society groups and industry representatives. Scientists must find ways to focus their efforts on maximising government delegates' understanding of available evidence, identifying and correcting mis- and disinformation, responding to government imperatives, utilising the most effective mechanisms for evidence uptake, and documenting approaches where possible (Syberg et al., 2024).

To contribute to strengthening the science-policy interface on plastics and to guide effective research agendas for informing policy, our study aimed to (1) understand perceptions and prioritisation of plastics' human health risks amongst government delegates negotiating the Global Plastics Treaty, (2) examine how their views and valuation of health evidence may influence their preferred strategies to reduce plastic pollution and (3) identify policy-driven priorities for scientific research and communication on human health throughout plastics policy cycles.

https://doi.org/10.1017/plc.2025.5

Methods

We conducted an electronic survey questionnaire among government delegates of the INC tasked with developing the Global Plastics Treaty. Ethical approval for this study was obtained on 11th April 2024 from the Observational Research Ethics Committee of the London School of Hygiene & Tropical Medicine (LSHTM Ethics Ref: 29939).

The questionnaire was developed and piloted by the Study Management Team at LSHTM. Ten questions were designed to assess different aspects of delegate perspectives on health evidence (Supplementary Material). We drew on existing surveys of citizen perspectives of plastic pollution (Barbir et al., 2021; Davison et al., 2021; Greenpeace, 2024) and the Policy Cycle Framework, adapted in a report of recommendations for a science-policy interface on plastics (GRID-Arendal, 2023b). Respondents were asked to rank items (1–3 or 1–5) according to priority concerns about plastics, preferred information sources and forms of evidence communication, the policy strategies they perceived as most promising for protecting human health and their recommendations for research agendas. Using Likert scales, respondents indicated their level of concern, conviction and satisfaction regarding available evidence and estimates of specific health risks across the plastics life cycle (Supplementary Material). Delegates provided further recommendations *via* free text. We collected information on government delegates' gender, country affiliation, employment position and the thematic focus area of their government ministry, department, or agency (e.g. "Environment," "Human Health," "Waste Management"), for which multiple options could be selected, including "Other" with free text to provide details.

The questionnaire was hosted as an interactive web form in Qualtrics. Questions were available in English only, but responses were invited in any preferred language. We envisaged the questionnaire should take no longer than 15 min; the median response time was 12 min.

Participant recruitment

The UNEP directory of National Focal Points defined the primary target population of our study (UNEP, 2024b). This public repository includes names, employment and contact details of the government delegates designated as the lead "National Focal Point" for each of the INC government delegations negotiating the treaty (UNEP, 2024b).

Recruitment was conducted between 16th April and 12th August 2024. We contacted all 255 National Focal Points *via* email and invited government delegates during science–policy interactions at the INC-4. Four invitations were emailed to all National Focal Points, one additional French-translated email was sent to all National Focal Points of francophone countries, and personalised emails to government delegates where appropriate. All received the *Survey Recruitment Email* with a link to the online questionnaire, where the *Survey Respondent Information and Consent* was detailed and obtained (Supplementary Material). The questionnaire was available for government delegates to respond to between 16th April and 16th August 2024.

Data protection and confidentiality

Respondent confidentiality was protected in accordance with the Data Protection Act. Access to the questionnaire was *via* an anonymous weblink, which prevented multiple submissions but did not record IP addresses, locations or contact information. All identifying data were anonymised, including assigning country affiliations to the respective World Bank Country Income Classification and region, and coding specific employment positions according to early-, mid- or senior-level policy or diplomatic career stages for the purpose of analysis and reporting.

Statistics and data analysis

Data were analysed using summary statistics and simple frequency distributions for Likert scales. Ranked responses were assigned weighted numeric values (i.e. 1st choice = 3, 2nd choice = 2, 3rd choice = 1) to calculate the sum of weighted rank scores for each rank position (pRS) and overall for each response category (SRS). The Fisher's Exact Test (FET) was used to assess associations between respondents' affiliated country income classification, region, gender and career stage (subsequently referred to collectively as 'respondent characteristics' unless individually specified), particular thematic focus areas of their ministry, department or agency and between categories of responses. We conducted a thematic analysis of free text responses, translating those provided in languages other than English with review by multiple study authors, to identify common themes in government delegate priorities for research, using the Policy Cycle Framework (GRID-Arendal, 2023b) to synthesise recommendations. The data presented are available in the Supplementary Material.

Results

Respondent characteristics

We contacted all 255 National Focal Points and additional government delegates corresponding to a total of 153 governments and four multi-state groups. We received 44 survey initiations, and 27 delegates (affiliated with 23 different countries) submitted responses to most questions. The response rate equates to 10% of National Focal Points, though other government delegates may have been included, and 15% of countries contacted. None withdrew consent during the study.

All World Bank regions and country income classifications were represented to some extent. Affiliations with countries in Europe and Central Asia were most frequent (n = 10 respondents from ten different countries), followed by Sub-Saharan Africa (n = 6 respondents from five countries) and Latin America and the Caribbean (n = 5 respondents from four countries), with just six respondents associated with four countries across East Asia and Pacific, South Asia, and the Middle East and North Africa. Across all regions, low-income countries were underrepresented (n = 2 respondents from two countries) (Figure 1).

