HERA

Health Environment Research
Agenda for Europe

EU RESEARCH AGENDA FOR THE ENVIRONMENT, CLIMATE & HEALTH 2021-2030

HERA CONSORTIUM

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Summary

The HERA project objective and methodology

The HERA Project was funded by the EU Horizon2020 program to develop priorities for the European Union in research on the environment, climate & health. During the course of the HERA project extensive reviews of current knowledge, policies and activities were performed. Web- based surveys targeting research communities and stakeholder groups were carried out along with a series of online and face-to-face consultation meetings, involving hundreds of researchers and other stakeholders. The HERA methodology was based on principles of transparency, inclusiveness and mutual learning and is fully described in the Annex I of the Interim Research Agenda. The specific research recommendations from the HERA project aim to support policy makers, authorities, the public health sector, industry, NGOs and citizens and are summarised in this report "The EU research agenda for the environment, climate & health, 2020-2030".

The HERA vision for future research

The vision for future research underlying this Agenda calls for an unprecedented effort to support a better understanding of the causes, interlinkages and impacts of environmental determinants on health. Integrated and holistic research will support policies and practices to protect and promote human health and wellbeing while simultaneously improving the critical state of the environment, including climate change mitigation and ecosystem restoration, in Europe and globally. Efforts are needed at multiple scales, in various sectors and across the disciplines to address this challenge. Strengthening of solutions-oriented and implementation research is needed in order to develop and implement effective measures and policies.

Relevance. Environmental factors, i.e. climate change, biodiversity losses, global pollution are likely to be among the major determinants of human and ecosystem health in the next decades. They are much less understood than other factors such as genetic determinants which have benefited from strong international and national research support. To address these challenges, major research efforts are needed.

Urgency. In view of the current rate of global environmental degradation, there is a clear need for ambitious research programmes across the nexus of environment, climate and health. This needs to involve the fast tracking of new research initiatives to tackle the 'Grand Challenges of our time', including challenges that are believed to be medium- or long-term in order to consider the timeline required from research to implementation and observable environmental and health improvements.

Integration. The HERA proposals are, in essence, inter- and transdisciplinary and participatory; they integrate several holistic concepts developed recently including One Health, Ecohealth, Planetary health and the Exposome concept. They address issues at different scales covering the global level (e.g. climate change), the community level (e.g. urban life) and more targeted stressor-related questions (e.g. chemicals).

The EU research agenda for the environment, climate & health, 2020-2030

The EU Research Agenda developed by the HERA project identifies six major research goals on the environment, climate and health to be addressed and numerous specific recommendations for research. The Research Agenda emphasizes research that can lead to policies promoting health and the environment. Figure 1 shows the overall framework of the HERA EU Research Agenda.

- **Research *goal 1 "Climate change and biodiversity loss – reduce effects on health and the environment"*** focuses on **global interconnected issues**. The consequences of climate change, biodiversity loss, disruption of food chains, emerging infectious diseases and decreased ecosystem services on health are not well understood despite evidence that they have major and persistent effects on life and the environment globally. The need to promote research for effective policies on mitigation and adaptation is identified as of paramount importance, as is the need to apply holistic approaches such as One-Health and Planetary health.
- ***Research goal 2 "Cities and communities – promote healthy lives in sustainable and inclusive societies"*** focuses on **problem-based research**. Living conditions in urban environments are of key concern as they impact the health and wellbeing of the majority of European citizens. The impacts of environmental factors may vary in different contexts, e.g. urban environment, workplace or polluted sites. Research should examine the complex relationships in these environments, and evaluate and promote positive interventions.
- ***Research goal 3 "Chemicals and physical stressors – prevent and eliminate harmful chemical exposures to health"*** focuses on **chemicals, other stressors and environmental media**. There are still many unknowns on

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the hazards and risks related to stressor families including chemicals and mixtures, physical stressors such as radiation, and the role played by the various environmental media carrying these stressors. Research should effectively address the challenges of a zero pollution paradigm and a sustainable future of mankind and our environment.

- ***Research goal 4 "Improve health impact assessment of environmental factors and promote implementation research"*** focuses on the need to develop new harmonized methodologies to evaluate the burden of environmental and climate change on health and to identify and assess the health benefits of human environmental interaction. Moreover, research should promote optimal ways to implement science-based decisions and policies as this is a limiting factor in many fields.
- **Research goal 5** ***"Develop infrastructures, technologies and human resources for sustainable research on environment, climate change and health"*** focuses on the need of European research infrastructures to be strengthened and further developed in the environmental health field as they provide a basis for excellent research. The proposals include large cohort coordination, exposome characterization, data analysis and planetary monitoring tools.
- **Research goal 6 "*Promote research on transformational change in environment, climate change and health*"** focuses on the need of transformational change to address the intertwined environmental, social and health issues and reach critical global goals towards sustainability and equity. Societies will need to adapt to the challenges elicited by environmental stressors and climate change and this will require significant transformation of individual and collective behaviour and of policy making across the sectors and silos. Development of research approaches directed to finding and promoting workable solutions is necessary for achieving such transformations.

Figure 1: Overall framework of the HERA EU research agenda for the environment, climate and health 2020-2030

INTRODUCTION: the context

The planetary landscape

Climate change, chemical pollution and disruption of ecosystems, including biodiversity loss, impact health and quality of life, and differentially affect socially disadvantaged and vulnerable groups and populations, thereby exacerbating inequalities[1]. Ecosystem services are essential life supporting services (i.e. air, water, food) - and their capacity to regenerate - are not unlimited; therefore, impacts of ecosystem degradation on health are expected to increase remarkably in the future.

Multiple interacting drivers (economic, political-legal, sociocultural, technological, demographic, commercial) are responsible for pressures and impacts on environment and health, locally and globally. These drivers need to be identified and studied to develop effective responses. Emerging and re-emerging infectious diseases, and the high frequency and increase in chronic non-communicable diseases such as neurodegenerative diseases, cardiometabolic, immune diseases, endocrine related diseases and disorders and cancer, are recognised threats to European and international public health. Determinants of individual and population health include personal characteristics, the physico-chemical, social and built environment at home and elsewhere, the work environment, and health services and related factors. It is the interrelationships among these factors that determine individual and population health. Because of this, interventions that target multiple determinants of health can be effective. Determinants of health reach beyond the boundaries of traditional health care and public health services; hence sectors, such as education, housing, transportation, agriculture, and the environment, are critical partners in improving population health.

Areas of concern related to environmental factors are diverse and include climate change, biodiversity loss, urbanisation, inequalities, the status of the health sector and occupational settings as well as air quality, water and food quality, and exposure to chemicals, noise, waste, infectious agents and many other stressors. Although rigorous studies of associated economic costs are missing for many environmental threats, it is believed that the socio-economic costs of environmental degradation are significant. Future costs of inaction and increasing costs of adaptation measures are likely to be much higher than the costs and associated co-benefits of actions; need to be taken now, such as climate change mitigation. It is also recognised that high-quality environments, for example environments providing good access to health care, inclusive and safe neighbourhoods, high quality green and blue spaces, and those promoting active and healthy living standards in cities, can have positive health and socio-economic impacts. Prevention and preparedness have not been sufficiently supported or applied despite the dramatic societal and economic costs that uncontrolled environmental stressors entail in the long run.

Several reports from international organisations such as IPCC[2], WHO[3] and the Lancet countdown[4] have described the current planetary landscape and highlighted the urgency to act, in particular to limit the temperature increase to 1.5°C. Above that threshold, the environmental consequences as well as the health impacts are expected to be severe, reaching limits to adaptation across the globe, although understanding the actual impacts of climate change on health still requires significant research efforts. The impacts are likely to be disproportionate, and in some cases extreme with significant impacts to ecosystems including quality and scarcity of water and food supplies, air quality, and major consequences for health equity, social displacement, migration and political stability. Global environmental changes are exceeding the Earth's planetary boundaries with tipping points in multiple possible systems over the coming decades (Rockström 2020[5], Ebi 2021[6], Halonen 2020[7]-2021[8]).

Other reports have focused on the environmental and health consequences of chemicals.[9] Understanding how the totality of human environmental exposures (the exposome) including multiple stressors over time affect human health, quantifying the corresponding population impact and characterising and assessing their possible interactions are major challenges that need to be addressed in order to develop effective prevention, preparedness and response measures. It is also important to improve the science-policy interface in order to ensure optimal utility of scientific knowledge and data as well as identify where and how risk governance should be improved.

The increased awareness of the links between health and environment has led to several concepts such as the One Health, EcoHealth, Planetary Heath and Global Health. These concepts have changed the traditional vision of human health which was primarily medically focused. While each of these concepts has its own scope linking human health to animal conditions, ecosystems health or to planetary boundaries, they do overlap and in fact each one promotes an integrated vision of health.

[1] WHO, Ostrava Declaration 2017
[2] IPCC 1.5 degrees' report: https://www.ipcc.ch/sr15/download/
[3] WHO report to support the 1.5 degrees' goalhttps://www.who.int/globalchange/181008_the_1_5_healthreport.pdf?
[4] https://www.thelancet.com/journals/lancet/article/PIIS0140-6736(19)32596-6/fulltext
[5] WHO 2020: who-manifesto-for-a-healthy-and-green-post-covid-recovery.pdf
[6] EBi et al.2021, Transdisciplinary Research Priorities for Human and Planetary Health in the Context of the 2030 Agenda for Sustainable Development, IJERPH
[7] Halonen JI et al, The Helsinki Declaration 2020: Europe that protects. Lancet Planet Health. 2020 Nov;4(11):e503-e505.
[8] Halonen JI et al, A call for urgent action to safeguard our planet and our health in line with the helsinki declaration. Environ Res. 2021 Feb;193:110600
[9] https://euchemicalspolicy2030.teamwork.fr/docs/report.pdf

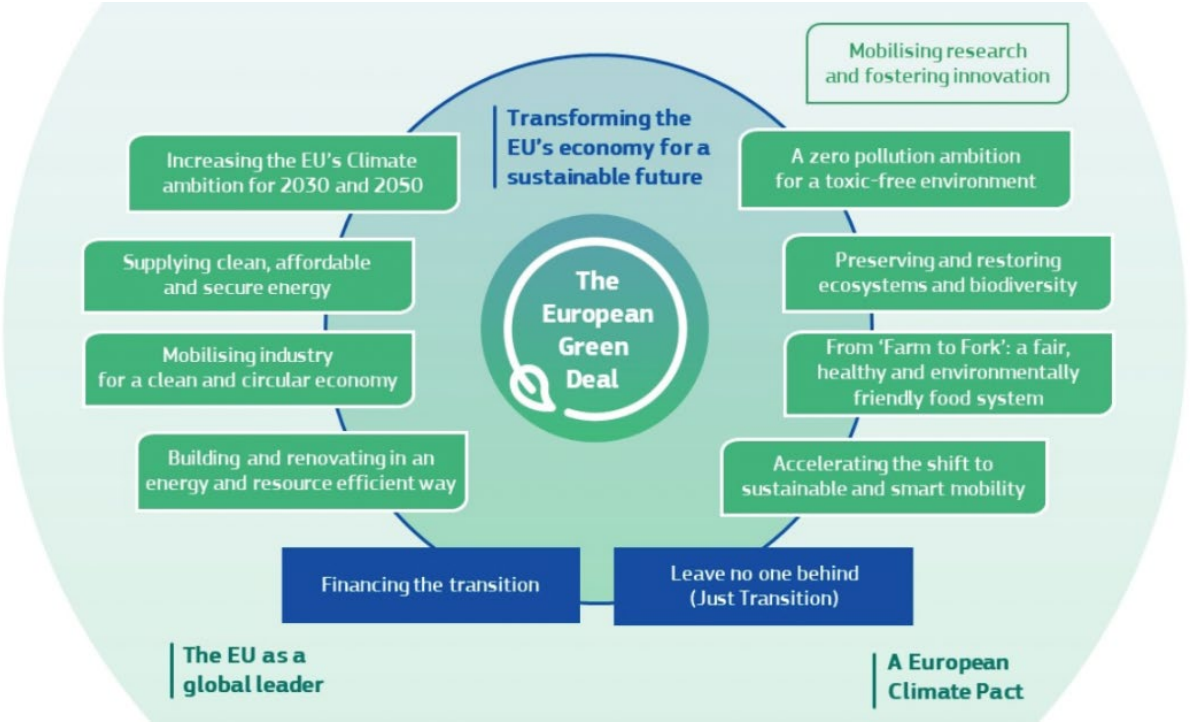
The policy landscape: The European Green Deal

Citizens across the EU and the world [10] are extremely concerned by the deterioration of their environment and related effects on both human and ecosystem health. Over the last few years, the political agenda has attempted to address these concerns culminating in the Green Deal[11] action plan by the European Commission in 2019. The Green Deal consists of a number of policy objectives and strategies, including no net emissions of greenhouse gases by 2050, economic growth decoupled from resource use, and no person and no place left behind (Fig.2). Strategies and action plans include a circular economy action plan, a biodiversity strategy to protect nature and reverse the degradation of ecosystems, an EU Action Plan towards a zero pollution ambition and a Farm-to-Fork strategy. Also, member states have developed dedicated efforts to address citizens' expectations, for example the "Make our planet great again" initiative[12].

In the WHO European region, the environment and health process coordinated by WHO Europe adopted the Ostrava Declaration in 2017 [13] to continue to address some of the major environmental determinants of human health and wellbeing. The Declaration strives to fulfil the vision of a healthy planet and healthy people and actively supports open, transparent and relevant research on established and emerging environment and health risks in order to strengthen the evidence-base to guide policy-making and preventive actions.

At the global level, the Sustainable Development Goals [14] provide a great impetus to integrate health and sustainability through the appropriate selection of indicators relevant to human wellbeing, enabling infrastructure for development and equity, and protecting natural systems, together with the development of strong governance and partnership models. It shows the need for coherent multi-sector strategies that emphasize system-wide and equitable preventive policies in order to improve environmental health conditions and the social determinants of health, particularly amongst the most vulnerable. The COVID-19 pandemic, "the greatest global health shock in decades" has highlighted the critical relationship between people and the planet, demonstrating the importance of nature and natural systems, emergency preparedness, resilient and strong health systems, and social safety nets for human health and well-being[15]. Incentives for recovery from the impacts of the pandemic need to promote a healthier, fairer and greener world - a global movement for health and the environment[16].

Figure 2: The European Green Deal sets a number of policy initiatives that are relevant for environment, climate change and health and related research.



[10] https://ec.europa.eu/info/strategy/priorities-2019-2024/european-green-deal_en
[11] https://www.campusfrance.org/en/make-our-planet-great-again-en
[12] Make our planet great again | Campus France
[13] The WHO European Region includes 53 Member States (WHO/Europe | Countries)
[14] https://ec.europa.eu/info/files/orientations-towards-first-strategic-plan-horizon-europe_en
[15] WHO 2020: who-manifesto-for-a-healthy-and-green-post-covid-recovery.pdf
[16] Barouki, Kogevinas et al. (2020). The COVID-19 pandemic and global environmental change: Emerging research needs. Robert Environment International (2020) Jan;146:106272

The research landscape

Global political strategies must be accompanied by a research strategy that aims to better understand the impacts of environmental and climate stressors on health and environment, the cost-benefits of measures and the optimal mechanisms for the implementation of health protective and promoting measures. At the EU level, this is translated into the key funding programme for research and innovation "Horizon Europe" [17] which includes five mission areas: 1) cancer, 2) adaptation to climate change, 3) healthy oceans, seas, coastal and inland waters, 4) smart cities and 5) soil health and food. All these mission areas are within HERA's scope, assuming that the health-oriented mission covers environmental factors and vice versa. In Horizon Europe, the Health Cluster includes a particular subsection on "living and working in a health-promoting environment", but other clusters and instruments are also expected to address environmental health and climate change related research, hence connecting to several research areas identified in HERA.

There are strong expectations on how research can support public policies to develop preventive and protective actions. A better understanding of the determinants of health is critical to select and implement rational and efficient policies, and above all, to improve health and well-being of citizens Research is needed to address global threats, such as climate change and biodiversity loss and their health consequences, but also to promote healthy and sustainable living in cities and rural communities. There are also fundamental knowledge gaps on the impact of different stressors on health and well-being. For example, only a fraction of commercially available chemicals has been sufficiently characterized with regard to their health hazards (Figure 3)[18]. There is a lack of information on both understanding current impacts and projected risks of recent and projected changes in the earth system, and on evidence-based solutions and policy measures and programs needed to prepare for and manage changing burdens of diseases (Ebi et al, 2021).

Due to the complexity of environmental systems and the clear urgency to implement adaptive and preventive measures, it is recognized that the Sustainable Development Goals will only be achieved through *transformational changes across the economic, social, political and technological fabric of society*[19]. Such holistic transformation would enable the simultaneous achievement of multiple societal goals, including those related to food, water, energy, health and well-being, as well as mitigation and adaptation to climate change and the conservation and sustainable use of nature. Inclusive, integrated and informed governance approaches are needed to enable sustainable transformations to take place and reduce the risks related to the uncertainties and complexities of the transformation processes and emerging global environmental crisis. Thus, in addition to targeted research aiming to specifically address the mechanisms and effects of particular stressors, more holistic research using transformational multi-, inter- and transdisciplinary approaches is needed. The aim of HERA is to identify and prioritise the major research fields and tools that could address the issues raised above. Research is required to not only increase knowledge in relation to the identified needs, but also to increase the integration of available knowledge and advance understanding of its effects in public policy implementation. We also identify the necessary infrastructures and tools that are required to strengthen European research in the environment, climate change and health fields and we make clear recommendations that underscore the importance to support human resources development, including training and education as well as citizen awareness and involvement. The specific research recommendations from the HERA project aim to support policy makers, authorities, the public health sector, industry, NGOs and citizens. The HERA methodology was based on principles of transparency, inclusiveness and mutual learning. The methodology will be further explained in the Annexes.

