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Short communication

Setting the European environment and health research agenda –under-researched areas and solution-oriented research

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ABSTRACT

Background: The aim of the EU-funded HERA (health and environment research agenda) project is to set priorities for the future European research agenda in the environment, climate and health nexus. We report results from a European researcher's perspective and identify research areas that have been inadequately investigated to date.
Methods: An online survey was completed by European researchers to assess, evaluate and visualise research gaps. These research gaps were identified for 21 predefined areas within 3 main categories: i) classical environment and health paradigm; ii) problem or sector-based research areas and approaches and iii) holistic research areas and concepts. All research gaps were then evaluated by expert groups with the pre-defined criteria and systematically summarized. For areas identified within the survey as under-reported, additional input was sought from a range of key selected experts. The EU project database Cordis was utilized to verify that these areas were under-researched.
Results: Between May and July 2019, 318 respondents from 38 countries reported 624 research gaps. The main areas for attention identified were: urban environments; chemicals; and climate change, (combined n = 313 gaps). Biodiversity loss and health; transport, mobility, sustainable solutions and health; energy transition and health; waste and the circular economy and health; ethics and philosophy and health were areas that were acknowledged as under-researched (combined n = 27 gaps). These under-researched areas were identified as having certain commonalities, they: i) mostly fell in the category "problem or sector based approaches"; ii) they are essential for developing and implementing solutions; and iii) require trans-disciplinary and cross-sectoral collaboration.
Conclusions: Currently attention is given to topical and highly researched areas in environmental health. In contrast, this paper identifies key topics and approaches that are under-researched, yet, are critical for the implementation of the EU Green Deal, related strategies and action plans, and require further investigation and investment. The findings reveal the imperative to foster solutions-oriented, trans-disciplinary and participatory research and its implementation through changes in research funding and research structures.

1. Introduction

Climate change, environmental degradation and pollution and disruption of ecosystems impact human health and the quality of life. Humanity currently faces three major crises which include: climate change, ecosystem degradation and access and equity in health. It is recognised that the impacts of ecosystem degradation on health are likely to increase (Whitmee et al., 2015). Areas of concern related to environmental risk are diverse and include climate change, biodiversity loss, urbanisation, socio-economic inequalities, access and equity in health and occupational settings as well as the quality of air, water and food, and exposure to chemicals, waste, infectious agents and many other stressors (Whitmee et al., 2015). These challenges call for research that leads to interventions, actions and change that carry public health benefits (Haines and Scheelbeek, 2020). In addition, while knowledge-oriented basic research is required for the development of long term

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innovations and solutions, research should also adopt a more immediate and solution-oriented focus directed at the most vulnerable and support associated regulatory and policy needs (Drakvik, 2020; Frumkin, 2015). These solutions need to be implemented, and this may require profound changes, including ethical and philosophical considerations regarding the relationship and responsibility of humans to nature.

Over the last few years, the political agenda has attempted to address these concerns, for example with the adoption of the Green Deal by the European Commission in 2019 (Commission and European, 2019). The Green Deal represents a number of policy objectives and strategies, including climate neutrality by 2050, the biodiversity preservation strategy, the zero pollution ambition and the sustainable food strategy as well as a new circular economy action plan. While these strategies and action plans are predominantly geared towards implementation and change, it has been recognised that these strategies must be accompanied by a research strategy: within the EU, this has been translated into the "Horizon Europe" initiative as well as the Green Deal research programmes. Nevertheless, beyond the existing programmes, many questions remain regarding the priorities for a future environment and health research agenda. The EU HERA (Health and Environment Research Agenda) project funded within the Horizon 2020 framework, aimed to set priorities for an environment and health research agenda in the EU (Barouki et al., 2022). To achieve this aim, the research community, as well as other relevant stakeholders were approached to identify relevant, important and urgent research gaps. This paper reports on the key findings from the engagement of these experts. Furthermore, it focuses on how significant topics and approaches, which are under-researched, but yet critical to the environment and health agenda were ascertained and their commonalities identified. We outline the resulting implications for future research structures and funding required to support both a future research agenda and the implementation of the EU strategies under the Green Deal which aim to tackle the main environment and health challenges.