Respondent gender was balanced (Figure 1). Employment information provided suggested respondents held early-career policy roles (n = 5), mid-level (n = 8) and senior diplomatic and policy roles (n = 5). Others provided educational status, particular appointments (non-specific to career stage) or no information (n = 9). Most indicated the thematic focus area of their ministry, department or agency related to the environment (n = 16), or waste management and pollution control (n = 12). Climate change was a common theme across organisations with more than one thematic focus (n = 8), and others included sustainable development (n = 5), marine and ocean (n = 4), energy and natural resources (n = 4), international affairs (n = 4), technology and innovation (n = 1),

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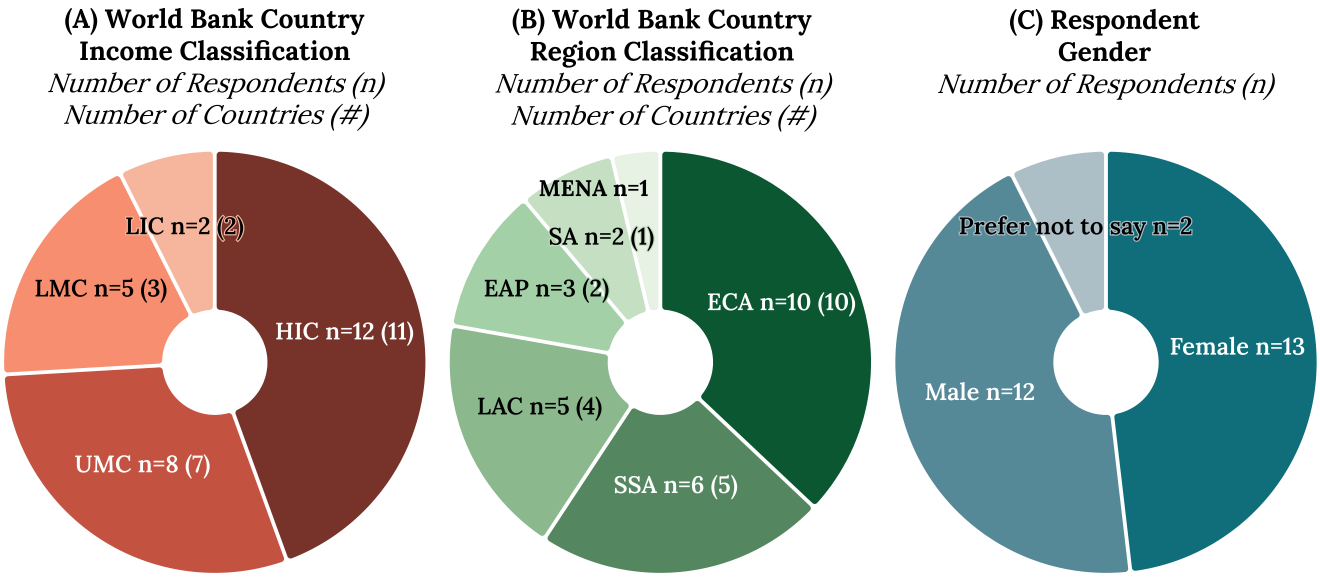

Figure 1. Respondent characteristics. Government delegate survey respondents characterised by (A) World Bank country income classification and (B) World Bank country region classification of respondents' country affiliations, and (C) gender as reported by respondents. Abbreviations: High-income countries (HIC), Upper-middle-income countries (UMC), Lower-middle-income countries (LMC), Low-income countries (LIC), Middle East and North Africa (MENA), South Asia (SA), East Asia and Pacific (EAP), Europe and Central Asia (ECA), Latin America and the Caribbean (LAC), South Asia (SA), Sub-Saharan Africa (SSA).

agriculture and food (n = 1) and water and sanitation (n = 1). Only three indicated a human health focus of their role or organisation.

Perceptions and prioritisation of the human health implications of plastics

Human health was the leading concern related to risks associated with plastics systems, products, polymers and chemicals, based on the sum of weighted rank scores of respondents' top three concerns (SRS = 54) (Figure 2). This was followed by ecosystems and biodiversity (SRS = 42) then climate change and air pollution (SRS = 34). Five respondents were primarily concerned with food systems and safety (pRS = 15), just one ranked human rights as their foremost concern (pRS = 3), and economic and employment risks were amongst the top three for four delegates (SRS = 5).

Unsurprisingly, respondents with an organisational focus on health ranked human health as their primary concern. For others prioritising health, there was no discernible pattern by country income classification (FET: p = 1), region (FET: p = 0.57), gender (FET: p = 0.85) or career stage (FET: p = 0.67). Only two delegates did not rank human health within their top three concerns, focusing instead on (1) ecosystems and biodiversity, (2) climate change