[17] https://ec.europa.eu/info/files/orientations-towards-first-strategic-plan-horizon-europe_en

[18] https://ec.europa.eu/environment/pdf/chemicals/2020/10/Strategy.pdf

[19] https://ipbes.net/global-assessment-report-biodiversity-ecosystem-services; Flagship2016_FullReport.pdf (unrisd.org)

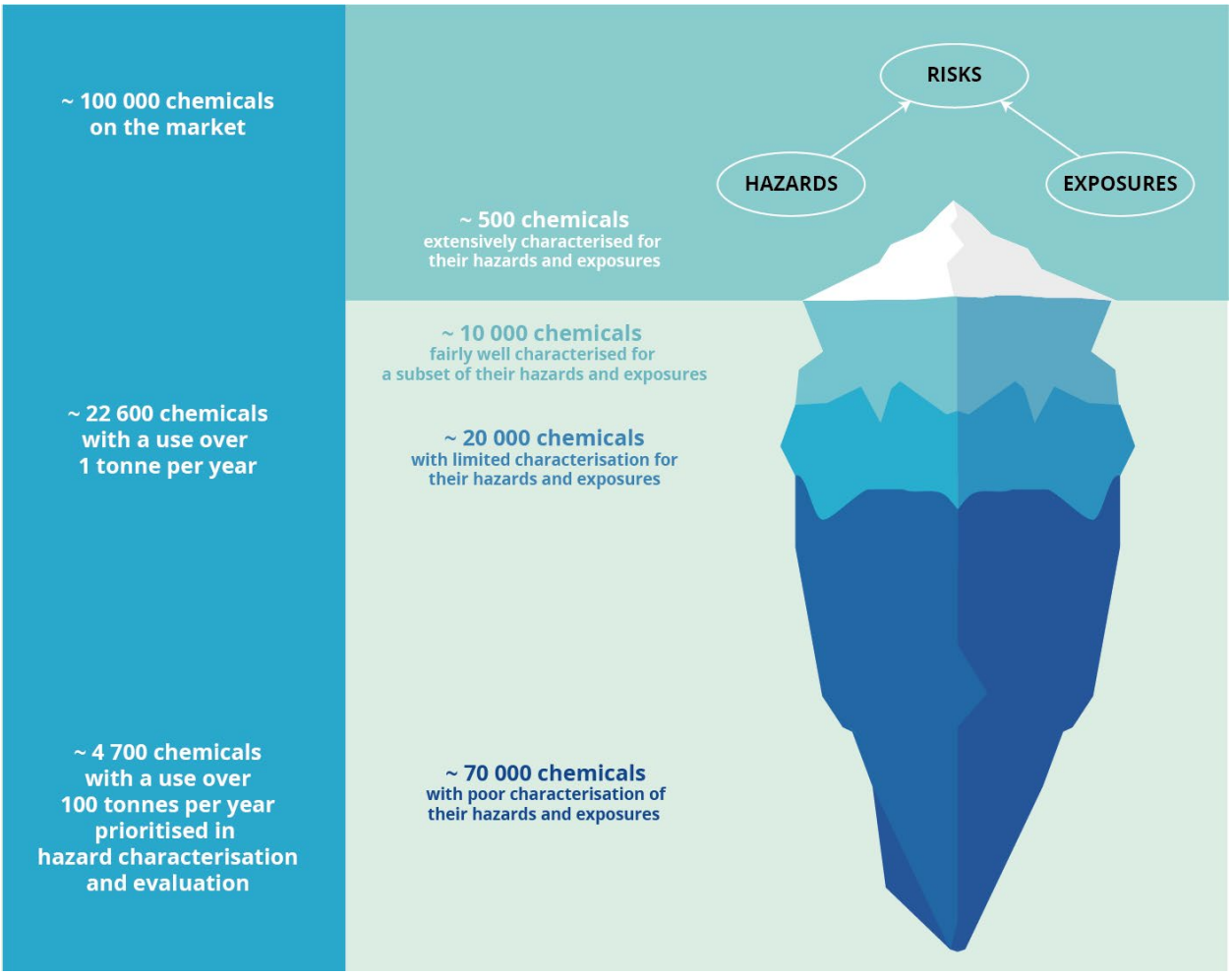


Figure 3: The unknown territory of chemical risk – For the majority of chemicals on the market only very little is known about their hazard and exposure characteristics, as visualised by just the tip of the iceberg. Approx. 500 chemicals: are considered sufficiently regulated), typically legacy and well-known chemicals characterised for most known hazards, which have limit values and are regularly monitored by quantitative methods in media. Approx. 10 000 chemicals are on EU or national legislation lists which are characterised for some but not for all known hazards, which have specific limit values, and are monitored quantitatively, but irregularly across time, media or space. Another 20 000 hazardous chemicals are characterised mainly by modelling, or where exposure data are based on qualitative screenings done occasionally and in few media. Finally, fore some 70 000 chemicals no or very few hazards characteristics are available and information on uses and exposure is scarce, not characterised or measured in very few media. Source: The European environment — state and outlook 2020 — European Environment Agency (europa.eu)

Research Goal 1
Climate change and biodiversity loss – reduce effects on health and the environment

Introduction

The climate change challenges highlight that human health and the health of our planet are inextricably linked. The sustainability of our civilization depends on the health of populations, flourishing natural systems, and fair stewardship of both natural and health resources. The most recent findings of the IPCC confirm that global warming of 1.5°C and 2°C will be exceeded during the 21st century unless deep reductions in carbon dioxide (CO_2) and other greenhouse gas emissions occur in the coming decades[20]. The environmental and health impacts of this temperature rise will be severe. Biodiversity [21] and the natural systems of our planet are being degraded to an extent unprecedented in human history, placing both our health and that of our planet in peril[22].

RG1 addresses several interconnected global challenges, related to climate change, biodiversity loss, biological agents, food systems and global pollution. It integrates and builds on holistic concepts such as Planetary Health, One Health, and Eco Health to operationalise integrative and transdisciplinary approaches involving several scientific and technological fields, multisectoral expertise as well as civil society, business sector, decision makers and other relevant stakeholders. Holistic and forward-looking approaches are needed for the detection, prevention, monitoring, control and mitigation of emerging/resurging diseases and exacerbating emergence of communicable and non-communicable diseases in the face of global environmental change. Research in this field would incorporate the complex interconnections and interdependencies among species, ecosystems, human health and society, while accounting for harmful drivers and consequences impacting human health and well-being as well as identifying the health benefits of biodiversity and healthy ecosystems. Research efforts will be needed to prevent negative health impacts, help optimize response management of disease emergence and spread in the interests of human health and wellbeing as well as of environment, biodiversity, food safety and security and promote sustainable and healthy lifestyles and diets. Methods development and data harmonisation will be crucial for applications of systems approaches to these various complex and interlinked challenges. Research on translation, implementation, communication will enable bridging the gap from knowledge to action and catalyse required measures and solutions based on existing and new knowledge. Methods, mostly arising from social sciences and participatory approaches, are needed to implement science-based recommendations into policies as well as society at large, both at local and global level. While most of the research needs on climate change, biodiversity loss and health are presented in this RG, several other proposals are also relevant and can be found in other RG, in particular RG6 on transformational change and RG5 on infrastructures.

RG1.1 Health and climate change

Objective: Investigate health impacts of climate change focusing on vulnerable groups and regions and improve climate services to prevent and adapt to future health impacts.

Relevance

Scientific relevance: Climate change poses the greatest global health risk in the 21st century. The climate crisis causes a range of direct environmental and health impacts, already today, and more in the future. Human activities are estimated to have caused approximately 1.0°C of global warming above pre-industrial levels. Global warming is likely to reach 1.5°C between 2030 and 2050 if it continues to increase at the current rate. The consequences of 1°C of global warming are already visible through more extreme weather events (hot weather, heavy precipitation, droughts), rising sea levels and diminishing Arctic sea ice. Climate-related risks to health, livelihoods, food security, water supply, human security, and economic growth are projected to increase with global warming of 1.5°C and increase further with 2°C. [23]Climate and ecological change induce population displacement and migration, and climate and ecological change impacts on resource security (water, food, and energy), depending on the vulnerability of communities. Thus, climate change threatens the security of livelihoods. In addition, climate change influences human health and disease patterns through many different indirect and complex ways, as through heat stress, allergies, vector-borne diseases and zoonosis, water borne diseases, food-related health impacts, air pollution, UV radiation and impact on mental health[24]. Some existing health

[20] IPCC 2021
[21] COM (2020)380. EU Biodiversity Strategy for 2030: Bringing nature back into our lives
[22] UNFCC (2021) Planetary Health: Momentum for change. United Nations Climate Change. https://unfccc.int/climate-action/momentum-for-change/planetary-health

[23] IPCC, 2021.https://www.ipcc.ch/, accessed August 13 2021
[24] Lea Berrang-Ford et al. (2021). Lancet Planet Health (2021). Systematic mapping of global research on climate and health: a machine learning review

threats will intensify and new health threats will emerge, with potentially larger impacts on disadvantaged socio-economic groups[25]. In addition to the classical direct exposure-effect assessments (e.g. heat stress, vector-borne disease transmission, pollen), further assessment of health impacts from climate change is needed in certain countries, regions or population groups and in connection with impacts in other natural and social systems like biodiversity or food systems[26]. Less researched health impacts of climate change include for example those on mental and occupational health [27] or gender-related impacts[28]. Also, joint effects of multiple risks (such as heat, pollen exposure, and air pollution) need to be further investigated. Across these research gaps, it is required to improve data-availability and the capacity to monitor, assess and research for evidence provision across countries and communities.

Policy relevance: The IPCC report finds that limiting global warming to 1.5°C would require "rapid and far-reaching" transitions in land, energy, industry, buildings, transport, and cities. Global net human-caused emissions of carbon dioxide (CO_2) would need to fall by about 45 percent from 2010 levels by 2030, reaching 'net zero' around 2050. This means that any remaining emissions would need to be balanced by removing CO_2 from the air. A better understanding of the impacts of climate change on environment and health is critical to support and justify policies for mitigation and adaptation. The aim of this topic is the identification, monitoring and quantification of direct and indirect impacts of climate change on human health, and related risk factors. In addressing drivers and risks, findings will support the development and implementation of climate change mitigation as well as adaptation measures. Outcomes of this research are expected to inform and improve the European Green Deal and related missions and policies and should also contribute to the achievement of the UN Sustainable Development Goals.

Research needs

- Identifying, elucidating and quantifying climate change effects on health with a focus on under-researched health effects (e.g. mental health effects) and vulnerable population groups (e.g. pregnant women, infants, elderly and disadvantaged groups due to income or ethnicity) as well as on joint effects of multiple exposures (including airborne allergens and multipollutant exposures).
- Improvement and harmonization of integrated assessment of (expected) disease burden related to climate change (see also RG4).
- Systemic research into the contribution of climate change to the emergence and spread of infectious diseases.
- Integrated research on the effects of extreme weather conditions (storms, floods, heat waves and drought) on health and well-being, including physical and mental health, social and economic consequences. This also includes improved health and economic impact assessments as well as predictive modelling.
- Develop health and climate-related information systems (including predictive forecast models) to anticipate future air pollution levels (e.g. based on mitigation measures, urban development, climate change scenarios) and to guide the development of adaptation measures and provide scientific evidence for climate change mitigation policies and regulation.
- Develop innovative health climate-related services including an integrated early warning system.
- Investigate the impacts of climate change and ecological change on resource security with emphasis on water stress, effects on the food chain, and population displacement and migration, including related health impacts, in the European Region and at a wider scale.

Tentative research call areas

Title: *Identify and quantify climate change impacts on health*
Scope: Investigate the impacts of climate change on health in an integrated way. Many impacts of climate change on body systems and mental health are still poorly understood. Improve methods for attribution of health effects to climate change, with special attention for combined exposures of environmental stressors (exposome: temperature, air pollution, pollen etc.) and linkage between environmental, socio-economic and health data. Research should pay attention to vulnerable (e.g. elderly, migrants) or high-risk groups (low-income groups) and vulnerable regions in Europe. An integrated framework should be developed and applied to assess the disease burden related to climate change across the European Region.

Title: *Development of better forecast models and improved surveillance system*
Scope: Develop integrated forecast models and tools for health impacts of climate change, including epidemiological models and socio-economic trajectories of exposure and vulnerability. Improve the linkages between existing surveillance systems and data on environment, climate change and health. Outcomes should contribute to the European Climate and Health Observatory and facilitate early

[25]EASAC policy report 38 (2019). The imperative of climate action to protect human health in Europe. German National Academy of Sciences Leopoldina 2019.
[26] Watts, N. et al. (2021). The 2020 report of The Lancet Countdown on health and climate change: responding to converging crises. The Lancet, 397 (10269), pp. 129-170.
[27] Daalen van K, HM Fussel, A. Kazmierczak et al. (2021). The Lancet countdown on health and climate change (2021). Responding to the health risks of climate change in Europe. EEA and Lancet countdown
[28] Watts, N. et al. (2021). The 2020 report of The Lancet Countdown on health and climate change: responding to converging crises. The Lancet, 397 (10269), pp. 129-170.

warning. Outcomes should allow a more precise planning and implementation of mitigation and adaptation measures (see 1.2)

Title: *Impact of extreme weather conditions on health*
Scope: Develop studies to assess health impacts of extreme weather conditions (e.g. storms, floods, heat waves and drought) and develop models to predict the impacts of increased frequency and intensity of such conditions in the future depending on the different IPCC scenarios.

Title: *Identify and quantify climate change impacts on health, effects of extreme weather event and attribution on a global scale*
Scope: The Research Agenda is focusing on research in Europe but many of the exposures and effects are global. The EU should promote strong networks of research globally investigating climate change impacts on health, effects of extreme event and attribution on a global scale. Research is also needed in understudied populations and specific calls should be planned to include climate effects and capacities for responses in low and middle income countries in conjunction with calls on “poverty related diseases”.

RG1.2 Health impacts of climate mitigation and adaptation measures

Objective: Assess and monitor health impacts of mitigation and adaptation measures, as well as impacts of new technologies.

Relevance

Scientific relevance: The health impacts of climate mitigation and adaptation measures (negative and positive) are not well known. Because of the health and environmental impacts of climate change, these measures are warranted, but there is emerging evidence that poorly planned energy transitions, including those with large greenhouse gas mitigation, can have severe consequences for livelihoods, employment and ultimately social determinants of health. It is fundamental to understand the nature and magnitude of those potential impacts in order to minimize them. Measures to adapt to increasing threats from heat and heavy rainfall, and other direct and indirect effects of climate change, for example more green spaces and trees in cities, may also be positive for health leading to significant co-benefits. Behavioural change is needed to achieve a shift towards e.g. more sustainable and healthy transport and diets.

Adaptation and mitigation measures may pose unintended health risks, such as an increased risk of allergies and infectious diseases when developing more green and blue spaces (water infrastructure) in urban areas to protect from heat stress and excessive rainfall. Health co-benefits of mitigation measures can be clearly identified, but optimization of initiatives requires adoption of systems thinking to identify potential for synergies, inadvertent consequences and trade-offs. Similarly, systems approaches are required to ensure adaptation strategies achieve their intended effects while negative impacts (locally and globally) are minimized. Moreover, new governance approaches are needed to ensure that measures are implemented in a fair and effective way and health benefits are distributed equitably. Over the last decades we have witnessed the rise of disruptive technologies and behaviour, including e-commerce, mobility-as-a-service, internet of things, urban farming, 3D printing and others. Yet there is a tremendous scarcity of their actual and potential effects on greenhouse gas (GHG) emissions, health and economic consequences thereof.

Policy relevance: Science-based adaptation strategies and mitigation measures are urgently needed. In addition to aiming for climate neutrality by 2050, the Commission will adopt a more ambitious EU strategy on adaptation to climate change. This is essential to create a climate-resilient and healthy society, as climate change will continue to create significant stress in Europe in spite of the mitigation efforts. Systemic changes in the energy, food and transport systems are required. Certain mitigation actions will also bring ancillary (co)-benefits for health. For example, a zero-carbon economy would potentially avert several hundred thousand deaths annually in the EU from air pollution caused by fossil fuel combustion[29]. Major health benefits are also likely to accrue from policies to mitigate the contribution of agriculture to GHG emissions. Health and environmental impact assessment should be part of all proposed initiatives, and monitoring should link climate and health data to assess the effectiveness of adaptation and mitigation strategies.

Research needs

- Develop better understanding of the potential beneficial or adverse health impacts of mitigation measures, including circular economy, energy transition, sustainable production and consumption, new technologies, nature-based solutions, and climate adaptation measures, including response planning.
- Identify co-benefits and clarify the challenges to, and effective policies for, climate mitigation and adaptation. How can health be a driving force in climate mitigation?
- Implementation research: focus on research that accompanies adaptation and mitigation interventions and evaluates their benefits, cost-effectiveness and possible unintended negative consequences and promotes the uptake of research findings related to interventions, health co-benefits and risks in policy and practice.
- Develop a unified EU approach on quality of life and burden of disease related to climate change measures
- Develop an evidence base to facilitate the science-policy dialogue on effectiveness and positive (health co-benefits as a driver to prioritise measures) and negative costs and benefits related to health of mitigation and adaptation measures.
- Investigate health-related economic effects of climate change mitigation and adaptation policies and foster the development of beneficial disruptive technologies and behaviours.
- Assess potential economic impacts of mitigation policies on disadvantaged groups.
- Investigate carbon and health economic benefits from mitigation policies as well as disruptive technologies and behaviours.

[29] WHO 2020; Gerlofs et al. How clean and healthy is our transport today. RIVM. THE PEP 2021

Tentative research call areas

Title: *Integrated health impact assessment of mitigation measures*

Scope: Develop and apply methods to evaluate and monitor the (cumulative) health impacts of mitigation and adaptation measures in an integrated and harmonized way within or across sectoral policies. Compile an overview of potential and already implemented measures/interventions (technological, including climate engineering, and behavioural, structural, systemic and regulatory), considering the intermediate results of earlier and ongoing EU-projects (e.g. in the framework of Green Deal calls). Develop a set of indicators for relevant health outcomes as well as a framework for integrated health impact assessment. Analysis and quantification of expected health risks as well as health co-benefits from climate change mitigation measures is required. On the basis of these results, provide recommendations for climate change mitigation measures that carry health co-benefits for stakeholders and decision makers. Cost-benefit analysis of health impacts of measures should be carried out as well. Attention should be paid to the distribution of health impacts and potential to apply measures across societal groups.

Title: *Integrated health impact assessment of adaptation measures*

Scope: Development and evaluation of adaptation measures is needed to improve resilience of countries, regions and cities, including new technologies and effective nature-based solutions. Since many cities and regions are starting to implement adaptation measures, there is an urgent need for more information on the effectiveness of adaptation measures, such as health action plans, response plans for extreme weather events and re-design of urban spaces (e.g. more green and blue space to deal with rainfall and extreme temperatures). Investigate what municipalities, other governmental actors, housing corporations, municipal public health agencies, water boards as well as residents can do to become climate-resilient. Distinguish between urban and rural areas. Compile an overview of potential and already implemented measures/interventions (technological, spatial planning, housing and behavioural measures), at international, regional and local level. Liaise with ongoing international and national research projects (e.g. in the framework of Green Deal calls). Develop a set of indicators for relevant health outcomes as well as a framework for integrated health impact assessment. Analysis and quantification of expected health risks and co-benefits from adaptation measures is required.