2. Methods

2.1. Survey

An online questionnaire was developed and sent to HERA participants and experts, representatives of research institutes within the EU and associated countries (Norway, Switzerland, Liechtenstein, Iceland), and to members of ISEE (International Society for Environmental Epidemiology), as well as EPICOH (Epidemiology in Occupational Health) societies. In total, a direct invitation to participate in the survey was sent to 470 researchers, with the request that they distribute the questionnaire further through access and contact with other researchers in the field. The online survey was open between 7 May and 20 July 2019 and was completed by 318 researchers. The survey required participants to identify gaps in current research, their significance, identify why they are occurring and possible actions to ameliorate them. Research gaps were reported for 21 pre-defined areas; these were grouped as: 1) classical environment and health paradigm (e.g. chemical, physical exposures and health); 2) problem or sector based approaches (e.g. urbanisation, occupational changes); and 3) holistic approaches (e.g. One Health, Planetary Health), for a full list see Table 1.

2.2. Evaluation and summaries

For each of the 21 pre-defined areas, within the HERA consortium, expert groups were identified and formed who then evaluated and summarised individual research gaps. To prioritize individual research gaps, we applied criteria that pertained to novelty, importance to people, importance to the environment, impact (on policies and practices), as well as the potential to promote innovation within the framework of the sustainable development goals (Kogevinas, 2017). The expert groups added further open research questions to the survey (e.g. based on relevant literature representing existing knowledge gaps). Some research areas (or sometimes sub-topics) received few (<10) research gaps and were therefore categorized as under-researched/under-reported areas. All summaries are available online (Barouki and Kogevinas, 2022) and the research agenda is also accessible (Barouki et al., 2022).

Table 1
Research areas and number of reported research gaps in the survey 2019.

1) Environmental exposures and human health	N	2) Problem/ sector based approaches to environment and human health	N	3) Holistic approaches to environment and human health	N
Urban environment including pollution (air, noise, etc.) and beneficial environments (green, blue space) and human health	134	Climate change including extreme weather, adaptation, mitigation and health co-benefits/adverse health effects	65	Ecosystems under pressure, ecosystem services and human health	25
Biological agents, incl. pollen (allergies) and human health	18	Urbanization, incl. sustainable urban development, healthy cities and human health	20	Socioeconomic factors and the environment, environmental justice, equity, sustainable economic growth, capacity building and human health	33
Chemicals including endocrine disruptors, pesticides and human health	114	Biodiversity loss and human health	2	Environmental change, economic crises, conflict and human health	11
Water contamination considering sea, surface and underground water and human health	13	Transport, mobility, sustainable solutions and human health	8	One health concept including animal and human interactions and health: the role of wild fauna, domestic animals and farming practices in pathogen transmission and human health	21
Ionising, non-ionising radiation and human health	26	Sustainable food production (incl. agriculture) and human health	15	Planetary health/ planetary boundaries, sustainable solutions and human health	37
Plastics (incl. micro and nanoplastics) and human health	11	Energy transition (incl. fracking) and human health	1	Ethics and philosophy concerning environment and human health	9
		Waste, circular economy and human health	7	Transformational change/mitigation action and human health	15
		Industrial, occupational changes and human health	24		

2.3. External experts

To add depth and breadth to the survey, a further group of 12 experts

were identified using a snowball sampling technique where HERA researchers assisted in identifying further potential expertise. These experts were scientists working within the under-researched areas as defined in this study, many from the health field but not all (e.g., including those from the field of ethics and philosophy). These scientists contributed further open research questions. Because only few experts could be identified, their expertise and willingness to contribute were the only selection criteria.

2.4. Ongoing EU environmental health research

To avoid replication of ongoing research, an assessment of recent and ongoing EU projects in the environment, climate and health nexus was completed. Using summaries of the 21 research areas, already outlined, we generated keywords to describe the research gaps. During this process it became clear that "exposome research" was not captured on the list, and this was subsequently added as a 22nd topic into the first category of "classical environment and health paradigm", together with "Covid-19" as a 23rd topic. The keywords were used to search for completed and ongoing research projects available on the EU project database Cordis (https://www.cordis.europa.eu). This was achieved by accessing and evaluating the research framework programs FP7, Horizon 2020, and Horizon Europe actively operating between 1st January 2015 and 15th June 2021, based on the available fact sheets, the results in brief, and other reporting, if available. We tabulated overviews of the projects and evaluated if the research projects addressed health-related questions or only referred to them.

2.5. Text mining of the survey entries

The survey text entries were analysed using text mining procedures without utilising the pre-defined 21 groupings of research gaps, in order to reduce any bias. The frequency of the most common keywords were displayed utilizing word clouds. We applied two types of procedures, n-grams as well as term frequency-inverse document frequency (TF-IDF). Text mining procedures were used on research gap descriptions provided by scientists in the survey, which had a text entry limitation of 750 characters. Text mining was carried out separately for each of the three research categories: classical environment and health paradigm; problem or sector-based approaches; and holistic approaches. In a second step, we performed the same procedure on the table of the EU projects, using the keywords of the projects in line with the above listed three research categories for text-based analysis.