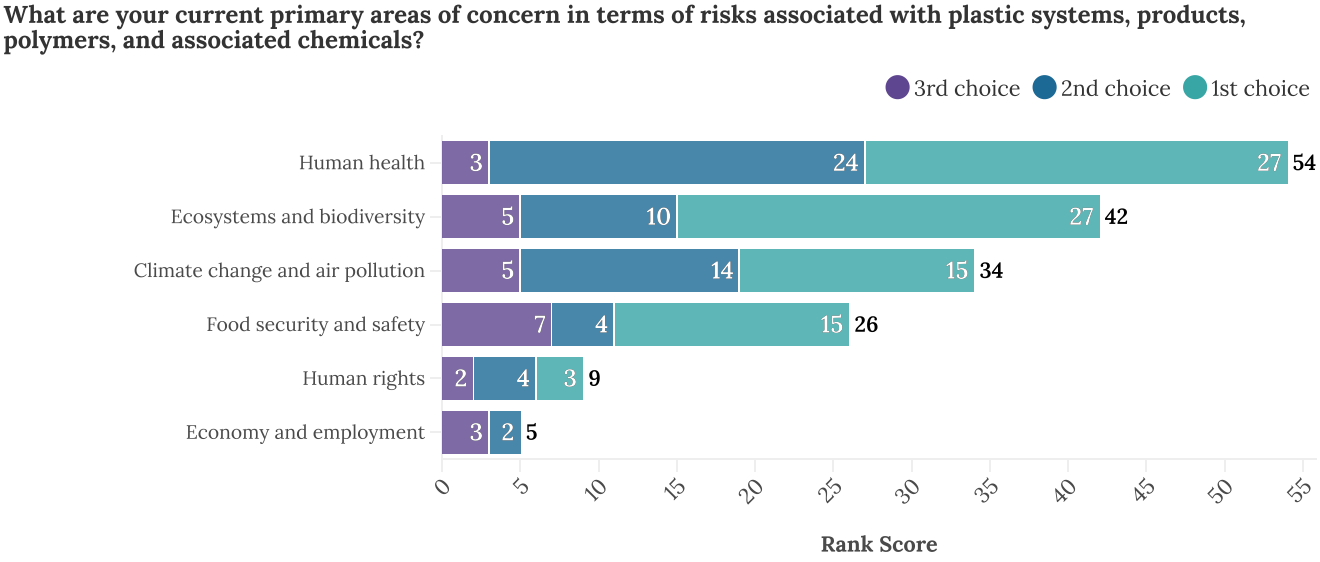

Figure 2. Primary areas of concern in terms of the risks associated with plastics systems, products, polymers, and associated chemicals. Respondents were asked to rank their top three areas of concern from the list of provided categories indicated in the bar chart including an option for 'other' with free text (Total respondents = 26, n = 4 respondents selected more than three areas of concern, no respondent selected 'other'). Ranked responses were assigned weighted numeric values (1st choice = 3, 2nd choice = 2, 3rd choice = 1) to calculate the sum of weighted rank scores for each rank position (values within bars) and overall for each response category (SRS). The SRS represents the total score for each area of concern based on respondents' 1st, 2nd and 3rd choices (indicated to the right of each bar). For example, human health was selected as 3rd choice by 3 participants (multiplied by 1 = 3), 2nd choice by 12 respondents (multiplied by 2 = 24) and 1st choice by 9 respondents (multiplied by 3 = 27), generating an overall SRS of 54.

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and air pollution, and (3) economy and employment, and (1) human rights, (2) climate change and air pollution, and (3) food security and food safety.

Despite differing priorities, on average, respondents expressed strong concern for plastics' health risks when prompted in the questionnaire (Figure 3A). Most were 'very concerned' about the risks of products and polymers (n = 18), chemicals (n = 19) and emissions associated with plastics life cycles (n = 19). One respondent was 'neither concerned nor unconcerned' about products and polymers, but was 'very concerned' about life cycle emissions. Conversely, another was 'neither concerned nor unconcerned' about life cycle emissions but was 'somewhat concerned' about products, polymers and chemicals. None expressed a lack of concern in any category. We found no evidence of an association between being 'very concerned' about all items and any respondent characteristics including country income classification, region, gender and career stage (FET: p = 0.65–1.00).

Similarly, all delegates reported strong conviction in available evidence of at least some of the specific health risks associated with plastics (Figure 3B). In particular, 88% were 'very convinced' that macroplastic pollution poses risks to food security and biodiversity, and 81% of respondents were 'very convinced' that plastics pollute across their life cycles. There was strong conviction (96%) in microplastic identification in human tissues and associated health risks and no respondent expressed doubt in the presence of chemicals of concern in plastics. We found greater variation and lower overall confidence in statements on the health risks of recycling and reuse. One delegate was 'somewhat unconvinced' of plastics production worker health risks and the energy intensiveness and toxic emissions of chemical recycling.

Human health effects expressed as the number of lives lost were perceived as the most impactful evidence framing overall (SRS = 60), followed by morbidity and mortality, which refers more broadly to the years of healthy life lost in a population as a result of premature death and living with disease or disability (SRS = 49), with economic terms scoring lowest as the sum of weighted rank scores (SRS = 47) (Figure 4A). However, seven respondents (26%) ranked morbidity and mortality as the most impactful, and another seven (26%) ranked economic terms first, indicating some difference of opinion. Whilst those with a preference for the economic framing were all from high or upper-middle-income countries, we found no statistical association with country income classification (FET: p = 0.69), or other respondent characteristics (FET: p = 0.30–0.88). Scientific journal publications (SRS = 47), discussions with scientists (SRS = 45), and policy briefs (SRS = 36) were reported to have been the most useful sources of information overall (Figure 4B). Industry reports (SRS = 7) and social media (SRS = 5) scored lowest and were the first choice for none.

Preferred strategies to reduce plastic pollution and protect human health

Overall, plastics production reduction (SRS = 53) and elimination of chemicals, polymers and products of concern (SRS = 53) were perceived as the most promising strategies for protecting human health in the context of reducing plastic pollution (Figure 5). Even amongst 11 respondents from ministries, departments or agencies with a focus on waste management and pollution control, seven (64%) selected production reduction as their first-order priority, and all but one included it in their top three. Material substitutes (e.g. glass, metal and paper) were ranked amongst the top three strategies by half of the respondents (SRS = 23). Bio-based alternatives (SRS = 12) scored lower overall than material substitutes, but six respondents ranked this strategy amongst their top three choices, and two saw this as the most promising approach, which did not appear to be associated with respondent characteristics (FET: p = 0.25–0.41) or their priority concerns. Although delegates expressed lower overall confidence in the evidence for the health risks of mechanical and chemical recycling, neither did they prioritise these strategies highly for protecting human health (RS = 5 and RS = 4, respectively).

We found no evidence of an association between participant characteristics and the prioritisation of upstream measures, including (1) production reduction, (2) elimination of chemicals, polymers and products of concern, and (3) polymer and chemical simplification (FET: p = 0.23–1.00). Upstream measures were prioritised even by participants who were 'neither concerned nor unconcerned' about products, polymers or life cycle emissions, and 'somewhat unconvinced' about risks to production workers and from chemical recycling, and amongst the top three strategies for the respondent who was 'not at all convinced' by risks of reusing and recycling plastics. For those whose primary concern was human health, 78% prioritised upstream measures, but a third saw eliminating open burning as equally, or in one case, more promising (though production reduction still ranked second). Prioritising elimination of open burning within the top three strategies did not appear to be associated with country income classification (FET: p = 0.46) or region (FET: p = 0.38).

Policy priorities for scientific research and evidence communication on the human health risks of plastics

Most respondents agreed that there was sufficient evidence of plastics' health *risks* to inform policy decisions (89%) though four disagreed. In relation to plastics' *benefits*, there was greater divergence in opinions. A third of respondents did not agree that this evidence was sufficient to inform policy decisions, four of which expressed strong disagreement. We found no evidence of an association between perceptions of evidence of risks or benefits and respondent characteristics (FET: p = 0.35–1.00) or their preferred sources of information (FET: p = 0.19–0.20).