Title: *How to achieve societal change and support for a transformation towards more sustainable, healthy and resilient societies?*

Scope: To advance implementation of effective adaptation and mitigation measures, investigation of implementation mechanisms as well as mechanisms of and triggers for transformational change in relation to climate change mitigation and health protection is needed, especially in multi-sector settings. For example: better insight into cultural values and norms, new tools and approaches to support the implementation of adaptation and mitigation measures, achieve behavioural changes and develop fair and effective governance.

There is a need to strengthen knowledge, capacities and actions across Europe and beyond on social, cultural, economic and organisational change. Research should provide insight into the capabilities, opportunities and motivations of individuals, communities and institutions to act.

Title: *Development of climate mitigation measures and sustainable technology for the health sector*

Scope: The health sector is an important source of greenhouse gas and pollutants and thus contributing to climate-related health impacts. Investigate what the health sector can do to limit its emissions, become more climate-resilient and more sustainable without decreasing the health service to the population. Research is needed to identify and mobilize the great potential in reducing carbon dioxide (or other GHG) emissions and implement opportunities for climate change mitigation in the healthcare sector. New technology such as recycling of materials and medicines should be developed and assessed for its potential environmental and health impacts.

RG1.3 Health and biodiversity loss

Objective: Investigate the interlinkages between biodiversity and ecological integrity and human health and well-being, develop solutions integrating human health and support related policy action.

Relevance

Scientific relevance: There is a growing concern that biodiversity loss has significant impacts on ecosystem and human health. Yet there are still important knowledge gaps in this field. Indeed, additional knowledge is needed on the relationship between changes in biodiversity at all scales from genes to landscapes and related ecosystems services, and human health. The impacts of increasing biodiversity in urban environments through nature-based solutions and restored green and blue spaces on air, water and soil quality, noise and other stressors and the health benefits of such measures are not sufficiently understood. We also need to better understand the role of local, recurring exposure to biodiversity on e.g. the immune responses via microbiomes, regarding allergy, asthma and other non-communicable diseases, NCDs, and on the loss of intact ecosystems and spill-over dynamics at the human/wildlife, livestock/wildlife interface and related pathogen transmission. Quantitative indicators defining the relationships between biodiversity and human and planetary health/well-being to inform and support transformational change pathways in economy, policy and planning are not sufficiently developed. To enable systematic evaluation of health impacts of biodiversity loss, both in terms of factors that reduce health and well-being (pathogenesis) and support it (salutogenesis), there is a need to fill data gaps from multiple sources and disciplines, incl. ecological and social sciences and drawing from local knowledge. Research is needed on the linkages between biodiversity changes and the immune system and infectious diseases as well as on dietary diversity and health. The implications of such studies for the treatment of some non-communicable diseases should also be further investigated.

Policy-relevance: In order to support effective implementation of the EU Green Deal [30] and Biodiversity strategy 2030 [31], future research should be able to evaluate the linkages between biodiversity, related ecosystem services and health and well-being considering the need to reduce social inequality. This would shed light on how to develop policy which can support the complex interlinkages between biodiversity and human health and well-being. Furthermore, this could support policies that address both biodiversity loss, climate change and improved health and well-being.

Research needs

Further research is needed to explore and understand the mechanisms linking biodiversity and human health, and to define the effective ways to avoid negative health impacts of ecosystem degradation and to support positive health impacts of biodiversity in Europe and globally. The research should integrate biodiversity, environmental risks and climate change from the solution-oriented perspective and co-create, experiment and implement relevant health-promoting innovations and interventions.

- Explore the interlinkages and integration of human health and urban and rural biodiversity, to better understand the spatial and temporal variation risks (e.g. continued exposure to certain chemicals or pollution) on the local, regional and global scales. Draw from local empirical observations and develop research inspired by the planetary health concept to study the links between these risks, protected and non-protected areas and their health impacts.
- Develop research on expanding the knowledge about resilience-increasing factors and salutogenesis related to biodiversity into policy and practice: investigate how biodiversity supports the safeguarding of human health directly (through e.g. microbiome and related immunological benefits) and indirectly (through ecosystem services and related safety and security) in various contexts; investigate harmful exposures and potential exacerbating factors and consider health consequences in different populations and vulnerable groups, taking into account predisposition to diseases, existing medical conditions, daily exposure to green areas or dietary diversity and their influences on the immune system.
- Develop science-based interventions at urban/suburban/rural areas to prevent and address infectious and chronic diseases and health problems. Study how the quality, quantity and frequency of nature contacts affects health, and how related positive behaviour or measures could be scaled-up and promoted to reduce negative health consequences. Explore also the role of interventions e.g. in kindergartens, schools, health care, elderly care in promoting systematically healthy exposure to nature.
- Explore policies (including e.g. land-use planning, intensified agriculture, forestry sectors, urban development, human security, sustainable economy, sustainable production and consumption) and their

[30] Green Deal: https://eur-lex.europa.eu/legal-ontent/EN/TXT/?qid=1588580774040&uri=CELEX:52019DC0640

[31] Biodiversity strategy for 2030 (europa.eu)

capacities to support health promotion, resilience, biodiversity conservation and restoration and multiple synergies.

- Study the underlying, direct and indirect drivers of transformational change in behaviour, policy, economy, and technology to reveal leverage points to bring about the conservation, restoration and sustainable use of biodiversity, while taking into account human and planetary health.
- Implement longitudinal research, which builds on existing and novel data sets and registers, measuring tools and artificial intelligence to better characterise, monitor and model biodiversity and health related pathways and related indicators to improve monitoring. Fill in data gaps by integrating social sciences and addressing the knowledge gaps in civil society by raising awareness. Improve data sharing and systematisation of data across Member States and research organisations.

Tentative research call areas

Title: *Health impacts of biodiversity*
Scope: Develop inter- and transdisciplinary research to understand the health impacts of biodiversity and their mechanisms in different socio-ecological settings. focus on scalable solutions in integrating human and planetary health into practical experimentations. Build on the longitudinal data sets, e.g. by exploring how the biodiversity of living environments explains the health differences and risks between the Member States or different regions. Furthermore, explore what types of nature access are deemed beneficial or harmful and how effective are the protective measures, e.g. nature-based solutions, or biodiversity itself, in combating the adverse health impacts caused by chemicals, pollution, ecosystem degradation and related social issues.

Title: *Framework for exploring nature-related health risks and benefits*
Scope: Develop a framework for analysis of the dynamic interactions between human populations and their pathogens, including host or vector species, and salutogens, covering land-use, food production and forestry. Implement a research observatory comparing health and well-being status and the state of biodiversity. Use such health impact studies to support transformational change for the conservation, restoration and sustainable use of ecosystems.

Title: *Nature-based interventions for encouraging positive biodiversity-health linkages*
Scope. Deepen the understanding of societal consumption and production patterns (in all sectors) in contributing to less damage on biodiversity and encourage nature-based solutions that integrate human and planetary health aspects. Special attention could be paid to the role of interventions and green and blue spaces, including e.g. in kindergartens, schools, health care and elderly care, in promoting systematic healthy exposure to biodiversity and health benefits, while also considering lifestyle factors as well as the role of biodiversity in climate change adaptation.

RG1.4 Biological agents, environment and human health

Objective: Advancing the knowledge on the circulation of biological agents in natural and human-driven ecosystems, on the monitoring of human exposure and the evolutionary responses of biological agents to environmental change and human activities.

Relevance

Scientific relevance: Biological agents include viruses, bacteria, fungi, alga and parasites that can cause acute intoxications, infectious diseases, but also cancer and allergies either directly or indirectly through exposure to related allergens or toxins. Emerging infectious diseases (EIDs, e.g. COVID-19) increase both the intensity and the frequency of epidemics[32]. In parallel, antimicrobial resistance (AMR) threatens effective prevention and treatment of an ever-increasing range of infections caused by biological agents[33]. Beyond infectious diseases, exposure to biological agents favours the development of non-communicable diseases (NCDs) and multifactorial diseases (MDs). Mitigation and prevention strategies first require an understanding of what biological agents circulate in ecosystems. This involves the development of molecular methods for monitoring the circulation and evolution of biological agents in soil/water/air/reservoir hosts, in the context of indoor, outdoor and occupational environments, both in natural and human-driven ecosystems. It is also key to determine how and why pathogens emerge and drug-resistance increases and to develop prospective scenarios. This starts with a better knowledge of the ecology of biological agents, their transmission routes and their evolution in response to environmental changes. In terms of disease management, it is key to understand the human and ecological factors leading to the emergence of new pathogens (more transmissible, virulent, resistant to drugs or vaccines) and to the worldwide increase of MDs. It is also key to understand the variations of susceptibility of populations/individuals to biological agents as well as the role of NCDs in human susceptibility to infections.

Policy-relevance: Research efforts framed by the One health concept will address the major interlinked crises our planet is confronted with, i.e. the problems of pandemics, AMR, climate change and biodiversity loss. Relevant strategies include Biodiversity strategy[34], Farm to Fork strategy[35], Zero Pollution Action Plan[36], EU One Health Action Plan against AMR, the Pharmaceutical Strategy for Europe [37] related especially to AMR challenges and the UN sustainable development goals[38].

Research needs

Research is needed on environmental, ecological, evolutionary sciences, biomedical sciences, genetics, epigenetics, social sciences, modelling and foresight to examine and characterize health effects of environmental change and human activities on disease risks and to design innovative solutions. Research should address the social-ecology of biological agents and the risk relative to human exposure. Increased understanding of exposure to biological agents and the severity of infectious diseases at an individual and population level will help targeted prevention and mitigation efforts. Preventing EIDs and AMR also requires clarifying the causal relationship that exists between environmental change, human activities and the evolution and spread of biological agents. More specifically research should focus on:

- The vulnerability of human populations in terms of exposure to biological agents (relative to human habitat and activities) and socially driven differences (e.g. socioeconomic status, gender, age) considering mediation by environmental exposures and societal dynamics.
- The genetic/epigenetic determinants of susceptibility to biological agents in human and animal populations to adopt mitigation strategies; whether and how gene-environment and microbiota interactions as well as chemicals may alter the disease risk, in particular through disruption of the immune system.
- The interactions between chemicals and biological agents causing multifactorial diseases (MD), particularly in the context of indoor, outdoor and occupational environments.
- The role of non-communicable diseases (NCDs) in human susceptibility to infections and the role of infections in the emergence of NCDs.
- The ecology of biological agents, including the identification of pathogen reservoirs (e.g. animal species, soil, water, air compartments) and vectors both in rural and urban habitats, particularly where human populations and livestock live in close contact with wildlife and/or where human exposure and vulnerability is documented.
- The thread of transmission and evolution of pathogens in reservoir hosts. How and how fast do pathogens evolve in animal species and become infectious for humans. The evolution of zoonotic pathogens in animal reservoirs. The use of phylodynamics to date outbreaks and identify the host taxa and geographic regions that define hotspots of disease emergence.

[32] https://www.preprints.org/manuscript/202106.0204/v1
[33] https://www.euro.who.int/en/health-topics/disease-prevention/antimicrobial-resistance
[34] Biodiversity strategy for 2030 (europa.eu)
[35] EUR-Lex - 52020DC0381 - EN - EUR-Lex (europa.eu)
[36] https://ec.europa.eu/environment/strategy/zero-pollution-action-plan_en
[37] https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52020DC0761&from=EN
[38] https://www.un.org/sustainabledevelopment/sustainable-development-goals/ & www.un.org/ga/search/view_doc.asp?symbol=A/RES/70/1&Lang=E

- The relationships between climate change, biodiversity loss and EIDs and the effects of human activities on the evolution of biological agents, e.g. toxins, their transmission to humans, and the host susceptibility. The effects of climate change and biodiversity loss on the dynamics of vectors and reservoirs and the pathogens they transmit.
- The modelling of disease risks and pathogen evolution to adapt prevention and mitigation strategies and anticipate the evolutionary potential of pathogens that may threaten treatment and vaccination strategies; The use among others of machine and deep learning approaches; Prospective epidemiological scenarios that consider global changes and political actions, adopting and bringing into force a foresight process involving all relevant stakeholders.
- Development of nature-based solutions to address the ecological and the health crises jointly.

Tentative research call areas

Title: *The social-ecology and evolution of biological agents*
Scope: Determine where, when and why biological agents circulate in natural and human-driven ecosystems. Characterize factors of human and animal host vulnerability. Implement ecological health observatories in hot spots of disease emergence. Develop molecular tools for better surveillance. Identify sentinel species. Implement open-access databases for data sharing. Characterize the competence of ecosystems to create risk maps for EIDs and AMR. Elucidate the causal relationship between human activities, global environmental changes and EIDs to adapt national and international environmental/agricultural/industrial/societal policies, mitigation, preparedness and response.

Title: *Multifactorial diseases and the role of non-communicable diseases in human susceptibility to infections*
Scope: MDs often emerge in organisms whose defence capacities have been reduced by changes in nutrition, temperature, exposure to pollutants, toxins, radiations, etc. It is key to characterize the vulnerability of humans in terms of multiple exposure in rural, urban, occupational environments (e.g. workers in healthcare, veterinary services, agriculture, sewage management, and laboratories. Develop a harmonized framework for biological agents and chemicals through “adaptive monitoring” of co-exposure, and system studies to assess impacts, manage risk, and apply therapeutic care. Study the effects of exposure to biological agents and their relations with NCDs. Determine how chemicals and microbiota alter the outcome of infectious diseases by their action on both hosts and microbes by developing integrated approaches that encompass the different scales of organization of living beings (macroscopic, cellular, biochemical, and molecular) both in controlled environments and in nature.

Title: *Delineate the mechanisms of resistance to infectious agents in certain species and implication for human therapeutics*
Scope: It is well known that certain species such as bats are resistant to infectious agents and this may explain why these species are reservoirs for such agents. It is critical to better understand the mechanisms of resistance of these species to better target therapeutic research in humans. Many biological pathways are partially conserved which supports such an inter-species approach. A focus on immune functions would be relevant.

RG1.5 Food, ecosystem services and farming

Objective: Develop, redesign and apply research on the food system transformation in order to provide healthy nutrition for European urban and rural populations while staying within planetary boundaries and also safeguarding natural capital for the future.

Relevance

Scientific relevance: additional knowledge on robust and resilient food systems is needed, including the identification of protective features of ecosystem services and traditional farming for health, and how to translate these into improved treatment/remediation/intervention strategies and sustainable and healthy living environments in rural as well as urban areas. There are also gaps in knowledge on 1) how to support mechanisms for increasing accessibility and affordability for food sustainability and sustainable and healthy diets in Europe; 2) which new solutions to promote alternative food production methods across countries; and 3) how to reduce dependency on pesticides, antimicrobials and excess fertilisation. Development of environmental risk assessment approaches to investigate how to redesign the food system in order to provide healthy nutrition for European urban and rural populations is necessary while considering sustainability aspects and planetary boundaries. This should include assessing human impact in the circular economy and the true cost of food and its waste. As food is a highly personal issue, linked to identity, culture, etc., studies on how to resolve people's disagreements regarding healthy and sustainable eating and the related food system transformation are required. In order to avoid potential conflicts related to food system transition, further relevant research is needed on cultural and political dimensions of sustainable eating and food production. It is also useful to assess the sustainability and health impacts of different agricultural practices, distribution schemes, and the Common Agricultural Policy (CAP) programme. Modelling could enable mapping of vulnerable groups across the EU. In parallel, it is required to assess what crops/food plants are vulnerable to extreme weather or environmental conditions. An additional question is the development of novel and synthetic food technologies including cellular agriculture; there are many unknowns on the environmental and health impacts of such technologies and their risks/benefits compared to more traditional food production.

Policy relevance: In the Green Deal roadmap and plan[39], and in the Farm to Fork strategy[40], there are strong expectations as to how research and tool development could support designing and implementing public policies. The goal is to develop preventive and protective actions, support green recovery and, furthermore, more broadly ensure the transition towards sustainability. More specifically, increasing organic farming and reducing use and risk of pesticides are emphasised in the EU Biodiversity strategy 2030[41].

Research needs

Further research is needed about sustainable and healthy food design and food production for Europe. The research should integrate environmental and health impacts of food and food value chain on the market and policy aspects.

- Investigate and characterise hazards and risks linked with the presence and/or accumulation of chemicals (including pharmaceuticals), other contaminants and their by-products and mixes in foods, especially those of plant origin. Investigate the solutions to prevent and mitigate such risks, e.g. through the protective and beneficial role of biodiversity in food production and diets, and the role of regenerative farming and nature-based solutions and improvement in chemical risk assessment.
- Evaluate food, food waste and circular economy in the context of food and water supply challenges as well as soil pollution and interlinkages to food safety and security (nutrition, antimicrobial resistance, emerging risks and impacts on ecosystem).
- Assess climate-driven food web changes and risks of hazardous substances and potential disease outbreaks.
- Investigate ecosystem services changes and impacts and their implications to human health, including climate change induced impacts
- Examine the environmental impacts of Common Agricultural Policy (CAP) programme and strengthen related governance research in order to better integrate environment, biodiversity, climate change and health issues into agriculture policy and the related food systems (e.g. various production and farming practises, consumption models and their interconnections).
- Explore sustainable agriculture and aquaculture to uncover the benefits and risks on food, diets and health, in relation to the synergies with climate adaptation and mitigation. Include scenarios with various climatic and biodiversity conditions.
- Investigate food, dietary choices and lifestyle as a determinant of human health and environmental impact and include socio-economic factors on European and national scales. Research is needed on risks,

[39] https://ec.europa.eu/info/strategy/priorities-2019-2024/european-green-deal/delivering-european-green-deal_en
[40] https://ec.europa.eu/food/horizontal-topics/farm-fork-strategy_en
[41] Biodiversity strategy for 2030 (europa.eu)

hazards and benefits of novel foods as well as people's perceptions and attitudes towards them and related technologies and solutions.