We analysed bigrams (the consecutive sequence of two words) to evaluate most common word combinations. We next performed TF-IDF, which assigns an inverse weight based on the overall frequency that a word appears in a text. The method thus allows us to identify rarely used (and therefore presumably valuable) words in the document (Qaiser and Ali, 2018). We visualised networks of TF-IDF scores to display relationships of simultaneously used words. For completeness, we also visualised networks of recently EU funded projects (2019 and later) and of earlier projects (before 2018). Finally, we calculated and displayed the overall Euclidian distance of the keywords appearing in the three research categories and the EU funded research projects of the past few years. Text mining and visualisation approaches were performed in R version 4.0.3 using the *quanteda* and *tidytext* packages (Qaiser and Ali, 2018; Benoit et al., 2018; Silge and Robinson, 2016).

3. Results

3.1. Survey results and identification of under-researched areas

Between 7th May and 20th July 2019, 318 respondents (52% women), from 38 countries reported 624 research gaps. Most of the respondents were senior scientists with a wide range of job descriptions. Of the EU28 (2019), only Lithuania, Malta and Hungary were not represented. Participants reported 1–134 research gaps per research area (Table 1, Supplementary material S1). The main areas where gaps were identified included urban environments, chemicals and climate change, (combined n = 313 gaps). There were five research areas that received less than 10 reported research gaps each (combined n = 27). These were biodiversity loss and health; transport, mobility, sustainable solutions and health; energy transition and health; waste and the circular economy and health; ethics and philosophy and health. Brief summaries with key points for each of the five identified under-researched/under-reported areas are presented in Table 2. The final summaries of the five areas extended and expanded upon by experts can be found in the supplementary material (supp. mat. S2).

3.2. EU-funded research

Taken together, we identified more than 448 EU-funded projects that met the criteria described above. Of these, most (n = 294) fell into the category of classical environment and health paradigms. Problem and sector-based approaches covered a total of 155 projects and only 39 projects covered holistic approaches. Of these projects, per category, 230, 46 and 29 projects respectively, also tackled some aspect of health-related research. An overview of the projects along with their time frames and keywords is provided in Supplementary Table S3. Overall, it became clear from the survey among researchers and key experts that some areas were under-reported/under-researched and this was found to correlate with the level of funding in terms of the EU list of projects. Indeed, no EU funded project directly addressed biodiversity loss and health; only one project included transport, mobility, sustainable solutions and health; two projects dealt with the energy transition and health; and waste and the circular economy and health; and none were identified that addressed ethics and philosophy and health.

3.3. Text mining approaches

Text mining approaches did not identify overlooked research gaps pertaining to four of the five under-researched/under-reported areas. Interestingly, research gaps pertaining to biodiversity loss and health were more likely to be named in the group of holistic approaches (e.g. as an element of planetary health), rather than in the biodiversity loss and health group. In addition, TF-IDF visualisation (Fig. 1) confirmed the identified under-researched gaps were not named under other research areas in the respective lists of the research gaps. Under-researched areas also did not appear as relevant word combinations or as rare word network connections. Text mining also did not identify these research gaps in the EU funded projects, suggesting that these areas are likely to be significantly underrepresented and under-researched. Graphs of all word clouds, bigrams as well as network visualisations (of the survey and the EU funded projects) are shown in Supplementary S4 Figures SF1-SF29.

4. Discussion

Five under-reported research areas were identified through an online survey completed by European researchers in environment and health. These five areas included biodiversity loss and health; transport, mobility, sustainable solutions and health; energy transition and health; waste and the circular economy and health; and ethics and philosophy and health. The analysis of ongoing EU funded research confirmed these areas as under-researched and under-reported. Although the analysis identified several aspects of these under-researched areas in the list of currently funded projects, we only identified a total of three projects within the five under-reported/under-researched areas that also addressed health. Text mining approaches confirmed this pattern.

Regarding the five under-researched areas identified in our survey, it is noteworthy that they are all strongly linked to, and are required for the implementation of the European Green Deal (Commission and

Table 2
Research gaps for under-researched/under-reported areas, provided through the survey plus direct expert consultation.