To help guide research agendas, delegates were asked to rank categories based on the Policy Cycle Framework according to where they felt evidence was most needed to inform policy: (1) filling existing data gaps, (2) horizon scanning, (3) policy formulation, (4) policy implementation, and (5) monitoring and evaluation (GRID-Arendal, 2023b). Half of the respondents provided further qualitative recommendations for health scientists (n = 14). We analysed qualitative responses thematically, mapping them to the same Policy Cycle Framework categories.

Overall, research aligning with the early stages of the Policy Cycle Framework was prioritised by respondents, as assessed by the sum of weighted rank scores. This included (1) filling existing data gaps (SRS = 102) and (2) horizon scanning for evidence of emerging health risks (SRS = 85). Respondents raised the importance of generating *quantitative* evidence of health impacts, including *cause-and-effect* relationships, and greater consideration of people who are most vulnerable and disadvantaged. Evaluating the health risks of all forms of plastic pollution and throughout plastics life cycles was suggested, including providing a greater understanding of the health risks of plastics recycling and reuse, and developing tools to capture these risks in life cycle assessment (LCA).

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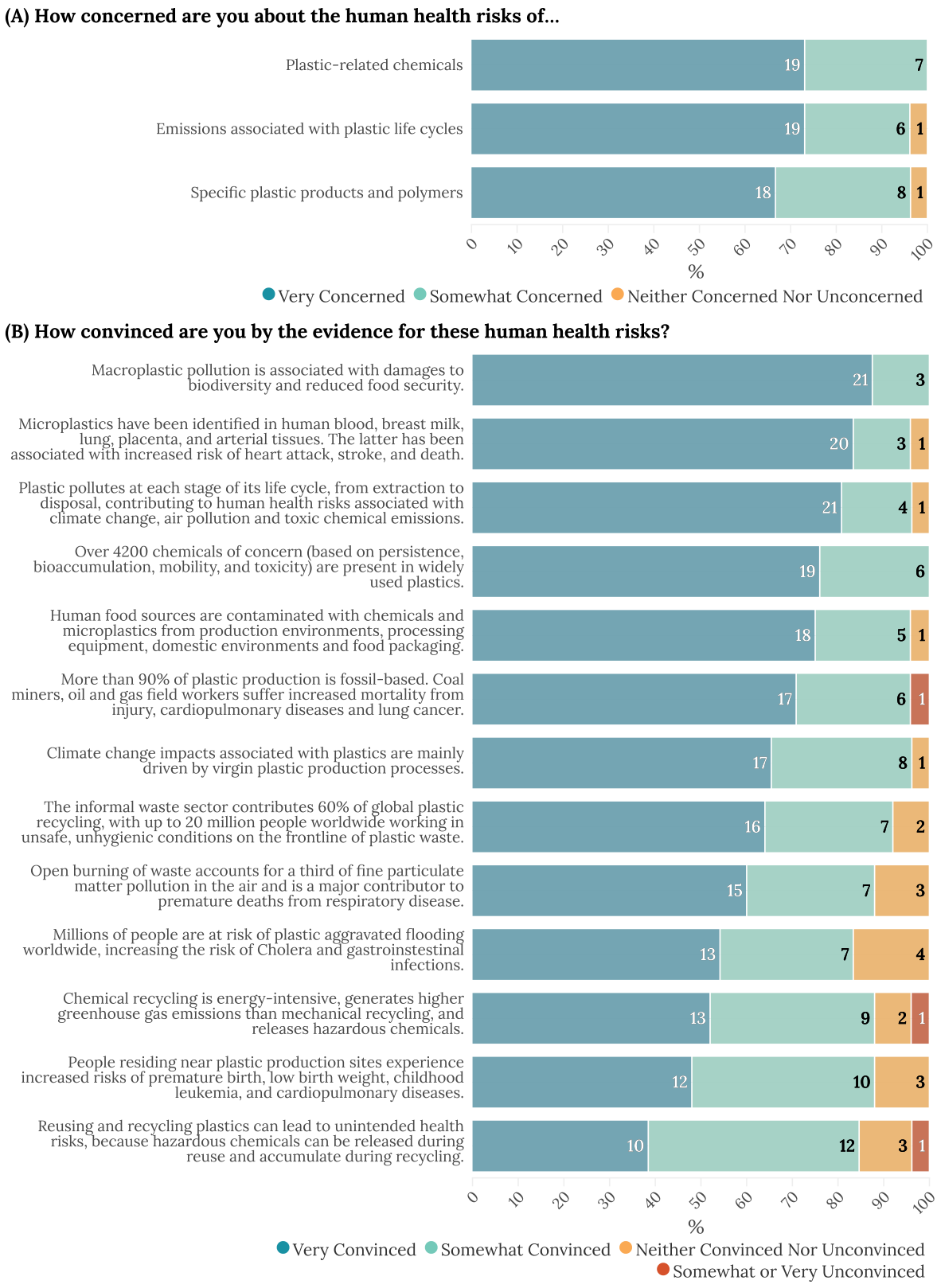

Figure 3. Levels of concern and conviction in evidence for the human health risks associated with plastics. (A) Reported levels of concern about the human health risks of specific plastics products and polymers, plastics-related chemicals, and emissions associated with plastics life cycles indicated by selection of one option from a five-point Likert scale: 'Very concerned', 'Somewhat concerned', 'Neither concerned nor unconcerned', 'Somewhat unconcerned', 'Not at all concerned' (Total respondents = 26–27 for different items). (B) Reported levels of conviction in the evidence for each sub-item listed in the bar chart, as indicated by selecting one option from a five-point Likert scale: 'Very convinced', 'Somewhat convinced', 'Neither convinced nor unconvinced', 'Somewhat unconvinced', 'Not at all convinced' (Total respondents = 24–26 for different items). Number of participants selecting each option are indicated within bars and scaled to represent 100% of respondents for each question sub-item.