- Investigate allergenicity of existing and novel foods and applications in order to better understand their dietary effects and to establish their safety, also from allergenicity perspective.
- Analyse and design what a sustainable European planetary health diet may look like. For example, how do soil health and biodiversity impact food safety and health; what is the value of creating healthy diets for people; and how to govern and encourage healthy and sustainable eating? This could also include the development of sustainability criteria for commodities, food trade and for agro-food business.
- Compare novel and synthetic technologies for food production to other more traditional methods in terms of environmental and health impacts.

Tentative research call areas

Title: *Development of European planetary diets*
Scope: Key is to explore how to produce food minimizing health risks (incl. chemicals, antibiotic resistance, pandemics/emerging infectious diseases, meat production and consumption). This would shed light on the European planetary health diet, integrating biodiversity, soil health and healthy food. The call area includes research on diet related risks, including increasing obesity as a health risk factor, directly and indirectly.

Title: *Environmental and health impacts of novel foods*
Scope: In order to limit the environmental and in some cases the health impacts of traditional food, new technologies (e.g. stem cell and nanotechnologies) have been developed for various applications in foods. While further development of such technologies is needed, it is critical to analyse the environmental and health impacts of such novel and emerging foods. Comprehensive analyses need to be undertaken to assess their chemical compositions, biological effects and any potential health risks. An important aim is also to investigate societal acceptance of novel foods and the actual environmental and health risks related to the upscaling of their production or presence in the food chain. A comparative benefit/risk analysis with traditional food is also needed.

RG1.6 Global pollution

Objective: Reduce health and environmental problems originating from global pollution and advance international prevention and control measures.

Relevance

Scientific relevance: Global pollution of long-range transport of environmental contaminants is related to air (particulates, polycyclic aromatic compounds), ocean and water pollution (e.g. plastics, microbial content), toxic chemicals in globally distributed products, materials and goods (inorganic and organic pollutants of endogenous and exogenous origin). Causes and sources of pollution vary, and their impact on human and ecosystem health occurs through various pathways – not all of which are well known or assessed.[42,43] Therefore, it is necessary to advance knowledge on pathways and magnitude of global pollution as well as on quantitative assessment of short- and long-term related health impact. Research results will optimize and advance agreements, policies, and international coordination and must be advanced in the context of other global processes and trends such as climate change, exploitation of natural resources including biodiversity loss, land degradation, and international trade[44].

Policy-relevance: As pollution knows no boundaries, the "EU's zero pollution action plan" promotes worldwide change for zero pollution. Tackling global pollution includes international and EU policies related to: UNECE multilateral environmental agreements[45], black carbon; polluter pays principle; Agenda 2030 for Sustainable Development; various UN resolutions; sound management of chemicals and waste; the Basel, Rotterdam, Stockholm and Minamata Conventions on waste and electronic equipment, hazardous chemicals, persistent organic pollutants and mercury; plastics; biodiversity; and restricting the export of certain products and wastes. In addition, to achieve progress in global pollution, development of policy interventions must be based on scientific understanding of multi-sectoral interactions.[46]

Research needs

Research is needed to quantitatively assess the magnitude, dynamics and trends of global pollution flows and their impact on human and ecosystem health. Research should tackle causes and consequences of global pollution in the context of governance and regulatory dimensions related to specific sectors. Research related to the impact of environmental drivers on global pollution is needed in order to tackle negative consequences to humans and planetary health, in general. Special attention should be given to vulnerable populations, gender and equity. Research needs include:

- Development of quantitative impact assessment of the new WHO air quality guidelines on the magnitude, dynamics and trends of global air pollution flows and their impact on human health.
- Identification and quantification of causes and consequences of global pollution in air, water and materials flow associated with changes in production factors and processes in specific sectors, including the impact of circularity in industrial/manufacturing processes.
- Assessment of the health impact of specific global pollutants for example metals, persistent organic pollutants (POPs) and pesticides, originating from various sectors and usages in the context of their related regulatory frameworks.
- Identification and assessment of the impact of drivers such as climate change, production and consumption patterns, land use and biodiversity loss on pathways and magnitude of global pollution and their pollution-related health consequences.
- Assessment of interconnected pathways linking global environmental changes, e.g., environmental pollution, biodiversity loss, land use change, climate change, as well as development of effective responses to these changes and their health impacts.
- Assess the contribution and impact of various environmental policies set by the European Commission (i.e. strategy and action plans related to the Green Deal) on global pollution and thus on health.
- Measure and assess the health impact of metals and persistent organic pollutants (POPs) in the context of global pollution.
- Assess health impact of plastic and specific contaminants in the marine environment and terrestrial water systems entering the food chain and their impact on human health and develop methodologies for measuring this impact globally.
- Investigate which drivers, consequences and solutions are shared by climate change and air pollution, impacting health and health-co-benefits.

Tentative research call areas

Title: *Advanced knowledge on the impact of global pollution on health including method development*
Scope: Development of quantitative impact assessment of air

[42] Driscoll, C.T., et al. Mercury as a Global Pollutant: Sources, Pathways, and Effects. Environ. Sci. Technol 47, 4967–4983 (2013).
[43] Ali, M.U., Liu, G., Yousaf, B. *et al.* A systematic review on global pollution status of particulate matter-associated potential toxic elements and health perspectives in urban environment. *Environ Geochem Health* **41,** 1131–1162 (2019). https://doi.org/10.1007/s10653-018-0203-z
[44] Zhang, Q., Jiang, X., Tong, D. *et al.* Transboundary health impacts of transported global air pollution and international trade. *Nature* **543,** 705–709 (2017). https://doi.org/10.1038/nature21712
[45] UNECE multilateral environmental agreements https://unece.org/about-5
[46] Amann, M., et al. Reducing global air pollution: the scope for further policy interventions. *Phil. Trans. R. Soc. 378 (2020)* https://doi.org/10.1098/rsta.2019.0331

and water quality guidelines and global flow of materials and goods regulations on the magnitude, dynamics and trends on a global scale. The global flows of pollutants and their base line impact on human health will contribute to understand the general impact of the pollution. The role and relative impact of the three main sources (air, water and materials/goods) of global pollution for human health are to be addressed. Further development of quantitative assessment of health effects of air pollution in a global scale should be promoted. Method development will be required for assessment of the environmental drivers. Results should be used as a driver for management of global pollutants and a tool for new international agreements.

***Title**: Rising waste production and global health*
Scope: Plastics and electronic waste (e-Waste) are among the most important solid wastes currently at a global scale and their volume is steadily growing and they threaten progress towards sustainable development. A significant amount of e-waste produced in high income countries is transferred (legally or illegally) to low income countries and is recycled using substandard methods that could be hazardous to human health and the environment. Research should develop methods and provide estimates of human exposure applying advanced exposure assessment, develop mechanistic research to evaluate toxic effects in humans to examine a wide range of health outcomes in children and adults and propose solutions to decrease exposure and improve management of e-waste (local and international level). Research should be primarily developed in areas with high exposures and include populations in low income countries, i.e. through global projects.

***Title:** Identification of similarities/dissimilarities in human and environmental exposures to mixtures of persistent and non-persistent pollutants around the globe*
Scope: Improved knowledge on content, mixture patterns and levels of pollutants in abiotic matrices and internally depending on the north to south and east to west perspective will visualize general global versus regional exposures of pollutants for humans. This will improve the understanding and knowledge on local backgrounds and threats to human health from specific societal exposures and also include better understanding of exposures to vulnerable groups to pollutants and hence a driver for management actions.

Research Goal 2
Cities and communities – promote healthy lives in sustainable and inclusive societies

Introduction

Environmental and living conditions in urban environments are of key concern as they impact substantially the health and wellbeing of the majority of European citizens, and likewise globally. Sustainable mobility, resource usage such as energy consumption, water and food, and healthy occupational settings are required to promote healthy living in urban areas. The research gaps identified in this area are cross-cutting and pursue integrated and holistic approaches directly addressing challenges covered in other HERA research areas. Specifically, research in this area faces challenges such as, i) Drivers of the interventions are often responses to global change and its challenges; ii) Interventions in environmental settings in cities and living conditions are long-term, by definition complex and nearly always alter multiple exposures each one frequently having small impacts on health per se; iii) Interventions affect to a varying degree specific diseases as well as wellbeing and their potential to promote healthy living may vary by life-stage and co-morbidities; iv) Methods for complex assessments of long-term changes are just evolving and v) Based on the complexity of the potential interventions, large infrastructures and especially large cohort studies spanning across the life-course and implementing long-term follow-ups in multiple European countries are needed to gather novel data on these issues and inform needed impact assessments. Health statistics indicate that despite higher exposures to negative environmental agents, life-expectancy in Europe is higher in urban than in rural areas. Healthy living in rural areas implies some of the same needs as those in cities but likely in a different and hitherto often underexplored fashion.

Research approaches that integrate observational studies and experiments are missing. Studies that include simulations and real-world experimental approaches with observational studies may be a way forward to advance the science in this area. There is an urgent need to develop methods to study the efficiency of implementation of change in the field of environment and health. The research goals proposed have the potential to contribute to novel approaches for developing sustainable metropolitan areas and to cope with urban growth and rural shrinking. The strategic research area has large potential impacts primarily on SDG3 and SDG11.

Figure 4: Earth's human-generated night-time lights for the calendar year 2003. Zoom on NASA's image by Robert Simmon based on data from the Defense Meteorological Satellite Program Operational Line Scanner

RG2.1 Healthy Urban Environments

Objective: Establish the interrelations between complex urban features and develop a systems understanding of positive and negative features of urban environments and urban living on health and estimate and reduce the health impact of urban exposures.

Relevance

Scientific relevance: The majority of people live in cities, around 80% in Europe. Cities are hotspots of exposures detrimental to health such as air pollution, noise, heat island, and excessive light. Current urban, transport and residential energy practices are partly responsible for these exposures. However, the links between the determinants and exposures are complex and still not well understood, while interventions to reduce the exposures have not been well evaluated and often lack a scientific basis. Furthermore, exposures and health impacts are often not equally distributed among the population. There is a real need to transform an urban environment that is currently detrimental to health to one that is promoting health by changing the current urban, transport and residential energy practices and make cities carbon neutral, more liveable and equitable and healthier.

A comprehensive assessment of healthy urban environments and its complexity should be based on observational and intervention studies in European populations across the life span and continuous policy planning interventions in cities. This assessment should not only characterise urban environments through negative exposures such as air, water, food pollution, noise, and heat but should build upon positive features. The latter include green and blue space, biodiversity, accessibility, active transport infrastructure, and novel concepts such as the exposome concept and planetary health to estimate the overall impact of healthy environments on health. In addition to physical and chemical factors, the characterisation of the urban environment should also encompass sociodemographic determinants, urban lifestyle, urban design and planning, mobility and mode of transport to provide a comprehensive picture of the "urban ecosystem." Research is needed to build such a healthy urban environment and to identify the best tools to achieve this.

Policy-relevance: Intensified research efforts to understand the complex relationships in the urban environments, evaluate interventions and change the current urban, transport and residential energy practices will promote the zero pollution ambition for a toxic-free environment[47] and the implementation of Climate-neutral and smart cities mission[48].

Other relevant strategies include Biodiversity strategy[49], Circular Economy Action Plan[50], Nature-Based Solutions[51], Farm to Fork strategy[52] and above all, the UN sustainable development goals[53].

Research needs

The fundamental needs are related to applied research required for robust and science-based decisions. This includes methodological developments, knowledge generation of the unknowns, and advanced research related to certain practices, interventions and policies. Research is needed to fully establish the role and complexity of urban environments in safeguarding the healthy mental and physical development of children, health and wellbeing of adults, and healthy ageing of the elderly to sustain healthy and inclusive European societies. The evaluation of policy planning and environmental interventions should establish the effectiveness of such measures. Implementation research should integrate small-scale experimental settings with large-scale mapping. Evaluating the health effects of living environments in urban and rural settings should consider current and future patterns and populations at different ages and disease states and estimate the magnitude of the urban burden of disease related to the changes in environmental exposures. This evaluation should consider both communicable and non-communicable diseases and incorporate plans to mitigate effects and prepare for future crises. Specifically:

- Assessing the current complexity and relationships between current urban, transport and residential energy practices, exposures such as air pollution, noise, heat island, excessive light and often lack greenspace and health effects and impacts
- Development of new tools and methods to estimate in complex urban environments the exposures, health effects and health impact tools for decision making
- Evaluating promising urban interventions such as Nature-based solutions in terms of effects on health and harmful exposures; study the lifecycle and biodiversity particularities of plants in public green spaces and generates evidence on potential allergenicity in an urban setting.
- Research the distribution and impacts of unequal distributions in the populations including social economic position, gender and race and ethnicity on population health

[47] https://ec.europa.eu/environment/strategy/zero-pollution-action-plan_en
[48] https://ec.europa.eu/info/publications/100-climate-neutral-cities-2030-and-citizens_en
[49] Biodiversity strategy for 2030 (europa.eu)
[50] Circular economy action plan (europa.eu)
[51] https://ec.europa.eu/info/research-and-innovation/research-area/environment/nature-based-solutions/research-policy_en
[52] https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52020DC0381&from=EN
[53] https://www.un.org/sustainabledevelopment/sustainable-development-goals/ & www.un.org/ga/search/view_doc.asp?symbol=A/RES/70/1&Lang=E

- Evaluating the effectiveness of knowledge translation of innovative methods and approaches to reduce harmful exposures in urban environments

Tentative research call areas

Title: *Assess the complexity and relationships between current urban transport and residential energy practices, exposures (air pollution, noise, heat island, excessive light and often lack of greenspace), and health effects and impacts*
Scope: The urban environment is complex and still not well understood in terms of the different relations sectorial activities (e.g. urban and transport planning, energy practices), environmental exposures (e.g. air pollution, noise, heat island, excessive light and lack greenspace), lifestyle factors (e.g. physical activity) and health effects (e.g. mental and physical health) and feedback loops. The proposed work would need to identify and quantify these different relationships with a systemic analysis framework taking in multiple exposures and feedback loops. New statistical and measurement methods and may need to be developed and applied. The expected results are a better and more in-depth understanding of the relationship between sectorial activities and health effects through multiple pathways and exposures. The effects on subpopulations including social economic position, gender and race and ethnicity should be evaluated.

Title: *Evaluate promising urban interventions such as Nature-based solutions in terms of effects on health and harmful exposures*
Scope: European cities are actively improving the urban environment through applying better urban planning (e.g. new urban models such as Superblocks, 15-minute city), better transport planning (increasing cycling lane length), Nature-based solutions (e.g. planting trees) and EU initiatives (e.g. Carbon neutral cities), but robust data is missing of the effect on environmental exposures (e.g. air pollution, noise, heat, excessive light), lifestyle factors (e.g. food consumptions, physical activity) and health effects (e.g. mental and physical health) and overall effectiveness. The proposed research call would need to quantity the effects of these interventions on environmental exposures, lifestyle factors and health using existing and novel methodologies and measurements (e.g. wearables). The expected results are a robust quantification of the effects and effectiveness of the interventions for environmental exposures, lifestyle factors and health. Cost benefit analyses is encouraged. The effects on subpopulations including social economic position, gender and race and ethnicity should be evaluated.

Title: *Evaluate the effectiveness of knowledge translation of innovative methods and approaches to reduce harmful exposures in urban environments*
Scope: Although much knowledge exists on the harmful and beneficial urban exposures, this does not always reach stakeholders including the general population and this may delay progress to make improvements in terms of environment and health. Furthermore, for many it is unclear what to do with the information or how to use it. Better knowledge translation is needed with a greater involvement of stakeholders. The proposed work will improve knowledge translation and uptake. It will need to involve a large number of disciplines (e.g. social scientists, urban planners, environment and health professionals) and stakeholders (e.g. citizens, NGOs, business, politicians and decision makers) to define the messages and content and effective way of translation and uptake leading to impactful actions. The expected outcomes are a better uptake and understanding of the current scientific evidence and improved urban environments through the implementation of targeted and effective actions with wide support.

Title: *Promote healthy living in the urban-suburban-rural continuum*
Scope: The urban-suburban-rural continuum is of major importance for promoting healthy living in Europe. However, a comprehensive assessment of reasons for underlying health inequalities and confounding factors is missing. Healthy living in rural areas implies some of the same needs as in cities but likely in a different and often underexplored fashion. Research should address jointly the long-term impacts of economic, social and environmental conditions to abate socio-economic disparities and how healthy environments can support inclusive societies in an urban-suburban-rural continuum and address understudied environmental and living conditions in rural areas.

Joint research call area for RG2.1 and RG5.3

Title: *Development of new tools and methods to estimate in complex urban environments the exposures, health effects and health impact tools for decision making*
Scope: The urban environment is complex and environmental exposures and health effects and impacts are hard to assess. Furthermore, much data is being generated through routine monitoring, lifestyle, environmental and health apps, remote sensing that is not being used. New method developments are needed to utilize and analyse the current and future conditions such as new statistical techniques to quantify relationships (e.g. mixture of exposures, machine learning), novel equipment to measure the exposures and potential confounders (e.g. apps, wearables, remote sensing) and health effects (e.g. administrative data, new data sources) and new methodology to quantify the health impacts (e.g. microsimulation, ABM). The expected outcome of the work is a range of new methodologies to assess the complex urban environment that have been tested, applied and validated.

RG2.2 Air pollutants in indoor and outdoor environments

Objective: Develop air pollution mitigation strategies to reduce risks of air pollution-associated diseases of European citizens in outdoor and indoor environments

Relevance

Scientific relevance: Ambient air pollution has been identified as the major environmental exposure associated with the burden of disease around the world. The release of the updated WHO Air Quality guidelines indicate that health effects are observed at levels substantially below current air quality standards anywhere. Health impact assessments build upon large population-based studies of fine particulate matter in relation to respiratory and cardiovascular disease morbidity and mortality in adults. Recent years have documented in addition health impacts on reproductive health, neurological and psychiatric disease, and systemic impacts affecting children's and adults' health. There is a knowledge gap on impacts of air pollution on function and structure of the barrier organs such as the lung, the skin, and the gut and systemic impacts on the heart, brain, kidney, vascular, and reproductive systems. Linking the novel understanding of the origins of cancer with assessments of air pollution will produce novel and highly relevant science. Data available to date on the COVID-19 pandemic and earlier evidence on lower respiratory infections indicate that the interaction of infectious agents with air-pollution needs systematic assessment.

European data on health effects and impacts of emerging or unregulated air pollutants, including ultrafine particles, air toxins, infectious and non-infectious micro-organisms, biological molecules (endotoxins, mycotoxins, and allergens), are largely missing. Novel technologies introduced in many sectors are likely to change the composition and distribution of air contaminants and a comprehensive assessment in space and time both outdoors and indoors are needed.