Research area	Research questions/gaps	Related EU strategy/ action plan
Ethics & philosophy	The area of ethics and philosophy and how it relates to environmental and human health is very broad, pertaining to not just the planning and implementation of scientific studies but also to how scientific findings (and perceptions of those findings) go on to impact society, both at an individual and an administrative (i.e. policy-making) level. Survey-reported gaps related largely to how scientific findings were communicated and how that communication could proceed in an open and trustworthy manner. Further expert consultation on ethics and philosophy as an overarching topic especially added the need to revisit value frameworks and discuss the relationship of humans to nature. A change of paradigm, clarity and transparency of value frameworks pertaining to different topics could aid in planning research calls, designing studies, prioritising research, and finally in decision making. At the same time, ethical and philosophical questions need to be included in research projects addressing environment and health challenges. Additional research gaps include tackling environmental justice, responsibility to future generations and animal welfare including, but not limited to biodiversity loss.	The EU Green Deal (Commission and European, 2019)
Biodiversity loss and health	There is limited understanding how biodiversity loss will alter the functioning of ecosystems and their ability to provide society with life-supporting services and health- and wellbeing-related goods. Potential risks include escalating threats due to climate change, decreased pollution control, and increased disaster risk - reduced adaptive capacity and resilience, exacerbation of natural disasters and increased vulnerability. In particular, evaluation of biodiversity loss is necessary at all scales, from genes to landscapes, and its effects to human health, both, in terms of pathogenesis as well as salutogenesis. Research gaps in the gaps span very different levels of detail and topics, such as from biodiversity loss metrics to monitoring, infectious diseases and spill-over dynamics, interlinkages from environmental biodiversity to food and dietary diversity, to microbiome diversity and human health as well as the underlying mechanisms of how biodiversity affects human health. Finally, social needs and cultural services of biodiversity need to be considered in investigations. Options for protecting and restoring biodiversity as part of nature based solutions for addressing environmental health risks, such as from climate change, need to be investigated.	EU biodiversity strategy (European Commission, 2030)
Transport, mobility, sustainable solutions and health	Pathways of health effects are mainly related to physical activity of travellers according to travel mode, air and noise pollution exposure of travellers and the wider community, road traffic injury, the contribution of the transport sector to climate change, and use of public space dedicated for vehicles rather than pedestrians, cyclists or green space. Urban planning and sustainable urban development need better integration of health considerations into mobility planning, and a systems view rather than a focus on just technological solutions (e.g. e-mobility). We need better approaches to health impact assessment to do this effectively, e.g. for the potential impacts of e-mobility on land use, travel patterns, access to services and different health pathways, including physical activity. E-mobility also includes the use of e-bikes, for which health effects also need to be assessed (benefits as well as risks from accidents). Assessments need to make use of new data. Further research is needed on strategies to implement, also unpopular, changes in transport concepts, e.g. in sustainable urban planning, and on how to further incentivize sustainable transport modes. Implementation can be supported through winning coalitions that consider trade-offs, unintended consequences, justice implications and vested interests.	Climate action (European Commission, 2030) Zero pollution action plan (European Commission, 2021)
Energy transition and health	Energy transition is crucial to reduce levels of air pollution and limit climate change. The negative effects of air pollution are well known as well as the potential direct and indirect health impacts that climate change can have through different pathways. In addition, harm to human health that could be avoided through transition to renewable energy, such as accidents, environmental pollution due to dangerous transport of hazardous goods or potential health consequences associated	Climate action (European Commission, 2030) Zero pollution action plan (European Commission, 2021) Clean energy/ Energy System Integration (Commission, 2020)

(*continued on next page*)

Table 2 (*continued*)

Research area	Research questions/gaps	Related EU strategy/ action plan
	with fracking need to be considered. Further evaluation is needed of potential health benefits of energy transition beyond reduction of air pollution and greenhouse gases emission (e.g. on water quality) and the identification of unexpected health risks (e.g. associated with changes in land use, including overlap with areas with high natural value and socio-economic, equity and energy security issues for the local population. A synergetic approach « what do we gain, if we plan together » of energy transition and health system strengthening could raise even more (new) research questions. Research on the effectiveness and acceptability of measures to reduce the health care sectorś contribution to CO2 emissions, including health and environmental impact assessments is needed (Keim et al. 2019).	
Waste and circular economy and health	Waste management has become an increasingly complex matter and a cause of concern in regard to effects of human exposure both to waste materials and to the products of waste management on health and well-being. Waste management is seen as an important component of a circular economy with possible benefits including saving natural resources through sustainable growth. Discussions on the benefits of a transition to circular are mainly focusing on efficient and sustainable production and consumption but only to a very limited degree on possible associated positive and negative health impacts. In particular, gaps mentioned that while there was growing knowledge on the toxicity of substances especially in regard to occupational health, there was limited knowledge on the safe usage of products by consumers and even less on the whole life cycle of products. It was also mentioned that health and environmental effects were often not considered by planners and even policy-makers when implementing circular economy policies/ changes/ investments or regulations.	New circular economy action plan (European Commission, 2020) Zero pollution action plan (European Commission, 2021)