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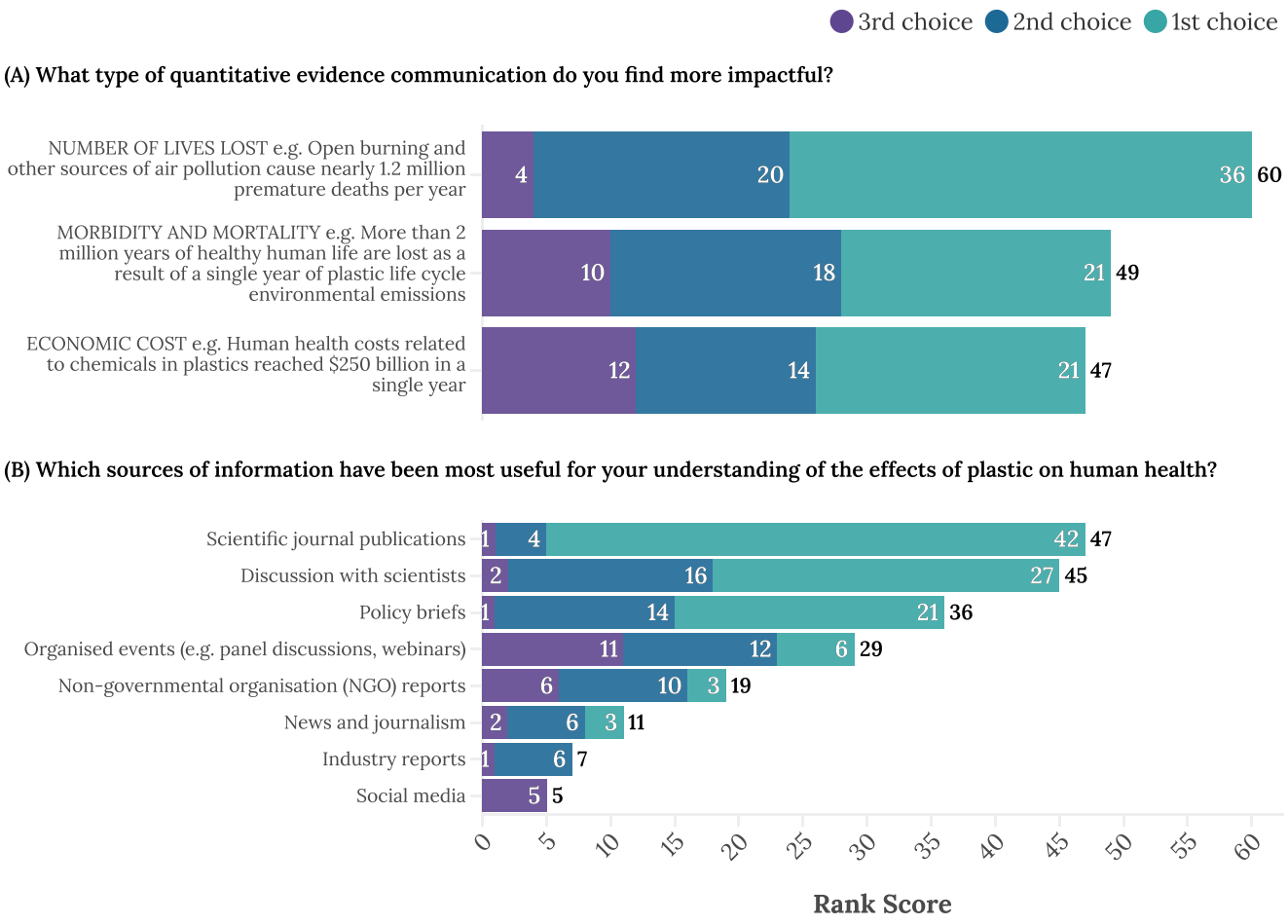

Figure 4. Perceptions of evidence communication terminologies and reported usefulness of different sources of evidence for informing government delegates' understanding of the effects of plastics on human health. (A) Types of quantitative evidence communication ranked according to how impactful government delegates perceived these terms to be. Respondents were asked to rank the three types of evidence communication provided from 1st choice = most impactful to 3rd choice = least impactful (total respondents = 26). Notes: The number of lives lost is the simple count of lives lost in a population, whereas morbidity and mortality refer more broadly to the years of healthy life lost in a population as a result of premature death and living with disease or disability. (B) Sources of information ranked according to reported usefulness for informing current understanding amongst government delegates. Respondents were asked to rank their top three sources of information according to which have been most useful in informing their understanding (total respondents = 27, $n = 7$ respondents ranked more than three categories, and one provided only their first choice). Ranked responses were assigned weighted numeric values (1st choice = 3, 2nd choice = 2, 3rd choice = 1) to calculate the sum of weighted rank scores for each rank position (values within bars) and overall for each response category (SRS). The SRS represents the total score for each option based on respondents' 1st, 2nd and 3rd choices (indicated to the right of each bar). For example, 'number of lives lost' was selected as 3rd choice by $n = 4$ participants (multiplied by 1 = 4), 2nd choice by $n = 10$ respondents (multiplied by 2 =, 20) and 1st choice by $n = 12$ respondents (multiplied by 3 = 36), generating an overall SRS of 60.

> "Human health scientists should, in my opinion, focus on […] the effects of all kinds of plastics pollution." Respondent, Subsaharan Africa region, male.

> "Detailed research and scientific evidence-based proof of health risk throughout the life cycle of plastic needs to be done." Respondent, South Asia region, male.

> "It is imperative to develop instruments that can inform LCA analysis on all risks connected to plastic production, use, reuse and recycling" Respondent, Europe and Central Asia region, prefer not to say.

Evidence to inform the third Policy Cycle Framework category of policy formulation, which we suggested could include scientific criteria for health hazards, pollution control measures and policy trade-off analyses, also scored highly overall (SRS = 88). Respondents recommended developing *criteria* for polymers and chemicals, and three requested more information on available plastics and chemical substitutes. Two delegates suggested "positive lists" for chemicals and polymers would be particularly important.

> "Scientists should provide classification criteria for primary plastic polymers and chemicals for the INC to inform the adoption of provisions that will facilitate the elimination of plastics pollution" Respondent, Subsaharan Africa region, male.

> "…information related to the substitution of plastic or chemical products in essential plastics, such as those in the health sector." Respondent, Latin America and the Caribbean region, female.

> "Chemicals of concern discussion is filled with uncertain information from different sources, so comprehensive study (positive list creation, for example - which chemical is safe to use?) is appreciated." Respondent, East Asia and Pacific region, female.