Policy-relevance: The Zero pollution action plan [54] will substantially transform multiple sectors including transport, energy production and manufacturing. Urban areas and large infrastructures such as harbours and air ports significantly contribute to pollution levels. Especially the transformation of the transport and the agricultural sector as well as innovations in heating and cooling systems has the potential to create important co-benefits with respect to health. There is the need to monitor and evaluate the impacts of these actions to abate negative unwanted impacts and derive the best options. Research and citizen engagement will be able to document improvements and support policy actions that promote healthy air and mitigate climate change. Clean air for all European citizens outdoors and indoors will support societal justice and transformation. The mission on climate-neutral and smart cities has great potential to contribute to clean air.

Research needs

- There is a need to provide time and space-resolved assessments of both regulated and unregulated air contaminants to fill gaps in data quantity and quality. Specifically, novel approaches in monitoring technologies, techniques and reporting of air quality are needed for an assessment of the new WHO guideline implementation. In addition, also novel approaches for the monitoring of ultrafine particulate air pollution is needed e.g. of dessert dust in PM. Assessment is needed of unknown unregulated components of particulate air pollutants including molecular carriers of toxicity.
- Susceptible subgroups such as pregnant women, children, elderly and low SES need specific assessments with respect to exposures and health. The relevant settings include home and work environments, times spent commuting and the school environments.
- Dedicated modern toxicological assessments are needed to understand the impacts of novel technologies and specific air pollution mixtures and to complement population-based research.
- Developments in digital health and large-scale as well as dedicated cohort studies are needed to monitor immediate to long-term impacts of air pollutants as well as their mixture.
- Comprehensive assessment employing the exposome concept with a dedicated focus on outdoor and indoor air pollution will spearhead novel scientific insights. This includes an improved assessment of personal exposure. Novel disease areas such as cancer, infectious diseases, reproductive health, mental health and the obesity epidemic would fully capture the disease burden. Potential interactions with other exposures such as noise, and the interaction with physical activity in the light of climate change and changes in source characteristics are needed.
- Evaluating the health effects of living environments in urban and rural settings should consider current and future patterns and populations at different ages and disease states and estimate the magnitude of the urban burden of disease related to the changes in environmental exposures. This evaluation should consider both communicable and non-communicable diseases and incorporate plans to

[54] https://ec.europa.eu/environment/strategy/zero-pollution-action-plan_en

mitigate effects and prepare for future crises. Involving citizens in mitigation strategies is also critical.

Tentative research call areas

Title: *Healthy outdoor and indoor air for children*
Scope: Children's environment is critical for early development specifically with respect to allergies, metabolic diseases and mental health. Air pollution from ambient and indoor origin is likely to affect substantially early development and sustained impact over the lifespan. Improved monitoring of exposures indoors and outdoors to airborne particulate matter, gaseous pollution and household chemicals employing exposome research tools will allow elucidating impacts in these critical early developmental periods. Large-scale administrative cohorts, parent-child birth cohorts, dedicated small studies and experimental toxicology jointly may contribute to support the implementation of zero pollution policies and inform the European chemicals strategy.

Title: *Healthy air for abating ageing-related diseases and individualized prevention*
Scope: Impacts of air pollution on function, structure, and, where applicable, malignancies of the barrier organs such as the lung, the skin, and the gut and systemic impacts on the heart, brain, kidney, and vascular system. Advances in understanding the underlying patho-mechanisms and the identification of novel biomarkers will allow to understand the contribution of air pollutants in age-related non-communicable diseases (NCD). It will allow quantifying the relevance of clean air for aged populations, interactions with common treatment of NCD and potential co-benefits.

Title: *Climate change mitigation and zero air pollution action plan – Quantifying the co-benefits of improving air quality*
Scope: Climate change mitigation action will have major impacts on European and global health impacts and will substantially contribute to sustainable development. Technological advancements will greatly profit from establishing co-benefits and health economic assessments. Novel monitoring infrastructures and tools together with modelling will be needed to capture air quality changes, develop evidence-based scenarios and predict local, regional and global impacts. They will allow to predict in a time-efficient manner benefits of mitigation strategies, guide implementation efforts and evaluate the progress towards the new WHO Air Quality Guidelines and their implementation.

Title: *Experimental and modelling approaches to characterize the impact of air pollutants on health.*
Scope: Development of novel technological approaches for monitoring and modelling the biological and health impacts of air pollutant mixtures. Experimental assessment of air pollution mixtures has been a challenge in toxicology as compared to other exposure pathways. Further development of innovative systems levering recent biomedical advances and integrated exposome toolbox to characterize and quantify the impact of exposure to multiple air pollutants and their interactions with other stressors is needed.

RG2.3 Noise in living environments

Objective: Understand the negative health effects of noise, to protect health and develop effective interventions for prevention. Improvement noise exposure characterization and the understanding of its negative health effects.

Relevance

Scientific relevance: Noise pollution is estimated to be the second most detrimental environmental factor for ill health just after air pollution in Europe[55][56], due to its high prevalence and impact on sleep, chronic annoyance, ischemic heart disease and also on learning impairment in schoolchildren exposed to aircraft noise. However, noise has been understudied and many of its health effects are still unknown. Due to its estimated great health impact, the WHO noise guidelines for the European Region[57] highlighted the need for more and better research on the effects of environmental noise on health. Moreover, better noise exposure assessment and coverage is needed for health research purposes, including tools for indoor and personal exposure, identification of new or altered noise sources, as well as dynamic assessments to capture the rapidly changing environment. Dedicated research efforts are therefore needed to better characterize noise exposure and advance on the understanding of its adverse health effects.

Policy-relevance: Strong research efforts to understand the negative health effects of noise are critical to inform policies and decrease the noise-related burden of disease related to this leading environmental pollutant. This need is highlighted in the conclusions of the WHO noise guidelines for the European Region (2018). The decrease of noise pollution would further contribute to the zero pollution targets, which is also essential for ecosystems and promotes the UN sustainable development goals.

Research needs

Research needs correspond to methodological developments on noise exposure assessment and longitudinal and intervention studies on main noise-related health research gaps, study of vulnerable groups, elucidation of biological mechanisms and role of non-acoustic factors. Research is also needed that assesses the implementation of the 2018 WHO noise guidelines for the European Region.

- Source-specific outdoor and indoor characterization of transportation noise and/or other common noise sources, including novel noise indicators beyond average noise levels, wider geographical coverage, assessment of low noise levels and relevant exposure windows.
- Development of methods and tools to automatically characterize noise exposure, identify sources and assess relevant personal exposure.
- Longitudinal studies and intervention studies covering main noise-related health research gaps, i.e. birth outcomes, behaviours, cognitive development and decline, mental health, metabolic health, cardiovascular health beyond ischemic heart disease and mortality.
- Study of noise perception, non-acoustic factors and quiet areas.
- Study biological mechanisms of noise on health.
- Study health effects of noise by sex, age, and in understudied vulnerable populations such as children, pregnant women, the elderly and the socioeconomically deprived.
- Assessment of the implementation of the 2018 WHO noise guidelines for the European Region; work on noise reduction strategies in the urban environment.

Tentative research call areas

Title: *Advancing noise exposure assessment for health research*
Scope**:** The quality, coverage and exposure range of available outdoor exposure data for transportation noise in Europe is mixed and vulnerable periods of exposure such as sleep or concentration require complementary indoor exposure assessment. Noise characteristics that are most detrimental, beyond average noise levels, are also unknown. Finally, with a rapidly changing environment, readily available dynamic assessments are needed. It is therefore necessary to invest in the development of methods and tools to improve noise exposure assessment of environmental noise sources indoors and outdoors, as well as for personal exposure, with the identification of relevant noise sources, novel noise indicators, improvement of the geographical coverage and assessment of low noise levels.

Title: *Health effects of environmental noise*
Scope**:** The range of health effects of noise is still uncertain. Robust knowledge is needed from longitudinal epidemiologic studies and intervention studies about the negative health effects of noise on birth outcomes, behaviours, cognitive development and decline, mental health, metabolic and cardiovascular health and cause-specific and all-cause mortality. Focus on vulnerable groups, including children, pregnant women, the elderly and socioeconomically deprived

[55] WHO and JRC, 2011 - https://www.euro.who.int/__data/assets/pdf_file/0008/136466/e94888.pdf
[56] Hänninen et al., 2014 - https://pubmed.ncbi.nlm.nih.gov/24584099/
[57] https://www.euro.who.int/en/publications/abstracts/environmental-noise-guidelines-for-the-european-region-2018

groups is needed, as well as the role of noise perception and non-acoustic factors.

Title: *Biological mechanisms of noise*
Scope**:** The actual biological effects of noise are still unclear and this is needed to better assess the health effects, including the development of effect markers. Experimental settings to study noise impacts are needed. Biological and pathophysiological pathways triggered by noise need to be explored and compared to those elicited by other stressors.

RG2.4 Changing work and employment conditions

Objective: Study effects on human health of rapidly changing work and employment conditions.

Relevance

Scientific Relevance: Occupation and employment are an essential component of adult life and a major determinant of health and healthy ageing. Health is strongly influenced by one's working environment and by the adaptation of this environment to the health status of the individual. Priority areas predominantly refer to an evaluation of rapidly changing work and employment conditions including, climate change and worker health, ageing workers, new technologies and chemicals, working time, changing employment patterns and precarious employment, mixed exposures and biomonitoring, work-life balance and neglected work-related diseases.

Policy Relevance: Policies on the green and digital transitions will bring enormous opportunities for European citizens but also many challenges. Changes linked to digitalisation, artificial intelligence, teleworking and the platform economy will require particular attention with a view to reinforcing social security systems and occupational health and safety (see RG2.5). Research on new patterns of employment have direct relevance to policies addressing the risks of exclusion for particularly vulnerable social groups, and policies that work actively to close gender gaps in employment, and to promote equality and fairness.

Research needs

- Climate change, key enabling technologies, the Green Deal and occupational health. Key enabling technologies and the European Green Deal, will rapidly transform the European economy, production systems, and the labour market. Full and socially sustainable use of these technologies, need to include occupational and environmental safety already in the design process. Advanced manufacturing including robotics, digitalization and AI can enhance productivity and eliminate dangerous or monotonous tasks, but simultaneously create new and complex human machine interactions, increase Taylorism, and affect intrinsic job quality. The use of advanced materials, e.g. nanomaterials, may cause new occupational and environmental risks, and considerable knowledge gaps remain with regard to their safe handling throughout the life-cycle. The circular economy is an important part of the Green Deal, but may potentially include increased occupational exposures to toxic compounds. Occupational heat stress is increasing with climate change for millions of primarily manual workers, leading to acute and chronic health risks, but also decreased productivity. New solutions will need to integrate risk assessment with the simultaneous implementation of sustainable technologies.
- Changing and ageing workforce. Long term and more recent changes in employment patterns, work patterns and an ageing workforce are all related to multiple effects on health and wellbeing. New national policies with economic drivers to prolong working life may adversely affect those who would have retired if they could, e.g. for health reasons, but need to go on working for economic reasons. The effects of these policies with regard to the health and wellbeing of workers and their families are largely unknown. Evidence of possible differential effects in an increasingly heterogeneous workforce, and diverse working conditions, is of vital importance to inform policy.
- Working time. The COVID-19 pandemic has profoundly affected global society in multiple ways, both introducing completely new challenges and accelerating ongoing trends in work. Working time is being identified as a major factor for occupational health, both with regards to length and time of work during the 24hrs, for example night shift work, long shifts, long working weeks and blurring of work and non-working times particularly in the new post-COVID-19 era. Non-standard working hours are increasingly common and a much better understanding of the underlying biological process behind the multiple health effects and tests of designed interventions are critical for evidence-based prevention measures.
- Changing employment patterns._Employment patterns have been changing since many years. Precarious employment has become increasingly common, and with little knowledge on potential effects on safety and health, e.g., mental, neurodegenerative, cardiovascular and other, as well as on quality of life. Non-standard employment particularly among women, immigrants, the young and low educated, relates to a wide variety of aspects including instability, having multiple jobs and the gig economy. The relationship of these types of employment to health is unclear. The societal changes following the COVID-19 pandemic tend to blur work and non-working times, accelerating tendencies that affected previously particularly mothers and the younger workforce. Resources should be provided to evaluate the full complexity of work-life balance in different ages with emphasis in younger women, with the ultimate goal to provide tailored intervention strategies.
- Neglected occupational diseases. Occupational health research has focused on injuries and specific diseases, such as cancer, respiratory and musculoskeletal. Several other diseases have been associated with occupational exposures including chronic kidney disease (of unknown origin and others), neurological and neuro-degenerative diseases, infections in specific occupations and cardiovascular diseases.

- Monitoring, electronic health records, and surveillance in occupational health. Linkage of electronic health records (EHR) with other available data (e.g. census data, population registers, other government and local data sets) is increasingly being used in health research in Europe. Although EHR have occupational information they generally do not link to detailed occupational records. There is considerable potential to use such data sets for occupational health analyses, and in many instances, this may be the best way to study particular occupational health problems. Improving these data sets by adding or linking with occupational employment and exposure data, using standard occupational codes, is a priority. In addition to electronic health records and surveillance systems there remains a need for well characterised occupational cohorts (population or industry-based). Combining electronic health records, surveillance systems and cohort studies provides a system in which pluralistic approaches can be used to obtain new insights on biological mechanisms, detailed exposure-response analyses and effect modification by lifestyle factors, conduct HIA and evaluation of implementation of preventive policies.

Tentative research call areas

Title: *Climate change, key enabling technologies, the Green Deal and occupational health*
Scope: Key enabling technologies and the European Green Deal, are rapidly transforming the European economy, production systems, and labour market. New materials are introduced and mitigation measures, e.g. circular economy, may result in new exposures. There are considerable knowledge gaps remaining in all these areas and research on new solutions will need to integrate risk assessment with the implementation of sustainable technologies.

Title: *Ageing workforce and prolonged working life*
Scope: New national policies with economic drivers to prolong working life may adversely affect those who would have retired if they could, e.g. for health reasons, but need to go on working for economic reasons. The effects of these policies with regard to the health and wellbeing of workers and their families are largely unknown. Evidence of possible differential effects in an increasingly heterogeneous workforce, and diverse working conditions, is of vital importance to inform policy. Research should evaluate health and social effects of prolonged working life and conditions of work among the aged, and also evaluate vulnerable groups including persons with health problems who continue working.

Title: *Working time – prolonged hours and shift work*
Scope: Long term and more recent changes in employment patterns and work patterns are all related to multiple effects on health and wellbeing. The COVID-19 pandemic has profoundly affected global society in multiple ways, both introducing completely new challenges and accelerating ongoing trends in work concerning working times and working at home. New research is needed on working-time both concerning effects of prolonged working hours and shift work, including exposome approaches and comprehensive evaluation of factors such as light, sleep, physical activity and diet in shift workers and emphasis on preventive measures and interventions.

Title: *Changing employment patterns - Precarious employment and work-life balance*
Scope: Precarious employment has become increasingly common, and with little knowledge on potential effects on safety and health, e.g., mental, neurodegenerative, cardiovascular and other, as well as on quality of life. Non-standard employment particularly among women, immigrants, the young and low educated, relates to a wide variety of aspects including instability, having multiple jobs and the gig economy. The relationship of these types of employment to health is unclear. The societal changes following the COVID-19 pandemic tend to blur work and non-working times, accelerating tendencies that affected previously particularly mothers and the younger workforce. Resources should be provided to evaluate the full complexity of work-life balance in different ages with emphasis in younger women, with the ultimate goal to provide tailored intervention strategies.

RG 2.5 Digitalisation, changed mobility patterns and effects on environment and health

Objective: Understand how digitalization alters our urban and personal environments and activity patterns and to develop tools and methods to ensure a sustainable development

Relevance

Scientific relevance: Digitalization alters dramatically our urban and personal environment and activity patterns. Homework and e-shopping have the potential to reduce emissions from traffic, reduce the need for expensive office space in central locations, and save commuting time and cost for individuals. Changed patterns in job commuting may lead to reduced pollution from transportation but may also increase the burden on the environment in residential areas as people spend more time there and non-digital services relocate to those locations. Social environments may also change when traditional workplaces are abandoned, and digital work rids of the social aspects such as breaks and small talk.

While less job commuting may lead to less pollution from transportation, digital systems require increased amounts of electricity, the production and distribution of which may increase the burden on the environment. Reduced time for commuting may yield increased time for family life but there are also risks, including social isolation and increased stress at work as meetings become more condensed and with less breaks as there is no relocation needed between meetings.

E-shopping may reduce emissions from private shopping transportation but yields increased use of packing materials and transportation of packages affecting international, national and local transport systems. This may lead to increased emissions and burden on local environments, such as congestion, noise, and accidents.

The social environment in cities may change when shops and offices move out. This may make cities less socially attractive, less alive and potentially also less safe with more empty spaces. This can negatively affect people's well-being and quality of life.

The environmental and health effects, in particular mental health but also physiological effects, of the changes and consequences that large-scale homework and e-commerce about are yet little researched. When people in large numbers spend more time at home there will be quantitative, temporal and geographical changes in both societal systems and social life, including energy consumption and production, traffic flows, emissions, delivery of services that are not digitally deliverable. Homework requires new technical tools and new ways to organize work for a more social "multisite" work life where the home is a major, but not the only, hub.

Policy-relevance: Digitalisation is central for transformational changes in production, infrastructures, business for the future and discussed as key tools in several of the action or strategic EU plans[58]. The EU plan is working on a digital transformation that will benefit all, helping to achieve the green transition. However, the implications on health and environment need further focus as covered in the present RG. Work at home requires improvements to technology but also novel ways to organize work that ensure a human work environment. This includes the need for upgraded legal regulation of work. While these issues are to some extent a matter between employers and employees, basic regulation concerning rights and responsibilities is needed.

Research needs

Research needs include both basic research on effects of changed mobility and activity patterns and applied research to design and implement innovative tools and practices.