European, 2019) and related strategies, namely the European Climate Target (European Commission, 2030), the EU strategy on energy system integration (Commission, 2020), the EU biodiversity strategy for 2030 (European Commission, 2030), as well as the zero pollution (European Commission, 2021) and the new circular economy action plans (European Commission, 2020). While health is not necessarily integrated directly into these action plans, a clear potential for health benefits has been put forward with the stated aims of the Green Deal (Haines and Scheelbeek, 2020). These identified under-researched areas potentially contribute to the achievement of specific sustainable development goals (SDGs), including; SDG 2 (zero hunger), 7 (affordable and clean energy), 12 (responsible consumption and production), 14 (life below water) and 15 (life on land) in connection to SDG 3 (Health and well-being) (United Nations, 2030).

The EU policy strategies and action plans seek to ensure swift implementation of the measures in their respective areas and rely on the availability of evidence (for example for biodiversity loss and health) and the development of solutions (e.g. for transport, mobility, sustainable solutions and health or energy transition and health) for their execution. At the same time, these research fields continue to evolve and new conceptual frameworks are being put forward, such as pathways linking biodiversity and human health (Marselle, 2021). Efforts in this direction need to be further supported. Interestingly, the majority of the identified under-researched topics fall into the category of, 'sector and problem-based areas and approaches' that involve non-health related sectors. As a general principle, most of the identified under-researched areas relate to processes and therefore require novel trans-disciplinary approaches to tackle complex questions. The current composition of research networks dealing with environment and health includes little evidence of researchers from cross-cutting disciplines and experts who work on relevant new and trans-disciplinary questions related to human health. The need to promote fresh thinking in the identified under-researched areas is a critical requirement in driving new approaches to the development of practical solutions (for example in the energy or the transport sector), to address current and future overarching questions in environment and human health, such as climate change or the ecosystem crisis. They are important areas for solution-oriented, trans-disciplinary and participatory research that is urgently needed to deliver feasible and effective solutions beneficial for societal well-being and human health (Ebi et al., 2020). Other sector-or problem-based research areas such as occupational changes and health (or climate change and health) have received a lot more attention in the past, showing that such a change is possible. The research area of "ethics and philosophy and health" provides an overarching conceptual context in which changes to the current political and socio-economic paradigm can be achieved. These required changes may be profound but necessary in tackling the current environment and health challenges. While it is not a sector or problem-based approach, similar aspects of cross-cutting disciplines apply. This in essence, also applies to other sector and problem-based research areas for which many research gaps were listed in the survey, such as climate change and health, or industrial and occupational changes and health. Hence, for the topic "ethics and philosophy and health" it may be more appropriate to integrate relevant research questions into respective environment and health projects, rather than designing entire stand-alone projects that address this area. This could be integrated for example in an "ethics by design" approach (van Veen and Safarlou, 2021).

In fact, all listed research areas (Table 1) can benefit from both environment and health research, including specific research areas identifying health exposures and impacts as a basis and prerequisite for problem-and sector-based research areas developing solutions and particularly investigating ways to implement required changes. Focused research on environmental stressors is needed to support these cross-cutting collaborations and sector-based questions. This specifically applies to the research areas such as urban environment, chemicals and climate change, for which a large number of research gaps were identified in the survey. These gaps provide evidence for three main pillars of urgency in the environment, climate change and health research areas. They also call for input and action, feeding into the European Green Deal (Commission and European, 2019) as well as toward achieving several key SDGs. The observed interlinkages underscore the importance of integrating key research areas into holistic approaches and concepts such as Planetary Health and One Health, to investigate, for example, the implications of biodiversity loss on human health Whitmee et al.,