> "Positive list of safe polymers and additives would be most helpful" Respondent, Europe and Central Asia region, male.

Delegates highlighted the need for more information on specific strategies for reducing pollution that could be adopted in national and international regulation and recommended producing estimates of the cost of inaction – *"linking that cost to (the absence of)*

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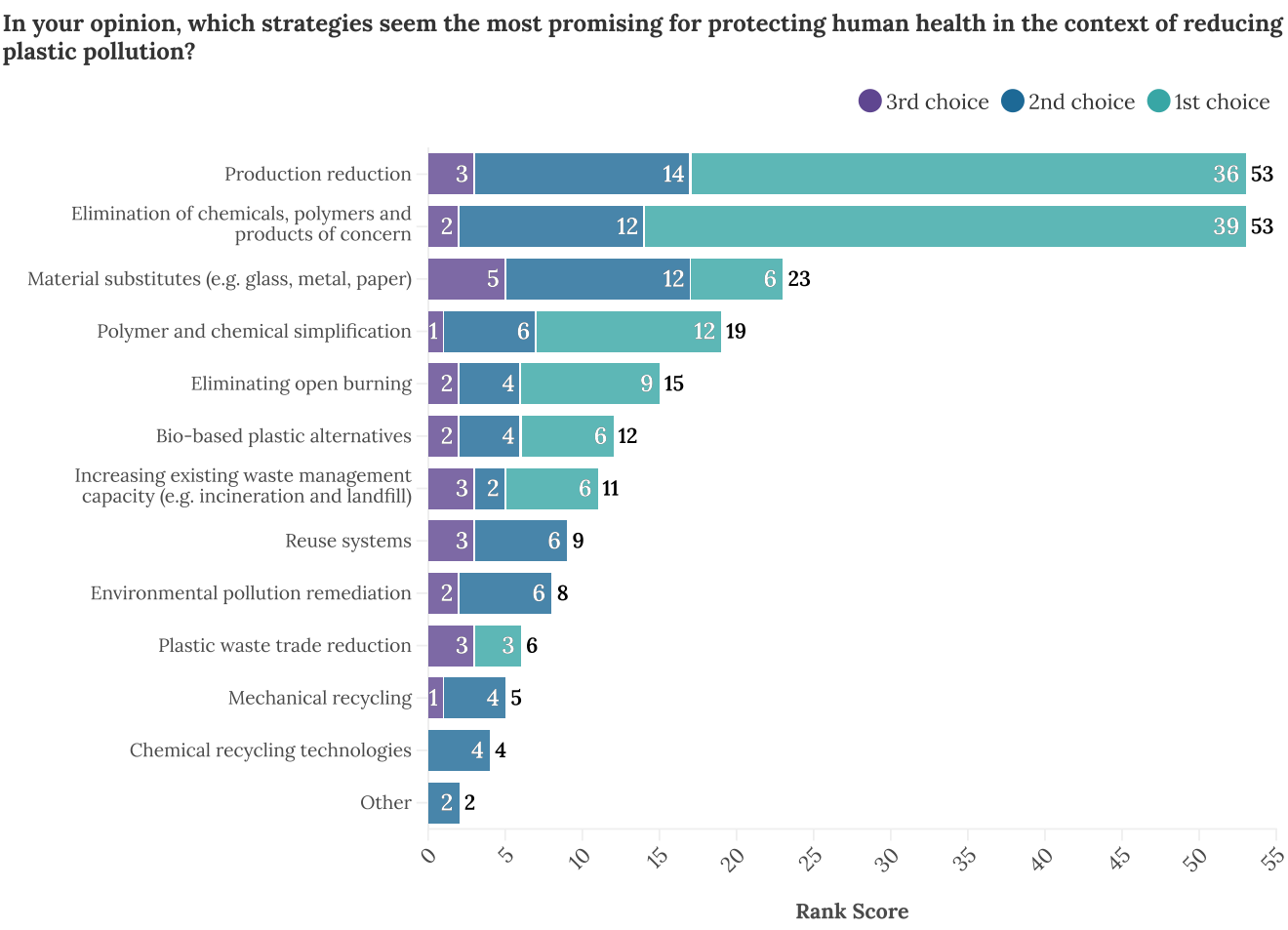

Figure 5. Strategies perceived as the most promising for reducing plastic pollution and protecting human health. Respondents were asked to rank the top three strategies, out of the list provided, which in their opinion would be most promising for protecting human health: 1st choice = most promising, 2nd choice = second most promising, 3rd choice = third most promising (total respondents = 26, *n* = 6 respondents ranked more than three strategies). Ranked responses were assigned weighted numeric values (1st choice = 3, 2nd choice = 2, 3rd choice = 1) to calculate the sum of weighted rank scores for each rank position (values within bars) and overall for each response category (SRS). The SRS represents the total score for each strategy based on respondents' 1st, 2nd and 3rd choices (indicated to the right of each bar). For example, 'Production reduction' was selected as 3rd choice by *n* = 3 participants (multiplied by 1 = 3), 2nd choice by *n* = 7 respondents (multiplied by 2 = 14) and 1st choice by *n* = 12 respondents (multiplied by 3 = 36), generating an overall SRS of 53.

specific measures" (Respondent, Europe and Central Asia region, female). We received calls for *stronger* and more balanced inclusion of health in the Global Plastics Treaty text and building on synergies with climate and tobacco control policies. The final stages of the Policy Cycle Framework – (4) implementation and (5) monitoring and evaluation - were lower-order priorities overall (SRS = 28 and SRS = 17, respectively), though one respondent recommended developing tools that could be easily applied to track policy impacts on human health.

Other recommendations reflected aspects of a broader supportive policy environment, including the need for capacity building, in particular relating to technology transfer, and increasing policy engagement by health scientists. One suggested that policymakers are not sufficiently aware of plastics health hazards and recommended using *"as vivid examples as possible, […] numbers are very powerful - both, related to diseases and to costs"* (Respondent, Europe and Central Asia, female). Two respondents mentioned engaging bilaterally and regionally with delegations, one specifically raised the importance of multilingual scientific communication of health risks.