- Digital innovation for a more social home work environment. Developing tools for cooperation and work organization to ensure a human work environment for work from at home.
- Advancing knowledge about the effects of work at home on personal health, cognitive development, stress, social inclusion and exclusion, and quality of life, considering gender, age and other relevant factors. *i:* Analysis of mental health related to work at home; *ii:* Design of workplaces conducive to good health; *iii:* Designing and implementing digital tools for personal health monitoring and *iv:* Understanding health effects and risk factors related to problematic usage of internet, e.g. in relation to reduced physical activity, "lives online" or internet addiction.
- Big data and AI to understand mobility patterns and their effect on emissions. Analysing how changed commuting patterns affect emissions, generally as well as locally. Likewise, analysing and predicting changes in how e-shopping affects use of packing and transportation of goods to understand changes in emissions and health consequences. Advancing knowledge of how increased work from at home and e-shopping affect different social groups by SES factors, occupation, gender, migration factors, ethnic groups, etc.
- Analysing the environmental effects of increased use of electricity required by digital systems. Advancing knowledge on how the extensive amounts of electricity required by digital systems can be

[58] Communication-shaping-europes-digital-future-feb2020_en_4.pdf (europa.eu) and Shaping Europe's digital future | European Commission (europa.eu)

produced and distributed in a safe and sustainable way.

Tentative research call areas

Title: *Health consequences related to the transformational change of work life digitalisation*
Scope: All societal sectors are undergoing large transformations due to digitalisation which are leading to major changes in the working life of a majority of the personnel. This will have benefits and also undesirable health consequences for many. Research to identify positive and negative effects and to enable proactive actions to minimise negative health effects is essential.

Title: *Environmental consequences of e-shopping*
Scope: E-shopping transforms mobility patterns related to shopping. While private shopping transportation is reduced, it is leading to increased use of packing materials and the transportation of packages increases which affects international, national and local transport systems. This may have both positive and negative effects on the environment locally as well as globally. Research to enable proactive actions to reduce negative environmental effects is essential.

RG2.6 Waste and contaminated sites

Objective: Improve understanding on ways to eliminate health risks related to environmental exposure to contaminants originating from recycled/reused contaminated material via the circular economy.

Relevance

Scientific relevance: Current efforts in changing the former linear approaches in economic activities, decreasing raw materials consumption and introducing circular economy concepts offer important benefits towards re-use of natural resources and minimization of wastes. However, there are large gaps in knowledge on the scope, levels and cycling of substances of concern/products in the environment. Waste management is a complex matter and a cause of concern regarding environmental contamination and health effects stemming from chemical content of materials, goods and products. The research needs to comprise how to identify safe limits for recycling and safe reuse of products potentially containing toxic chemicals and improve knowledge on consumer product handling, while enhancing waste management and product safety. Aspects related to waste and contaminated sites and research & interventions for sustainable remediation are also relevant. This will require methodological development identifying chemicals in waste streams to promote circularity at the EU level. At the same time, contaminated sites are well identified hot spots that remain a source of exposure to legacy compounds for decades and there is a need to identify both their impacts on human health, as well as targeted actions for reducing these impacts. While most of the focus is on chemical contamination, similar issues are raised by radioactive wastes and by contamination with biological agents.

Policy-relevance: Intensified policy and adoption of legal frameworks in support of the transition towards the circular economy is needed including export of waste to LMICs where regulations are less restrictive. A greater emphasis must be given on waste prevention in waste policy, for example through waste prevention plans, aiming to zero pollution ambition policies. Hence the chemical pollution in wastewater mirrors the human use and discharges of chemicals which can be a base for actions. Furthermore, integration and mainstreaming of circular economy approaches in existing policies and legal frameworks is highlighted at international and EU level (e.g. OECD Policy Guidance on Resource Efficiency, the European Green Deal action and strategy plans, and the EU Circular Economy Action Plan.[59]

Research needs

The most important needs are related to the prevention and elimination of the adverse environmental and health effects, as well as to addressing the costs, inequalities and inequities related to waste and contaminated site management practices. Stronger support to the transition to a circular economy using the EU waste management hierarchy as a guiding framework to reduce waste production and its adverse health impacts through reduction of the impact of substances of greatest concern is needed. In this context, the safe and sustainable by design concept for chemicals, materials and products should be the guiding principle by avoiding the use of improperly recycled materials. More specific research is needed:

- Understanding of potential health risks from exposure for populations (consumers, citizens, workers, vulnerable populations like children) or for the environment (contamination of soil, water, food) and Identification of drivers of environmental toxicity and toxicity of substances/mixtures in waste streams.
- Methods development. Development of tools for assessing complex mixtures of chemicals in wastewater (receiving waters, grey water and biosolids) to promote management in application of chemicals in materials, products and goods. Investigation of methods on how to extract substances of concern/regulated toxic substances from recycling streams without breaking the circular economy cycle (if in use). Methodologies for the determination of safe limits for recycling and safe reuse of products potentially containing toxic chemicals.
- Generation of comparable/sufficient data on toxic substance use (including mercury, other metals, substances of very high concern (SVHC) and/or regulated/banned persistent organic pollutants (POPs) in products and commerce including PMT substances (persistent, mobile, toxic).
- Further research on chemical mixtures formed by the creation of new products from recycled materials concerning the circular economy principles considering possible exposure rates of those products users from harmful substances that may contain.
- Environmental monitoring of contaminated sites and human biomonitoring/health survey of the population living in proximity to contaminated sites. Large scale analysis of biological agents in waste
- Identification of targeted cost-effective actions for decontamination, prioritised on the basis of critical health impacts, and research to develop guidelines for urban planning related to the redevelopment of contaminated sites for new functions. Research to

[59] https://ec.europa.eu/environment/pdf/circular-economy/new_circular_economy_action_plan.pdf

optimise development of substitutes for hazardous chemicals through “Safe and sustainable by design” to avoid regrettable substitutions and to meet the requirements of circularity. Translational research enables the consideration of adverse effects on human health and the environment when designing and implementing circular economy policies and regulations and when making financing and investment decisions.

Tentative research call areas

Title: *Assessment of health impacts related to contaminated sites and identification of targeted interventions and recovery*
Scope: In order to identify the impact of contaminated sites, data from existing or prospective cohorts for populations living in the proximity to contaminated sites should be evaluated. This should involve extensive biomonitoring and identification of early markers of effect (involving also omics techniques), together with comprehensive exposure assessment to waste related contaminants, attributing the part of exposure that is related to waste management activities. Health outcomes identified in the cohort study should be identified clearly and should be associated with major exposure sources originating from the contaminated site, while these associations should also be mechanistically anchored with in vitro testing. Identification of the exposure sources leading to the most critical health impacts should guide the prioritisation of decontamination actions. Involvement and engagement of all related stakeholders with particular emphasis to citizen science approaches are essential for successful projects.

Title: *Identification of safe limits for recycling and safe reuse of products potentially containing toxic chemicals*
Scope: Chemicals with hazardous properties can cause harm to the environment and human health. While not all hazardous chemicals raise the same concerns, certain chemicals cause cancers, affect the immune, respiratory, reproductive and cardiovascular systems, weaken human resilience and capacity to respond to vaccines and increase vulnerability to diseases. More efforts must be made in the production and use of safe and sustainable chemicals. It is particularly important that research and innovation results give more alternative solutions to the industry for substituting, as far as possible, substances of concern. Moving to safe and sustainable-by-design chemicals, including to sustainable bio-based chemicals, and investing in finding alternatives to substances of concern is crucial for the environment and the human health, as well as an important precondition for reaching a clean circular economy.

Title: *Waste water as a mirror of production and consumption of chemicals for promotion of safety and sustainability by design and development of a circular economy.*
Scope: It is instrumental to move away from persistent, bioaccumulative and toxic chemicals in materials, products and goods, hazardous chemicals with shorter half-lives, i.e. the retrospective uses of chemicals and look forward. The proactive needs for developing the circular economy goes through production and use of safe and sustainable chemicals. Learning from the present situation into the future is essential and the objective of this call area.

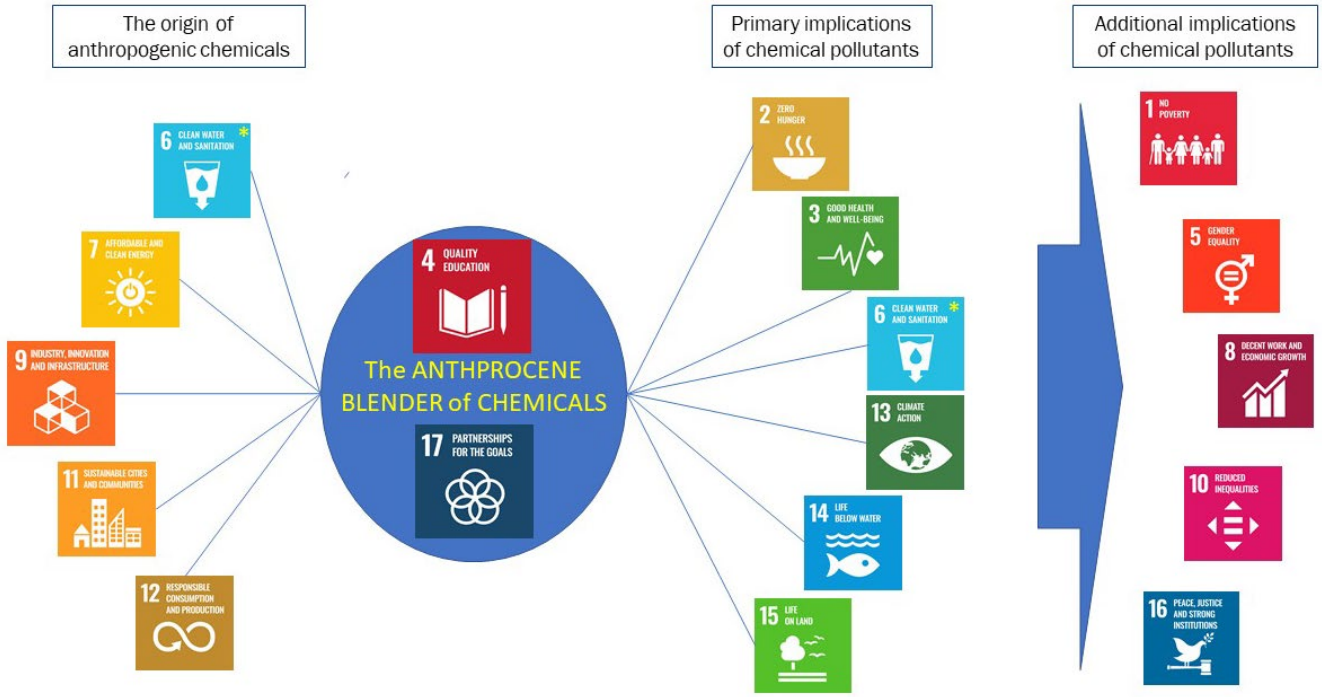
Research Goal 3
Chemicals and physical stressors – prevent and eliminate harmful chemical exposures to health

Introduction

The challenges of a zero pollution paradigm and a sustainable future of mankind and our environment require the interlinking, and integration, of all the UN Sustainable Goals to create a healthy planet. Chemicals, i.e. anthropogenic chemicals and chemicals formed through refinement from natural sources or formed as by-products from human activities (e.g. energy production, transport, manufacturing products and goods) are a major threat with serious effects both on climate change and biodiversity loss. The knowledge on the origin and fate of anthropogenic chemicals must be addressed since when they are discharged, used and distributed to the environment, the incredibly complex mixtures that are formed will impact health and environment in an exposome perspective. These primary effects will have secondary pronounced and important consequences that need further scientific attention in order to move in the direction of a sustainable future.

The research goal 3 covers toxic chemicals and their mixtures to which the population is exposed, including all chemicals of anthropogenic origin, i.e. metals, organic chemicals, polymers, plastics, incl. nano- and micro-plastics. The effects of environmental exposures on ecosystems and humans are considered, the latter especially in relation to development of chronic conditions, diseases and disorders. Adverse health effects of environmental exposures to chemicals are a function of the levels and intrinsic properties of these chemicals individually and in mixtures. The properties of chemicals include their persistence, mobility, toxicity which describes how they interact in/with the abiotic environment and with living systems (biota). Two major external exposure pathways are covered in this RG, water and food contamination, the latter also including soil contamination as a source of food and feed contamination. However, people may also be exposed through other pathways and physical stressors of anthropogenic origin, such as radiation while other stressors are covered in RG1 and RG2.

Figure 5: A complex world of anthropogenic chemicals. The chemicals in use should be known but are not (far left). The chemicals leak out, become transformed and are threatening environment and health. The effects if pollution cases also secondary effects (far right). Multidiscipline partnerships and better education are needed.



RG3.1 Exposure to chemicals including legacy chemicals, emerging chemicals and mixtures

Objective: Advance the scientific knowledge on environmental pollution exposures to promote characterisation of what constitutes a toxic-free environment.

Relevance

Scientific relevance: The environment is receiving tens of thousands of anthropogenic chemicals through manufacturing, applications and use in products, materials and goods leading to unintended exposures of the ecosystems, i.e. plants, animals and humans. The spectrum of chemicals spans from those being highly stable, bioaccumulative and mobile to chemicals that are rapidly transformed *in vivo,* to others that are reactive or have become biologically activated as well as to other hazardous compounds. Likewise, exposure to anthropogenic polymers (plastics) and nanoplastics/nanomaterials need to be considered. Parent molecules, as well as their biotic and abiotic transformation products, should be taken into further scientific considerations. Exposure occurs throughout the lifecycle of a chemical, i.e. from manufacturing and use to their environmental mobilisation and final disposal forming part of the exposome perspective[60],[61]. The chemicals may constitute traditional structures or nanostructures of inorganic (metals incl. heavy and post transition metals (e.g. gallium and indium)) or novel organic chemicals i.e. small molecules, <1200 Dalton and polymers, among e.g. antimicrobial agents, flame retardants, food additives, pesticides, pharmaceuticals, plasticisers, surfactants, etc. If bioavailable, their biological properties may cause harm leading to risk for both the environment and humans when exposed to these chemicals or mixtures thereof. Non-bioaccumulative chemicals may exert other effects due to their presence in the abiotic environments, e.g. ozone depleting chemicals. The environmental occurrence and behaviour and the human exposure to a majority of these chemicals are yet unknown or only rudimentary scientifically described. Both immediate and long-term research efforts are needed to address the exposure to novel, i.e. yet unknown, and emerging chemical pollutants (e.g. organophosphates, cyclic silicone-based chemicals, chlorinated paraffins, PFAS and others), and yet unknown chemical exposures and to relate such exposures to known pollutants and their exposure trends/patterns.

Policy-relevance: Intensified research efforts on exposure to anthropogenic chemicals will be amplified by the Zero Pollution Action Plan[62] for a toxic-free environment and the implementation of the related actions especially under the Chemicals Strategy for Sustainability [63]. Other relevant strategies include Biodiversity strategy[64], Circular Economy Action Plan[65], Farm to Fork strategy[66], and above all, the UN Sustainable Development Goals[67].

Research needs

The fundamental needs are related to Directed Basic Research on chemical exposure which is required for future robust and science-based regulatory decisions. The exposome perspective is essential which includes methodological developments, knowledge generation of the unknowns e.g. unprejudiced identification efforts, and advanced research related to certain endpoints, diseases and disorders (see RG3.2).

- Identification, occurrence and assessment of exposure to novel and emerging environmental pollutants representing persistent/bioaccumulative and bio-transformational but abiotically stable chemicals.
- Development of methods and tools for assessment of potential exposure to chemicals proposed for use in the Technosphere or as substitutes of hazardous chemicals.
- Data on micro-/nanoplastics and nanoparticles exposure sources, pathways, fate, and levels (including realistic and worst-case exposure scenarios) including accumulation in human tissues are presently limited and need to be expanded.
- Further research on the exposome, chemical mixtures, both intentional and unintentional, is needed across regulatory sectors and various usages.
- Research applying abiotic matrices to comprehensively mirror the environmental and human exposures to anthropogenic chemical pollutants.
- Exposures of people with various socioeconomic status (SES), such as income and educational attainment, different ethnicity, gender and age should be studied to better understand societal driven differences in exposures to anthropogenic chemicals.
- Exposure data should be collected on particular types of chemical mixtures related to specific usage (antimicrobial agents, flame retardants, food additives, pesticides, pharmaceuticals, plasticisers, surfactants, etc.).
- Research gaps regarding mixture effects on chemicals existing in daily consumer products such as food, textiles and cosmetics, as well as on multi-pollutant exposure.
- There is a clear need for longitudinal data on low-dose and chronic exposures and interdisciplinary approaches considering multiple and also non-chemical exposures

[60] Miller, G. W. & Jones, D. P. The Nature of Nurture: Refining the Definition of the Exposome. Toxicol. Sci. 137, 1–2 (2014).
[61] Vermeulen, R., Schymanski, E. L., Barabási, A. L. & Miller, G. W. The exposome and health: Where chemistry meets biology. Science (367, 392–396 (2020).
[62] adopted 12 May 2021, https://ec.europa.eu/environment/pdf/zero-pollution-action-plan/communication_en.pdf
[63] Chemicals strategy (europa.eu)
[64] Biodiversity strategy for 2030 (europa.eu)
[65] Circular economy action plan (europa.eu)
[66] resource.html (europa.eu)
[67] https://www.un.org/sustainabledevelopment/sustainable-development-goals/ & www.un.org/ga/search/view_doc.asp?symbol=A/RES/70/1&Lang=E

(i.e. radiation, noise, socioeconomics, psychological stressors).

- Further development of exposure modelling linking sources to internal exposure ultimately leading to improved prediction of body burden based on environmental data.

Tentative research call areas

Title: *Developing methods for assessing internal exposures to non-persistent chemicals.*

Scope: Persistent and bioaccumulative chemicals have long half-lives in humans which make it less difficult to calculate the dose (i.e. integral exposure over time). Dose-calculation is very difficult for chemicals with a high stability in the abiotic environments but rapidly metabolised when taken up in a living organism (i.e. non-persistent chemicals), e.g. in humans. Methods need to be developed to assess exposures to semi-persistent chemicals and to calculate their internal dose.

Title: *Mixture variations in environmental and human exposure to anthropogenic chemicals due to spatial and socioeconomic status as a base for improved exposure assessments.*

Scope: It is hypothesized that the environmental and human exposures differ depending on geographical locations and living conditions while the status of the existing knowledge is poor. Extensive studies on the chemosphere external and internal exposures are needed. Based on the results, modern, future exposure scenarios, complexity and differences in the mixture constitutions can be achieved to promote actions for better health protection.

Title: *Improve exposure modelling from sources to internal dose.*

Scope: Exposure data are often missing or scarce which hampers both environmental health research and regulatory action. It is thus critical to further develop modelling approaches linking different exposure stages including pollutants sources and emissions, aggregated exposure pathways, tissue levels prediction using Physiologically-based Toxicokinetics. This should lead to improved prediction of body burden based on environmental data. Reverse dosimetry is also useful to better predict the contribution of different sources.