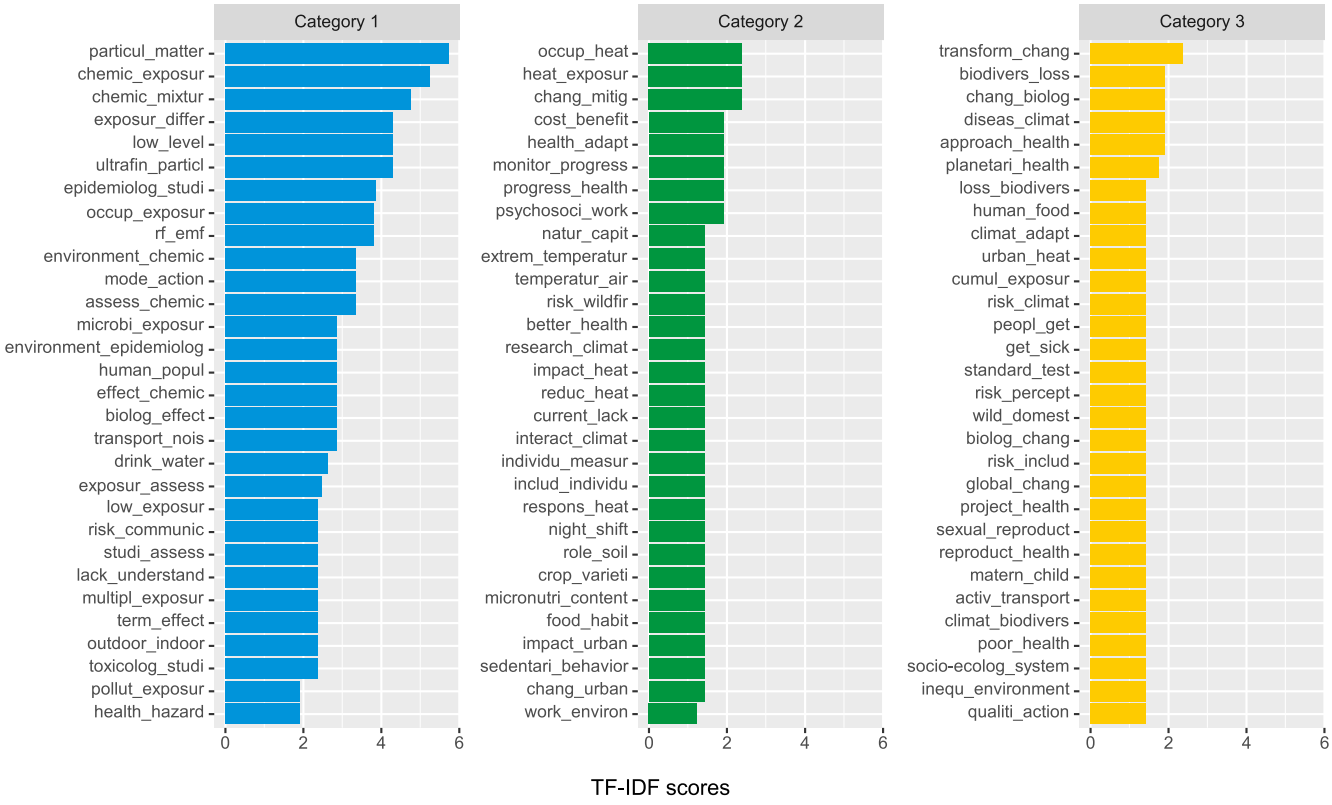

Fig. 1. TF-IDF scores were developed based on survey data of research gap descriptions for 1) classical environment and health paradigm (e.g. chemical, physical exposures and health); 2) problem or sector based approaches (e.g. urbanisation, occupational changes); and 3) holistic approaches (e.g. One Health, Planetary Health).

2015; Haines and Scheelbeek, 2020; Kogevinas, 2017. The needs identified call for changes in research funding and the administrative and implementation structures to strengthen collaboration across disciplines and sectors and to foster the application of new and participatory research that actively involves stakeholders and citizen's perspectives and ideas (Frumkin, 2015). Research to facilitate and ensure the actual implementation of developed transformational solutions needs to be integrated into key projects at all levels. Additionally, this implementation research provides a robust context for a deeper understanding of the inter-relationships within the science-policy-public communication activity and as such will greatly strengthen this critical process (Frumkin, 2015). Capacity building and training in solution-oriented approaches for researchers (and actors) is required, including the incorporation of an ethical context (Frumkin, 2015; Barouki, 2021). Clearly, the magnitude of investment needed to fill these research gaps remains unclear.