Discussion

We explored government delegate perspectives and priorities for evidence of plastics' human health implications in the context of the development of the Global Plastics Treaty. Our survey respondents included a balance of genders and career stages, though certain regions and lower-income countries were underrepresented. Human health was the highest-ranking concern related to the risks of plastics, over environmental and economic issues. All delegates were concerned about the health risks of plastic chemicals, most were convinced by health risks associated with microplastics and those resulting from plastics' life cycle contributions to climate change, air pollution and chemical toxicity. Reducing plastics production and eliminating chemicals, polymers and products of concern were highly prioritised strategies to protect human health, even amongst delegates affiliated with waste management and pollution control ministries, agencies or departments, and those less convinced or concerned by evidence for plastics' health risks. We found more diverse perceptions of the health risks of plastics recycling and reuse, and the lowest regard for recycling as a strategy to protect human health. More delegates ranked material substitutes within their top three strategies than plastics alternatives

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(i.e. bio-based plastics). Eliminating open burning was the most prioritised downstream measure, particularly amongst those concerned primarily by human health, though increasing existing waste management capacity, reducing waste trade, and pollution remediation also featured. Whilst delegates largely found evidence of health risks sufficient to inform policy decisions, many identified filling existing evidence gaps and horizon scanning for emerging health hazards as research priorities.

Government delegates expressed views broadly aligned with scientific consensus on plastics' human health implications and mirroring high levels of risk awareness reported in a survey amongst members of the public in Europe and Australia (n = 15,179) (Davison et al., 2021). In the case of plastics chemicals, strong and growing evidence reveals links to reproductive and developmental disorders, neurotoxicological effects, obesity, cancers and other chronic diseases, even at low levels (Maffini et al., 2021; Lambré et al., 2023; Landrigan et al., 2023). Several recent scientific publications (Geueke et al., 2024; Symeonides et al., 2024; Trasande et al., 2024; Wagner et al., 2024) have provided policy-relevant, robust data on the *quantities* of chemicals of concern in plastics or *quantitative* associations with particular disease outcomes, using simple and definitive messaging and conveying complexity, all of which are considered important for influencing policy (Oliver and Cairney, 2019). This is particularly pertinent given delegates indicated a preference for scientific publications as a source of information in our survey. Mainstream media is potentially more influential amongst the public (Barbir et al., 2021) and can be an important proponent of raising awareness. For the nascent field of research on the human health implications of microplastics, which is receiving significant media attention, caution is needed to communicate that the biological effects are not yet fully understood (Thompson et al., 2024). Building relationships between scientists and journalists can ensure accurate and timely science reporting to amplify public knowledge and motivation for change.

In addition to direct health concerns, statements reflecting plastics' contribution to the triple planetary crisis (i.e. pollution, climate change and biodiversity) received strong agreement in our survey. This could be connected to repeat messaging from reputable sources including scientific publications (Carney Almroth et al., 2022; Persson et al., 2022), non-governmental organisation (NGO) reports (GRID-Arendal, 2023a), policy briefs (Scientists' Coalition for an Effective Plastics Treaty, 2024a) and UNEP communications (UNEP, 2022b, 2023), which have emphasised plastics' planetary health impacts, potentially leveraging different facets of delegate concerns (Oliver and Cairney, 2019). These concerns could also be related to delegates' existing expertise (Oliver et al., 2014; Oliver and Cairney, 2019), given their affiliations with organisations focusing predominantly on the environment and climate change. We found diverse preferences for evidence communication in our sample and one delegate suggested that it "depend[s] on who you are talking to." Evidence uptake will likely be accelerated if scientists can generate, situate and translate evidence for different concerns, addressing the existing knowledge of policymakers (Oliver and Cairney, 2019).

Support for reducing plastics production and eliminating chemicals, polymers and products of concern may be partly due to a highly motivated, self-selected sample of delegates in our survey, but this also reflects broader support for upstream measures to address plastic pollution, expressed firmly by scientists (Scientists' Declaration, 2024) and by many governments (Centre for Science and Environment, 2024). The support from delegates with a focus on waste management and pollution control, and those expressing lower levels of concern or conviction in plastics' health risks may indicate motivations other than human health for reducing plastics production, possibly including reducing burdens on waste management processes and other environmental, social or economic impacts of plastic pollution.

What may remain less clear to delegates, is how to ensure that the *responses* to plastic pollution, such as reducing or replacing plastics, protect and promote health. Both in our survey and through the INC intersessional technical working groups, delegates have requested scientific criteria and 'positive lists' for plastics chemicals, polymers and/or products, and more information on safe substitutes (TESS, 2024). In an analysis of international regulation of other chemical pollutants, the availability of viable alternatives was found to determine support for strict regulation, more so than evidence of harm to the environment or humans (Aanesen et al., 2024). It is important however, that strategies higher in the waste hierarchy (including redesign, reduction and reuse), aligning with the prevention principle (UNGA, 2021), take precedence over the search for safer and more sustainable alternatives, though the latter is a critical area of active research. The Essential-Use Concept can guide the systematic phase-out of hazardous and unsustainable plastics chemicals, polymers and products by prioritising the removal of unnecessary applications whilst ensuring any essential functions for health, safety and society are maintained through safer, more sustainable alternatives. Or, where no alternative is available or feasible, with careful regulation, time-bound exemptions accompanied by risk minimisation, planning and resourcing for their timely phase-out (Scientists' Coalition for an Effective Plastics Treaty, 2024b).