RG3.2 Health effects of anthropogenic chemicals.

Objective: Advance health and environmental effect sciences through deeper and broader understanding of what constitutes safe chemicals and which are the leading chemical risks.

Relevance

Scientific relevance: Assessment of the health risks associated with human and environmental exposures to chemicals, from reactive species to persistent chemicals, including plastics and nanomaterials, is complicated by the complexity of biological events in humans and other mammals leading to a variety of diseases and disorders in humans and effects among wildlife jeopardising the species survival. Additional research is needed, beyond the traditional evaluation of CMR (carcinogenic, mutagenic or toxic to reproduction) risks and endocrine disruption (ED), focusing on less developed areas of ED, the immune system, neurological and metabolic related diseases and disorders and interaction of environmental chemicals with infectious agents. The perspective of absorption, disposition, metabolism and excretion (ADME) need to be better included in future research. An exposome approach is favourable, prioritizing the 3R approaches (replace, reduce and refine) and promoting *in silico* strategy testing, mechanistic experimental studies, and link effects in living environmental species with human health, incl. e.g. large human population studies. The many anthropogenic chemicals and their real-life mixtures require intensified research efforts to promote improved toxicity testing methods and strategies, safety assessments, both environmental and human biomonitoring which form the base for adequate policy actions. Chemicals of concern must be expanded into those that are poorly studied to those being of emerging concern (e.g. antimicrobial agents, flame retardants, food additives, pesticides, pharmaceuticals, plasticisers, surfactants and other substitutes for additives to materials and goods). Some of the present chemicals of concern are e.g. organophosphate additives, cyclic silicone-based chemicals, chlorinated paraffins, PFAS and substitutes of phthalate esters and bisphenols.

Environmental and human risks are distributed inequitably among people of different socioeconomic status as well as vulnerable population groups (women in fertile ages, migrants, children and elderly people). Gaps in communication of hazards and risks to the public and relevant stakeholders exist.

Policy-relevance: Improved knowledge for actions on emerging chemicals, chemicals of very high concern and endocrine disruptors has been expressed as a priority by stakeholders. This is promoted by several of the present Green Deal action or strategy plans[68], in particular the Chemicals Strategy for Sustainability[69] and the Zero Pollution Action Plan[70] and above all, the UN sustainable development goals[71]. The Chemical Strategy also highlighted *i)* the large number of chemicals (more than 70% of commercially available chemicals) for which no data are available and *ii)* the importance of insufficiently studied outcomes such as immunotoxicity and neurotoxicity.

Research needs

The fundamental needs are the evaluation of human health effects in large families of understudied chemicals (e.g. antimicrobial agents, flame retardants, food additives, pesticides, pharmaceuticals, plasticisers, surfactants and other substitutes for additives to materials and goods) and health effects of endocrine disruption (ED), focusing on less developed areas of ED, the immune system, neurological and metabolic related diseases and disorders and interaction of environmental chemicals with infectious agents (e.g. immunotoxicity). The detrimental importance of the dietary constitution of endo- and exogenous chemicals for sustainable health need further understanding. The perspective of absorption, disposition, metabolism and excretion (ADME) need to be better included in future research and the development of methodology for comprehensive and faster risk/safety assessments of individual chemicals and mixtures of chemicals. Also, the interconnections to human diseases and disorders and effects in non-human species need to be included on population levels covering all age groups of populations. The research needs in RG3.2 are linked to the efforts in RG3.1 and include:

- New effect biomarkers should be developed for early detection of emerging environmental and health risks from anthropogenic chemicals and of chemical mixtures prioritizing 3R methods.
- There is a need for additional studies on certain priority outcomes such as immunotoxicity, neurotoxicity (including developmental neurotoxicity), endocrine disruption (in addition to (oestrogen, androgen, thyroid, steroidogenic –EATS-pathways and effects), metabolism and obesity and on new areas of research on mental health and infectious diseases in relation to environmental exposures.

[68] https://ec.europa.eu/environment/strategy_en
[69] Chemicals strategy (europa.eu)
[70] adopted 12 May 2021, https://ec.europa.eu/environment/pdf/zero-pollution-action-plan/communication_en.pdf
[71] https://www.un.org/sustainabledevelopment/sustainable-development-goals/ and https://www.un.org/ga/search/view_doc.asp?symbol=A/RES/70/1&Lang=E

- Absorption, distribution, metabolism, and excretion (ADME) data and new toxicokinetic models are needed to better understand the link between external and internal exposure and to integrate this data into health risk assessment.
- Health (toxicology/epidemiology/molecular mechanisms) data should be collected on the risks of chemicals in general but in particular on pesticides and on plastics, micro- and nano-plastics and chemicals in plastics (additives and residues of process chemicals). Research based on large cohort studies using biomarkers and other methods for accurate cohort assessment are required. So far only a few chemicals have been widely studied but limited to certain health domains.
- Synergistic mixture of chemical and physical stressors to human health and wildlife effects need to be further investigated to control life's quality development of actual and future technical societal developments.
- Mechanistic studies are needed to assess new Adverse Outcome Pathways (AOPs), in particular mitotoxicity and toxicity related to epigenetic dysregulation.
- There is a need for longitudinal health data on low-dose and chronic exposures and interdisciplinary approaches considering multiple and also non-chemical (i.e. lifestyle, radiation, noise, socioeconomics, psychological) stressors, incorporating new approaches such as interactions of the exposome with the microbiome.

Tentative research call areas

Title: *Expanding environmental effect and health studies into novel areas of endocrine disruption, immunotoxicity and neurotoxicity.*
Scope: The impacts on endogenous systems, specifically the immune- and the nervous system should be investigated. The focus on endocrine disruption has so far been on EATS (oestrogen, androgen, thyroid, steroidogenic) while the number of the hormonal systems in humans counts to fifty with approximately 100 signalling endogenous chemicals. The interference possibilities of anthropogenic chemicals are extensive which need to be identified, described and assessed in an environmental effect and health perspective in order to better understand the impact of endocrine disruption and other toxicities.

Title: *Expanding the ADME knowledge of emerging contaminants as such and as mixtures to improve risk and safety assessments*
Scope: The ADME *(*absorption, distribution, metabolism, and excretion) data are required in order to understand the environmental and human effects of chemicals. The present situation, e.g. the continuity of major data gaps, has to change. It is necessary to develop methodologies based on advanced present chemical analytical techniques with application of labelled chemicals to enable traceability.

Title: *Development of a large cohort infrastructure to evaluate long term health effects of pesticides using exposome approaches*
Scope: Risk assessment on pesticides is frequently based on a single U.S. cohort, the Agricultural Health Study. There is a need for additional large, diversified epidemiologic cohort studies developed in the EU using exposome approaches that should include biomarkers of exposure and pathway analyses for a diverse set of adverse effects in the general population, susceptible populations and professionals. Missing toxicological data should be obtained and integrated with population data.

Title: *Large scale development of Adverse Outcome Pathways (AOP) and AOP networks and tools to link chemicals to AOPs*
Scope: The AOP concept is a framework organizing the causal relationships between molecular initiating events (MIE), subsequent key events (KE) at different biological levels and ultimately adverse outcomes. AOPs are useful for basic and regulatory research. There are many critical outcomes that lack AOPs (e.g. diabetes) despite an international effort to develop them. Additional AOPs should be developed for outcomes such as endocrine disruption, immunotoxicity, neurotoxicity and metabolic disorders. Tools to link chemicals or other stressors to AOP should also be further developed. AOP networks can also be used to better assess the mechanistic effects of mixtures.

Joint research call area for RG3.1 and RG3.2

Title: *Advancing knowledge on real-life mixtures of chemicals in the EU and beyond*
Scope: Combinations of exogenous chemicals including chemicals at non-endogenic concentrations for which humans and the environment are exposed to are endless. The variations of the mixtures are dependent on a number of factors, such as age, living environment, occupation, geographical location, dietary preferences/habits among others. The knowledge of the complex combinations of chemicals are not yet known, so increased knowledge is needed on exposure and health patterns in a north-south/east-west perspective.

RG3.3 Radiation

Objective: Determine the effects of low-dose and chronic exposures to ionising and non-ionising radiation and identify adverse outcome pathways and direct and indirect impacts of technological development and new communication technologies on human health.

Relevance

Scientific relevance: The area of radiation includes the whole electromagnetic spectrum, from static, extremely low frequency magnetic fields (ELF-MF), intermediate (IF) and radiofrequency electromagnetic fields (RF-EMF), visible light, ultraviolet (UV) radiation and ionizing radiation. Some of these exposures are increasing or changing due to technological development (IF/RF-EMF), others may be more gradually changing (e.g. ELF-MF, UV) or are primarily workplace exposures (e.g. strong static fields). According to current knowledge, sources, exposed population, exposure routes, mechanism of interaction with the body and known health effects vary greatly across the electromagnetic spectrum. Ionising and non-ionising radiation are multifaceted types of exposure. Especially non-ionising radiation (radiofrequency fields) partly overlaps with other types of exposures from which it is difficult to disentangle, e.g. blue light exposures or behavioural issues (lack of physical activity, addiction and stress). Many but not all of these exposures are near-ubiquitous, may affect persons across all age ranges and therefore even subtle effects or small risks could be relevant for public health. Possible effects of some of these exposures on the environment are under-researched and may vary widely between organisms. Technological advancement and favourable human behaviour may both contribute to reduced exposure levels. Introduction of new technologies without adequate risk communication can also contribute to adverse health effects, depending on exposure and risk perception of the respective population.

Policy-relevance: Technological advancement can contribute to exposure reduction, relevant for the EU zero pollution strategy [72] . Technological advancement especially for telecommunication technology (associated with RF-EMF exposures) can assist in digitalisation and thus contribute to several of the UN sustainable development goals[73].

Research needs

The fundamental research needs are related to improved exposure assessment across the whole electromagnetic spectrum - including life-course (long-term) exposure in population studies and for occupational exposures; evaluation of possible subtle health effects; interaction effects of new technology on exposure patterns including exposure reduction strategies and possible effects on humans and/or the natural systems it relies on. Research needs also pertain to better communication strategies during the introduction of new technologies.

- Methods to validly assess life-course exposures across the EMF spectrum, including new technologies and changes in use patterns of technology over time.
- Knowledge on interaction of new and upcoming technologies (5G/6G/…) with different types of organisms and natural systems (e.g. interaction of mm waves with small organisms such as insects).
- Long-term effects of light exposure patterns, especially effects from light at night exposure on disruption of sleep patterns and possible subsequent health effects.
- New methods for environmental and individual exposure assessment should be developed and health effects including NCDs should be examined.
- Effects of UV on novel outcomes, alone and in combination with other exposures.
- Low level (often with long duration) exposures from sources such as tritium, residential radon exposure or medical applications and health concerns are overlooked given the large amount of exposed people.
- There is a need for longitudinal data on low-dose and chronic exposures and interdisciplinary approaches considering multiple and also non-chemical (i.e. radiation, noise, socioeconomics, psychological) stressors.
- Perception, health worries/concern and general societal changes are also on the list as further possible causes of decreased wellbeing.

Tentative research call areas

Title: *Advance knowledge on Effects of the entire spectrum of electromagnetic fields (EMF) exposure*
Scope: Research is needed to improve exposure assessment over the entire EMF spectrum, as well as to better identify and understand the effects of exposure on health through mechanistic and epidemiological studies. This includes an improved understanding of the impacts of EMF on human health, for example, assessment of potential long term effects of strong static field exposure, further exploration of the possible association between extremely low frequency magnetic fields, childhood leukaemia and neurodegenerative

[72] Biodiversity strategy for 2030 (europa.eu)

[73] https://www.un.org/sustainabledevelopment/sustainable-development-goals/ and https://www.un.org/ga/search/view_doc.asp?symbol=A/RES/70/1&Lang=E

diseases using novel approaches; studies of the possible biological and health impacts of intermediate frequency fields (300 Hz to 1 MHz); studies of the impact of RF exposure on neurodevelopment, neurodegeneration, and organs like the skin and eye and possible environmental effects. A deeper mechanistic understanding of the cellular effects of EMF, beyond inflammation and oxidative stress is also warranted, for example on membrane and organ functions. Research is needed on how risk communication can be improved.

Title: *Effects of exposure to Artificial Light At Night (ALAN) on long term adverse outcomes in children and adults*
Scope: Research is needed on long-term effects of light exposure patterns, especially effects from light at night exposure including the use of new technologies on disruption of sleep patterns and possible subsequent health effects. Exposome approaches and new methods for environmental and individual exposure assessment should be developed and health effects including NCDs in long term studies should be examined.

Title: *Effects of UV radiation*

Scope: Improve UV exposure assessment, leveraging real time UV ambient monitoring data, and explore effects of exposure on novel endpoints, including diseases and conditions related to hormonal imbalance in post-menopausal women. Update assessment of global burden of disease.

Title: *Advance knowledge on effects of ionising radiation on non-cancer endpoints and of individual variation in risk from ionising radiation*

Scope*:* Improve understanding of ionising radiation effects on non-cancer outcomes, in particular neurodevelopmental and immune effects through research to understand mechanisms of actions, coupled with epidemiological studies that integrates, where possible and informative, biological and molecular markers to improve health risk evaluation of radiation exposure. Improve understanding of individual variation in risk (both for cancer and non-cancer effects) following ionising radiation exposure through a combination of mechanistic and epidemiological studies.

RG3.4 Water contamination

Objective: Characterize fresh and marine water contamination and its health impacts.

Relevance

Scientific relevance: Water [74], in the broadest perspective, is polluted by chemicals, including pharmaceuticals, additives to materials and goods and microplastics of anthropogenic origin to which wildlife and humans may be exposed. In addition, natural hazards (e.g. arsenic, fluoride, manganese, radioactivity), treatment-related chemicals (e.g. disinfection by-products, fluoride), minerals (e.g. calcium, magnesium, lithium), microorganisms and antimicrobial resistance genes may also occur. Assessment of human exposure to chemicals in drinking water, including frequently occurring pollutants and mixtures, also at low concentrations needs to be addressed to better evaluate health risks particularly in the long-term. Development and application of novel techniques for assessment of various pollutants and chemical mixtures in water are needed. Likewise, better understanding of exposures and drivers of toxicity are needed to evaluate and prevent the health and environmental risks, including from multiple exposures. This will also require synthesis reports, systematic reviews and enhanced interdisciplinary cooperation. Finally, water scarcity issues are paramount, particularly in the context of the climate crisis.

Policy-relevance: The recent EU Action Plan Towards Zero Pollution [75] puts a lot of emphasis on water quality and stresses the need to address emerging pollutants, support better monitoring, and reduce pollution from key substances in surface and ground waters. Multiple EU strategies, including the "Chemicals Strategy for Sustainability" [76] emphasize the need for research and advanced monitoring to understand and prevent chemical-related risks and drive innovation in risk assessment and regulatory science. In addition, the Drinking Water Directive (EC 2020)[77] requires scientific knowledge to periodically update regulatory limits to guarantee the safety of drinking water and the wellbeing of the population. All research gaps are central to several of the SDGs.

Research needs

Research is needed both for legacy and emerging contaminants considering the risks of combined exposures and of by-products/metabolites formed during the water cycle. Novel exposure assessment methods are needed to encompass the multiple exposures and assess potential effects of low dose long-term exposures to chemical mixtures. The following research needs to focus mainly on chemical and physical stressors, as this belongs to RG 3. However, given the relevance of climate change in relation to water scarcity, this topic is also mentioned here. Other wider issues of the water cycle, including treatment technologies are also covered. Contamination by pathogens and water-borne infections and radioactivity pollution is not addressed herein (see RG1.4. Biological agents and RG3.3. Radiation). Specific research needs on safe water access are:

- Assessing the burden of disease for legacy contaminants in drinking water through exposure-response functions estimated from systematic reviews and meta- or pooled-analyses.
- Quantify the contribution of drinking water as exposure pathway for emerging contaminants, e.g. micro-/nanoplastics, per- and polyfluoroalkyl substances (PFAS), pharmaceuticals and personal care products (PPCPs), and their metabolites/by-products. Integrate multiple exposure routes (water, food and air).
- Conduct multi-pollutant, incl. natural toxin, studies to evaluate holistically the real human exposure (exposome) through drinking water and associated health effects. Studies in low- and middle-income countries are specifically needed, where evidence on chemical occurrence in drinking water and studies on health effects is scarce.
- Develop and implement New Approach Methodologies (NAMs) for exposure, hazard and risk assessment and identification of risk drivers (e.g. innovative sampling, effect-based monitoring with a focus on *in vitro* NAMs, effect-directed analysis (EDA), suspect and non-targeted screening, *in silico* methods) to address the issue of complex mixtures in water.
- Evaluate the role of the water pathway in the spread of antimicrobial resistance. Develop efficient technologies and pollution mitigation measures to reduce water contamination by micropollutants, micro-/nanoplastics, excess nutrients, antibiotic resistant bacteria/ antibiotic resistance genes, etc. Evaluate their effectiveness, also for potential wastewater and sludge reuse.
- Elucidate the role of water treatment alternatives (e.g. desalination, reverse osmosis, including domestic devices) on essential mineral composition, and evaluate pollution patterns generated.
- Develop research on the wastewater surveillance and assessment as a predictor of infection propagation and of emerging chemical and/or biological contamination.

[74] WHO (2017). Chemical mixtures in source water and drinking-water. Available at: https://www.who.int/water_sanitation_health/publications/chemical-mixtures-in-water/en/
[75] Zero pollution action plan (europa.eu)
[76] Chemicals strategy (europa.eu)
[77] EU Drinking water directive (europa.eu)

- Address sustainability aspects such as carbon footprint and waste products (e.g. brine from desalination) to quantify environmental impacts of treatment alternatives and personal drinking water choices (e.g. bottled water) to promote sustainable personal choices.
- Improved understanding of links between water scarcity and quality with climate change events.

Tentative research call areas

Title: *Towards a better understanding of effects of drinking water quality on human health*
Scope: Close the research gaps concerning the links between chemical occurrence in drinking water and human health. Evaluate the combined effects on human health throughout the life-course from occurrence of multiple pollutants and formed disinfection by-products in drinking water. Studies with biomarkers to disentangle intermediate mechanisms of action. Leverage existing evidence on chemicals to generate robust exposure-response functions to estimate the burden of disease. Consider beneficial effects from minerals.