Strengths of our approach presented here include the systematic survey and its analysis involving a range of environmental health scientists from many fields. In addition, for areas where only a few research gaps were reported, we additionally contacted specialised experts in and outside of the field to provide additional knowledge and input. The areas identified here appear not to be the principal research focus, with only a few experts actually working at the intersection of the relevant sectors within health. A possible weakness within the approach adopted is that the surveys might not have been fully representative of the scientific community working in the field and that we defined research areas that received few reported research gaps as under-researched or under-reported. In designing the approach used, it was suspected that some of the areas would be challenging and off the "beaten track". In essence, some of these areas may have received little attention because there are only a few scientists working on these topics, or possibly because the needed interdisciplinary experts were not represented in the HERA network of scientists. When scrutinising ongoing EU funded projects, we found limited funding that had been directed towards these research areas involving aspects of health. Finally, we would also like to highlight that the list identified here is not conclusive and could be expanded with further research topics or sub-topics, such as for example digitalisation and health, climate change/conflict and migration and health, which were also identified in our survey as sub-topics that had reported a relatively small number of research gaps (Barouki et al., 2022). Notwithstanding this, it remains the case that even within well-researched areas, important gaps remain (Barouki et al., 2022).

Approaches to develop research agendas have applied different methods, including systematically reviewing scientific publications (Greenstone and Jack, 2015; Chiappetta Jabbour et al., 2019; Robinson et al., 2011), model-based theoretical approaches (Miles, xxxx), or some form of interviews or workshops with different types of stakeholders (Ebi et al., 2020; Leal et al., 2018; Wine, et al., 2019; Wuijts, 2017). The available literature and data suggest that only a few researchers have attempted to integrate ranking systems or suggest approaches on how to prioritize research gaps (Carey, 2012), opting instead to classify or group research gaps. For example, gaps were grouped as an evidence or methodology gap (Miles, xxxx) or along PICOS (population, intervention, comparison, outcome, setting) characteristics (Robinson et al., 2011). Kogevinas (Kogevinas, 2017) has suggested the application of criteria pertaining to novelty, importance to people, importance to the environment, impact on policies and practices, as well as the potential to promote innovation within the sustainable development goals to achieve prioritisation, although a clear methodology on how to achieve a priority list across these criteria was not described (Kogevinas, 2017). We would like to stress that the application of such criteria to a novel research area can be hampered by lack of insight and evidence, which render it difficult to prioritize the short list of individual research gaps.

5. Conclusions

In summary, the identified under-researched areas in the environment, climate and health nexus merit more attention and need to be translated into research topics. Transformational change and implementation research need to be included in addressing environment and health issues. This will inform the implementation of global as well as EU strategies under the umbrella of the European Green Deal (Commission and European, 2019).

CRediT authorship contribution statement

Anke Huss: Conceptualization, Formal analysis, Investigation, Methodology, Writing – original draft, Writing – review & editing. **Annette Peters:** Conceptualization, Writing – review & editing. **Tianyu Zhao:** Formal analysis, Visualization, Writing – review & editing. **Robert Barouki:** . **Manolis Kogevinas:** Funding acquisition, Project administration, Writing – review & editing. **Roel Vermeulen:** Conceptualization, Writing – review & editing. **Franziska Matthies-Wiesler:** Conceptualization, Investigation, Writing – review & editing.

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.

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Appendix A. Supplementary material

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References

Barouki, R., Kogevinas, M., et al., Reports to Research Agenda for the Environment, Climate & Health, accessed 18 Feb 2022 at https://cordis.europa.eu/project/id/825417/results. 2020.

Barouki, R., Kogevinas, M., et al., 2022. EU research agenda for the environment, climate & health 2021-2030 - final draft. Accessed 18 Feb 2022 at: https://www.heraresearcheu.eu. 2021.

Barouki, R., et al., 2021. EU Research agenda for the Environment, Climate & Health 2020-2030. 2021.

Benoit, K., Watanabe, K., Wang, H., Nulty, P., Obeng, A., Müller, S., Matsuo, A., 2018. quanteda: An R package for the quantitative analysis of textual data. Journal of Open Source Software 3 (30), 774. https://doi.org/10.21105/joss10.21105/joss.00774.

Carey, T., et al., 2012. Prioritizing future research through examination of research gaps in systematic reviews. Prepared for the Patient-Centered Outcomes Research Institute.

Chiappetta Jabbour, C.J., Sarkis, J., Lopes de Sousa Jabbour, A.B., Scott Renwick, D.W., Singh, S.K., Grebinevych, O., Kruglianskas, I., Filho, M.G., 2019. Who is in charge? A review and a research agenda on the 'human side' of the circular economy. J. Clean. Product. 222, 793–801.

European Commission, 2019. The European green deal. Brussels, Belgium: European Union, 2019.

Drakvik, E., et al., 2020. Statement on advancing the assessment of chemical mixtures and their risks for human health and the environment. Environ Int 134, 105267.