Science-policy collaborations will be essential to exploring and selecting appropriate, evidence-based policy responses (Oliver and Cairney, 2019). Recycling, reuse, material substitutes and alternatives (i.e. bio-based plastics) require particular focus. These categories of approaches include a range of complex materials, technologies and systems that require specialist knowledge and comprehensive evaluation to mitigate burden-shifting. Delegates may be exposed to mixed messaging on these topics, creating confusion or uncertainty, particularly in the context of rapid technological innovation and emerging scientific evidence, and due to deliberate industry misinformation campaigns, for example around the benefits of plastics recycling (UNGA Human Rights Council, 2021). At the INC-4, fossil fuel and chemical industry representatives outnumbered registrations from 87 of the smallest government delegations combined (CIEL, 2024). Ensuring access to independent science, free of conflict of interest, is critical for policy decisions that are based on robust evidence and the Precautionary Principle where evidence is emerging to protect human health (UNGA Human Rights Council, 2021). This is supported by a growing number of statements from governments at the INC on the need for 'best available science' (IISD, 2024), which in turn corroborates calls for a formal science-policy interface, with strict mechanisms for declaring and managing any conflicts of interest, that can support the implementation, monitoring and evaluation of the Global Plastics Treaty (Syberg et al., 2024).

Strengths and limitations

Our questionnaire was informed by existing surveys and used the theoretical framing of the Policy Cycle Framework to structure the questions and analyse responses. We designed the survey as a form of evidence dissemination and collaborative research agenda-

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setting (Oliver and Boaz, 2019). Whilst we cannot formally assess the impact, survey recruitment facilitated informal science-policy engagement and stimulated further information requests from government delegates.

Our findings may not be representative of government delegate perspectives because of the relatively small number of respondents that likely reflect individuals particularly motivated by health concerns and science-policy exchange. We had limited statistical power to detect trends by categories of respondent characteristics, which in themselves generalise the complexity of influences on individual perceptions and values. The underrepresentation of low-income countries, and certain geographic regions, is an important limitation. Our findings could have differed substantially if we had received more responses from government delegates affiliated with countries for which open burning is a particular issue for example, major importers of plastic, or countries where plastic pollution has more immediate and/or acute impacts on food security, typically associated with lower-income economies (Knoblauch et al., 2018). Similarly, analysis by World Bank country income classifications and regions obscures highly heterogeneous and unique national challenges. We did not receive sufficient responses to create more disaggregated classifications, for example for Small Island Developing States, whose experiences are poorly reflected by World Bank country classifications, and require particular focus and consideration. Overcoming barriers to participation, including delegate time, funding, other resource constraints and linguistic barriers, within all forms of science-policy engagement is critical to understanding diverse challenges and perspectives to guide effective research and policy (Oliver et al., 2014).

Our results may be influenced by social desirability bias and the unobscured focus of the survey on human health, made clear in the research objectives. We did not randomise response options, potentially biassing responses towards those appearing first. The survey was available in English only, which may have limited participation and broadening multilingual engagement emerged as a delegate priority within our survey. Concern and prioritisation of human health in itself should not be interpreted as a proxy or determinant of policy decisions. Government delegates are subject to broad geopolitical decision-making hierarchies, in which scientific evidence is amongst a range of complex and dynamic influences on decisions, not least the economy and the brevity of most political cycles (Oliver et al., 2014). The Policy Cycle Framework is useful for framing evidence required at different stages within policy cycles, but a simplified depiction of a much more complex, non-sequential process (Oliver and Cairney, 2019). Despite these limitations, our results show that many delegates are willing to engage with health science outside of their existing pressures and obligations and to be active partners in developing research agendas for advancing understanding and preventing human health harm from plastics (Oliver and Boaz, 2019).

Conclusion

Our study revealed high levels of concern and conviction in scientific evidence of the health risks associated with all forms of plastic pollution and emissions amongst most government delegates responding to our survey. Science appeared to play an important role as the preferred source of information that informs knowledge amongst these government delegates, which may in turn contribute to their support for upstream measures to reduce plastic pollution and protect human health. Government delegates indicated several priorities to streamline research agendas to better inform policy and to encourage collaboration at the science-policy interface. These priorities included (1) generating quantitative, causal data on health impacts across plastics life cycles; (2) horizon scanning for emerging health risks; (3) establishing criteria, safe lists and identifying substitutes across plastics chemicals, polymers and products; (4) providing tools to track policy impacts on health; and (5) greater bilateral and multi-lingual engagement and communication with policymakers. Increasingly, scientists are required to be agile knowledge generators, communicators and translators within the multi-stakeholder, interdisciplinary, dynamic and often polemic nexus of plastics and health. Establishing a formal science–policy interface under the new plastics treaty, that addresses barriers to participation and mitigates conflict-of-interest, would provide an important bidirectional, transparent, communication platform that streamlines evidence-based policy formulation, implementation, and monitoring and evaluation, guiding both research and policy that ultimately protects and promotes global human health.

Open peer review. To view the open peer review materials for this article, please visit http://doi.org/10.1017/plc.2025.5.

Supplementary material. The supplementary material for this article can be found at http://doi.org/10.1017/plc.2025.5.

Data availability statement. The authors confirm that the data supporting the findings of this study are available within the article and its supplementary materials. Personal and identifying data has not been made available for reasons of confidentiality and in accordance with the ethical approval of this study.

Acknowledgements. We are deeply grateful to all government delegates who took the time to respond to our survey, providing critical insights for research to inform policy, and for their ongoing work in connection with the Global Plastics Treaty to end plastic pollution.

Author contribution. Conceptualisation: M.D., R.G., S.K. J.Y.; Survey dissemination and translation: M.D., X.C. M-F.D., T.F., M.W., J.Y., R.G; Formal analysis: M.D.; Writing original draft: M.D.; Writing – review & editing: All authors.

Financial support. This work is funded through the Innovative Methods and Metrics for Agriculture and Nutrition Action (IMMANA) programme, led by the London School of Hygiene & Tropical Medicine (LSHTM), in partnership with Tufts University and the University of Sheffield. IMMANA is co-funded with UK International Development from the UK government and by the Gates Foundation INV-002962 / OPP1211308. The conclusions and opinions expressed in this work are those of the author(s) alone and shall not be attributed to the Foundation. Under the grant conditions of the Foundation, a Creative Commons Attribution 4.0 Generic License has already been assigned to the Author Accepted Manuscript version that might arise from this submission.

Competing interest. The authors declare none.

Ethics statement. Ethical approval was obtained from the London School of Hygiene and Tropical Medicine (LSHTM) Observational / Interventions Research Ethics Committee (LSHTM Ethics Ref: 29939) on the 11th April 2024.

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