Ebi, K.L., Harris, F., Sioen, G.B., Wannous, C., Anyamba, A., Bi, P., Boeckmann, M., Bowen, K., Cissé, G., Dasgupta, P., Dida, G.O., Gasparatos, A., Gatzweiler, F., Javadi, F., Kanbara, S., Kone, B., Maycock, B., Morse, A., Murakami, T., Mustapha, A., Pongsiri, M., Suzán, G., Watanabe, C., Capon, A., 2020. Transdisciplinary research priorities for human and planetary health in the context of the 2030 Agenda for sustainable development. Int. J. Environ. Res. Public Health 17 (23), 8890. https://doi.org/10.3390/ijerph17238890.

European Commission, 2020. Powering a climate-neutral economy: An EU strategy for energy system integration. 2020, European Commission Brussels, Belgium.

European Commission, 2020. A new Circular Economy Action Plan: For a cleaner and more competitive Europe. Communication, COM/2020/98 final, 2020.

European Commission, Pathway to a Healthy Planet for All—EU Action Plan: "Towards Zero Pollution for Air, Water and Soil". 2021.

European Commission, Communication from the Commission to the European Parliament, the Council, the Economic and Social Committee and the Committee of the Regions, in EU biodiversity strategy 2030 - bringing nature back into our lives. 2020. p. 1-14.

European Commission, Communication from the commission to the European parliament, the Council, the European Economic and Social Committee and the Committee of the Regions - 'Fit for 55': delivering the EU's 2030 Climate Target on the way to climate neutrality, in COM(2021) 550 final. 2021.

Frumkin, H., 2015. Work that matters: toward consequential environmental epidemiology. Epidemiology 26 (2), 137–140.

Greenstone, M., Jack, B.K., 2015. Envirodevonomics: a research Agenda for an emerging field. J. Econ. Lit. 53 (1), 5–42.

Haines, A., Scheelbeek, P., 2020. European green deal: a major opportunity for health improvement. The Lancet 395 (10233), 1327–1329.

Kogevinas, M., 2017. Setting priorities in environmental health research. Environ. Epidemiol. 1 (1), e001.

Leal, W., et al., 2018. Reinvigorating the sustainable development research agenda: the role of the sustainable development goals (SDG) (vol 25, pg 131, 2017), Int. J. Sustain. Dev. World Ecol 25(2) (2018) p. I-I.

Marselle, M.R., et al., 2021. Pathways linking biodiversity to human health: a conceptual framework. Environ. Int. 150, 106420.

Miles, D.A., A Taxonomy of Research Gaps: Identifying and Defining the Seven Research Gaps.

Qaiser, S., Ali, R., 2018. Text mining: use of TF-IDF to examine the relevance of words to documents. Int. J. Comput. Appl. 181 (1), 25–29.

Robinson, K.A., Saldanha, I.J., Mckoy, N.A., 2011. Development of a framework to identify research gaps from systematic reviews. J. Clin. Epidemiol. 64 (12), 1325–1330.

Silge, J., Robinson, D., 2016. tidytext: Text mining and analysis using tidy data principles in R. J. Open Source Software 1 (3), 37. https://doi.org/10.21105/joss10.21105/joss.00037.

United Nations. Transforming our world: The 2030 agenda for sustainable development. 2015: https://www.un.org/ga/search/view_doc.asp?symbol=A/RES/70/1.

van Veen, E.-B., Safarlou, C.W., 2021. Ethics by design in exposome research. ISEE Conference Abstracts 2021 (1). https://doi.org/10.1289/isee.2021.O-SY-128.

Whitmee, S., Haines, A., Beyrer, C., Boltz, F., Capon, A.G., de Souza Dias, B.F., Ezeh, A., Frumkin, H., Gong, P., Head, P., Horton, R., Mace, G.M., Marten, R., Myers, S.S., Nishtar, S., Osofsky, S.A., Pattanayak, S.K., Pongsiri, M.J., Romanelli, C., Soucat, A., Vega, J., Yach, D., 2015. The rockefeller foundation-lancet commission on planetary health. Safeguarding human health in the Anthropocene epoch: report of the Rockefeller foundation-lancet commission on planetary health. Lancet 386 (10007), 1973–2028.

Wine, O., et al., 2019. Building a children's health and environment research agenda in Alberta, Canada: a multi-stakeholder engagement process. Gateways-Int. J. Commun. Res. Engage. 2019. 12(1).

Wuijts, S., et al., 2017. Towards a research agenda for water, sanitation and antimicrobial resistance. J. Water Health 15 (2), 175–184.