Title: *Integrative strategies for effective assessment of water quality*
Scope: Develop and implement innovative strategies for integrative exposure, hazard and risk assessment of different waters (surface, ground, drinking, waste waters) and identification of risk/toxicity drivers using advanced tools and NAMs (e.g. complementary use of representative sampling, effect-based monitoring, EDA, suspect and non-targeted screening, *in silico* and modelling tools) to address the issue of complex mixtures in water across different scenarios and prioritize the contaminants of major concern.

Title: *Novel technologies for water treatment and contamination reduction*
Scope: Develop innovative technologies for minimizing contamination by chemical mixtures and micro-/nanoplastics. Evaluate their effectiveness for reducing risks by complex assessment using effect-based tools and non-target analytical methods to examine the removal of pollutants and toxicity in parallel and prevent toxic metabolites/transformation products arising during the treatment.

RG3.5 Food and soil contamination

Objective: Prevent and minimize exposures from food, feed and soil contamination and their negative impacts on human and animal health and ecosystem services, including new solutions for decontamination.

Relevance

Scientific relevance: While direct human health risks of soil contaminants can be seen to be lower than those of water or air contaminants, it is still not negligible in fact, its significance increases when considering food and feed production which is dominantly based on soil. There are concerns over negative impacts of food and soil contamination on human and animal health, but soil contamination also starts a cascade of degradation processes leading to the damage of the key terrestrial ecosystem services and their damage leads to serious impacts on society. Due to integral connectivity of soil to other environmental compartments, the soil contamination has potential to decrease water and air quality. Environmental pollutants in any abiotic matrix, including soil, feed and food contact materials, can contaminate our food. These are primarily common abiotic chemicals with high persistence and bioaccumulation but occasionally also novel and emerging chemicals of concern including undesirable elements in fertilizers. Research is needed on prevention and elimination of adverse effects and inequalities related to food consumption. It relates in part to waste management and contaminated sites. Research requires novel approaches for the examination of population exposures to specific stressors and mixtures. This is including development of tools for comprehensive assessment of contaminants in food and food contact materials but still considering current methodologies. Since soil is a primary raw material to grow feed and food it is essential that the soil is uncontaminated. Research focusing on soil status (e.g. pH, salinity, degree of chemical pollution, soil microbiome) is needed to address effects to human health. Soil contamination requires improved/new methods for decontamination.

Policy relevance: According to the EU "New Soil Strategy – healthy soil for healthy life" (European Roadmap for Soil protection) [78] , soil is crucial for fighting climate change, protecting human health, safeguarding biodiversity and ecosystems and ensuring food security. Healthy soils are a key enabler to achieve the objectives of the European Green Deal [79] such as climate neutrality, biodiversity restoration, zero pollution, healthy and sustainable food systems, and a resilient environment. Intensive research on soil and food contamination and its negative impacts will promote the zero-pollution ambition for a toxic free environment and the implementation of the related actions especially under the Chemicals Strategy for Sustainability [80] . Non-polluted and healthy soil conditions sufficient food and feed quality and quantity and implementation of the Farm to Fork strategy. Protecting soils also means protection of more than 25% of Earth's biodiversity.

Research needs

While the sophisticated process for predictive risk assessment is well established for chemicals in general and pesticides specifically, the retrospective risk assessment and post-registration control are much less developed and require novel concepts and tools, and their science-to-policy transfer.

- Development of tools for comprehensive assessment of levels, hazards and risks related to contaminant mixtures (including emerging pollutants) in soil, food, food contact materials and feed.
- Assessment of impacts of soil contaminants on ecosystem services (including soil fertility, resilience, or biodiversity and soil microbiome) and thus, their indirect effects on human health and wellbeing.
- Risk of soil-food/feed transfer of metals, legacy and emerging pollutants and consequent impacts on human and animal health.
- Investigating effects of food packaging on the quality of food and related health effects.
- Developing novel, effective soil decontamination methods and tools.
- Development of monitoring tools for establishing an EU priority watch list for soil contaminants and scientifically based limit values for priority contaminants to contribute to development of legislation in this area (similar to air and water quality legislation).
- Investigating best practices and providing guidance for a passport for the safe, sustainable and circular use of excavated and remediated soil.
- Explore potential re-use of valuable (nutrients, organic matter) materials such as sewage sludge, dredged sediments, biodegradable waste, while ensuring the environmental safety at the same time by proper tools for their predictive risk assessment.

Tentative research call areas

Title: *Prevention and elimination of adverse effects and inequalities related to food consumption applying novel approaches for the examination of population exposures to specific stressors and mixtures*
Scope: The exposure routes to soil contaminants call for re-

[78] Healthy soils – new EU soil strategy (europa.eu)
[79] EU climate action and the European Green Deal | Climate Action (europa.eu)
[80] https://ec.europa.eu/environment/strategy_en

evaluation with regard to the effects of climate change (e.g. dust from dry soil transported by wind, flood events moving eroded soil particles). At the same time the mixture character of soil and food contamination must be considered, and tools developed to address the cumulative risks.

Title: *Investigating best practices and providing guidance for the safe, sustainable and circular management of soil*
Scope: Potential of re-use of valuable (nutrients, organic matter) materials such as sewage sludge, dredged sediments, biodegradable waste, while ensuring the environmental safety at the same time by proper tools for their predictive risk assessment.

Title: *Waste water and sewage sludge as mirrors of the human chemosphere (common with RG3.4)*
Scope: Wastewater and sewage sludge will contain basically all chemicals, incl. metabolites and abiotically formed transformation products, released through/by human activities. Accordingly, this will allow identification and potentially quantification of novel and traditional pollutants with high persistency and metabolites of those that are undergoing biological and abiotic transformations. The results will lead to improved understanding of the complex mixtures of pollutants generated through human activities and promote management.

Research Goal 4
Improve health impact assessment of environmental factors and promote implementation research

Introduction

Health impact assessment is the ultimate and often overlooked step of environmental health research. Health impact assessment studies are at the interface between science and decision making and it is a crucial step to help society decide if and how to make use of scientific knowledge in a specific area. Very often, the economic costs of a regulation on a given sector are used as a reason not to regulate, while the health benefits of the regulation are not properly estimated. A systematic quantification of the relationship between human disease and the environment (the environmental burden of disease, EBD), allows a ranking of exposures in terms of population impact as well as cost-benefit analysis and paves the way for more efficient and transparent public health policies and budget allocation. It is necessary to move towards a harmonized methodology in health impact assessment that would enable the comprehensive consideration of environmental factors and the societal and economic impacts thereof. The portfolio of approaches and discipline contributors should be diversified to include biological and chemical sciences in addition to social sciences.

Research on HIA also requires the development of methodologies and scientific tools to address current gaps, for example between exposome and risk assessment studies, while formalising weight-of-evidence approaches to environmental and human health risk assessment. Improved and more integrative impact indicators would allow the measure of societal progress towards improved wellbeing.

Implementation research is the scientific inquiry into questions concerning implementation of policies, programmes, or individual practices (collectively called interventions). It seeks to understand and work within real world conditions, rather than trying to control them or to remove their influence as causal effects. This implies working with populations that will be affected by an intervention, rather than selecting beneficiaries who may not represent the target population of an intervention. The development of implementation research on climate and environmental health and the development and harmonization of methodologies are crucial for the success of the goals of this Agenda.

RG 4.1 A unified European approach on quality of life and burden of disease

Objective: Develop a unified approach in the EU on quality of life and on the burden of disease related to environmental factors and related integrative impact indicators.

Relevance

Scientific relevance: Based on harmonised exposure assessment methodologies and data, disease incidence and socio-economic data RG4.1 aims at providing results on an integrated and comprehensive assessment of quality of life and environmental burden of disease both globally and stratified based on socio-economic determinants. Improved and more integrative impact indicators should be developed allowing us to measure societal progress towards improved wellbeing. The indicators should reflect a number of aspects related to human wellbeing: subjective well-being, health, work-life balance, education, housing, biodiversity, safety, income, job availability and quality, community functions including access to social services and retail stores and civic engagement. The concept here is to embody both physical, mental and psychological health and wellbeing in a way that would allow ready development of the respective indices that would permit multi-faceted analysis of the elements that constitute overall human wellbeing (incl. health).

Policy-relevance: The use of integrative indices for assessing the overall quality of life and the respective burden of disease, will allow the uniform assessment of policies and strategies that promote human health and wellbeing across various EU regions. In this sense, both the medium- and long-term impacts of strategies such as the Zero Pollution Ambition[81] for a toxic-free environment and the implementation of the related actions especially under the Chemicals Strategy for Sustainability[82] including Farm to Fork strategy[83] will be evaluated, together with indices that affect socioeconomic development and subjective wellbeing parameters. The unified methodologies built upon these indices should be used for the identification of the most cost-effective interventions promoting human well-being while maintaining EU competitiveness and sustainable growth, further promoting social coherence and subjective well-being.

Research needs

- Develop indices for subjective well-being, life satisfaction, working environment and other socioeconomic perception factors.
- Develop methodologies for quantifying the burden of subjective wellbeing and the impact on quality of life of environmental health stressors. In this context it is essential that any economic analysis includes the costs of health care and the costs of remediation.
- Refinement of methodologies so as to:
  - Explicitly account for inter-individual susceptibilities related to age, gender, minorities, occupation, etc.
  - Address the risks of aggregate and cumulative risks related to chemicals in environment, consumer products and diet.
  - Address the impacts of lifelong exposure to environmental stressors and their latent effects including direct and indirect consequences to health and well-being.
  - Address the impact of internal lifelong exposure to anthropogenic chemicals (pollutants)
  - Update the weighing factors being used on QALYs (Quality-Adjusted Life Year) and DALYs (Disability-Adjusted Life Year) estimates.
- Develop advanced approaches for incorporation of early effect markers in the environmental burden of disease assessments.

Tentative research call areas

Title: *Development of a unified framework for the assessment of burden of disease associated with multiple environmental factors*

Scope: Account for the multitude of environmental stressors (including chemical, biological and radiological risk factors) and develop harmonised methods for quantifying the burden of disease associated with these factors, as well as the way they interact among them towards deprived health status. Towards this direction, the inclusion of markers associated with early effects on the quantification and the predictions of health impacts will be of utmost importance. Data from existing and newly established cohort studies addressing multiple environmental factors should be included.

Title: *Development of a unified framework for the assessment of overall quality of life accounting for both physical health and perceptual wellbeing factors*

Scope: Starting from the unified framework for addressing the environmental burden of disease, development of methodologies that account for overall well-being should be established, accounting for the various factors that define human wellbeing, including in particular the individual perspective. These, together with the environmental burden of disease estimates, will deliver an integrated score of human welfare, that takes stock of the multiple dimensions that define quality of life.

[81] adopted 12 May 2021, https://ec.europa.eu/environment/pdf/zero-pollution-action-plan/communication_en.pdf

[82] Chemicals strategy (europa.eu)

[83] resource.html (europa.eu)

Title: *Develop indicators and methodology to compare environmental and climate-related health impact on the same scale and baseline.*

Scope: Environmental burden of Disease is a major step ahead to quantify environmental impact on health but existing indicators are complex and not easy to use in policy. There is a need to develop indicators and methodology to compare environmental and climate-related health impact on the same scale and baseline which will allow grading. There is a lack of valid impact indicators that are easier to interpret than existing ones by non-experts.

RG 4.2 Develop tools and methodologies for integrative environmental health risk assessment

Objective: Develop tools and methodologies for comprehensive assessment of health risks associated with environmental burden.

Relevance

Scientific relevance: Development of the necessary methodologies and scientific tools are needed to enable us to address current gaps between exposome and risk assessment studies, while formalising weight-of-evidence approaches to environmental and human health risk assessment. Gaps include the exploration of the most relevant health and quality of life indicators including DALYs (Disability-Adjusted Life Year) and wellbeing, the assimilation of epidemiological and toxicological approaches to risk assessment and the consideration of the effect of risk perception on actual health impact through change of behaviour. There is a clear need for harmonisation of approaches for integrated impact modelling to overcome the piecemeal developments that characterise the historical evolution of the health risk and impact assessment science. Moreover, implementation studies require the mobilisation of multidisciplinary resources and the engagement of all relevant stakeholders including in particular the civil society. Particular effort has to be put in this framework towards the co-creation of these implementation studies ensuring active participation of citizens as integral part of the scientific teams involved.

Policy-relevance: A successful coordinated effort would facilitate the faster translation of research results into policy relevant knowledge, contributing thus to improved environmental health policy development and regulation on the EU and national levels. This would have to be done in a systematic manner in order to ensure that there would be no "pushing over" of environmental health problems to socio-economic subgroups of the population, regions, and even countries that may be more vulnerable due to geopolitical, socio-economic and even climatic reasons.

Research needs

- Strengthen inter- and trans-disciplinary implementation research to develop and propose effective measures. Promote more participatory, inter- and transdisciplinary intervention research focusing on resolving actual real-life problems and governance through the creation and use of environmental health living labs.
- Development of methodologies that take stock of multiple lines of evidence coupling epidemiological evidence from human cohort studies and toxicological data. Include pathway-based approaches from toxicological sciences into human risk assessment and health impact; expand the adverse outcome pathway networks concept and use of cross-omics data in molecular epidemiology.
- Inclusion of sociodemographic factors into integrated health impact assessment and contributions from social sciences towards a better understanding of exposure determinants and susceptibility factors to environmental stressors leading to adverse health outcomes.
- Strengthen attribution research in health impact assessment
- Development of harmonised and transparent protocols for health impact modelling using FAIR data.
- Assimilation of big data from sensor-based Internet of Things (IoT) technologies to better define the individual aspects of behaviour that define exposure.
- Integration of multiple stressors in identifying cumulative effects, linking also ecosystem functioning and health
- Development of self-sampling devices for blood-based human biomonitoring in combination with medium-throughput analytical chemistry (targeted screening and suspect screening).
- Linking human biomonitoring of exposure and effect biomarkers to citizen-science by making sampling easier, cheaper, less invasive. Towards P4H = Predictive, Personalized, Preventive and Participatory Health.

Tentative research call areas

Title: *Bridging toxicological and epidemiological lines of evidence towards improved human health risk assessment from chemicals*

Scope: This topic proposes the development of an exposome-based alternative strategy chemicals risk assessment that combines advanced human and cell biology knowledge (adopting a systems biology paradigm), human biomonitoring, *in vitro* and non-vertebrate in vivo (phylogenetically lower and early fish life forms not considered animal experiments in European legislation) data for the identification and characterization of AOP networks relevant to human health. In this sense, exposome based approaches that represent the totality of exposures throughout a person's lifespan from conception onwards, should play a decisive role in understanding the molecular mechanisms of disease through the preservation of pathway perturbations among human, *in vitro* and non-vertebrate *in vivo* data.

Title: *Development of harmonised approaches for modelling frameworks relevant for human health risk assessment*

Scope: Despite the significant number of models relevant for health risk and impact assessment, there is lack of

harmonisation on their aims, scope and implementation domains. Most of the models deal with different levels of refinement regarding the various exposure pathways or they do not address them at all, rendering the need for using multiple modelling tools for the comprehensive assessment of cumulative and aggregate exposure. This topic suggests an in depth analysis of the array of exposure modelling tools and the development of a harmonised protocol for models that should be used in a regulatory context in risk and health impact assessment. Specific focus should be placed on modelling approaches that integrate external and internal exposure within an integrative framework to facilitate the translation of scientific evidence into effective implementation actions.

RG 4.3 Advance and systematise implementation research in environment and health

Objective: Provide a systematic framework for the implementation of intervention studies in environmental health.

Relevance

Scientific relevance: Implementation research is the scientific inquiry into questions concerning implementation of policies, programmes, or individual practices (collectively called interventions). The interventions can carry any aspect of implementation, including the factors that affect it, the implementation process and its results, ways to introduce potential solutions into the health, environmental and social systems or how to promote large scale use and sustainability. Implementation research seeks to understand and work within real world conditions, rather than trying to control them or to remove their influence as causal effects. This implies working with populations that will be affected by an intervention, rather than selecting beneficiaries who may not represent the target population of an intervention (such as studying healthy volunteers or excluding patients who have comorbidities). A central role in implementation research is played by the context, encompassing the social, cultural, economic, political, legal, and physical environment, as well as the institutional setting, comprising various stakeholders and their interactions, and the demographic and epidemiological conditions. Thus, implementation studies require the mobilisation of multidisciplinary resources and the engagement of all relevant stakeholders including the civil society. Particular effort has to be put in this framework towards the co-creation of these implementation studies ensuring active participation of citizens as integral part of the scientific teams involved. Implementation research may examine strategies that are specifically designed to improve the execution of health interventions or assess variables that are defined as implementation outcomes. Outcomes include acceptability, adoption, appropriateness, feasibility, fidelity, implementation cost, coverage, and sustainability.

Policy-relevance: Key targets of implementation research are the users of the research and not purely knowledge generation. Users range from policy and decision makers up to environmental health practitioners, from individuals influenced to change their behaviour towards a healthier life up to communities who conduct the research and act to improve their condition. A successful coordinated effort would facilitate the faster translation of research results into policy relevant knowledge, contributing to improved environmental health policy development and regulation on the EU and national levels. This would have to be done in a systematic manner in order to ensure that there would be no "pushing over" of environmental health problems to socio-economic subgroups of the population, regions, and even countries that may be more vulnerable due to geopolitical, socio-economic and climatic reasons.

Research needs

- Systematise pragmatic trials and develop methods to assess comprehensively the effectiveness of an intervention in a normal practice setting with the full range of study participants.
- Enhance participatory action research and consolidate its efficacy in implementation studies addressing environmental health problems.
- Foster the development of mixed method research using both qualitative and quantitative methods for data collection and analysis and provide optimised guidance for the application, reporting and justification of mixed methods.
- Analyse how parts of a programme tackling environmental health issues change dynamically with its context and why.
- Identify and quantitatively assess the effects of implementation strategies tackling environmental health.

Tentative research call areas

Title: *Integrate implementation research into public health programmes tackling environmental health challenges with particular focus on the interaction between EU and low and middle-income countries (LMICs)*

Scope: This topic focuses on the effective integration of implementation research into public health programmes tackling issues encompassing the full scale of interactions between environmental factors and human health. Of particular importance in this context is the study of the interactions between EU Member States and low and middle-income countries (LMICs) when tackling issues such as mitigation of the complex and adverse effects of climate change or of the circular economy onto public health. Implementation research in this context should take stock of the specific socio-economic conditions of the research participants and of how the research itself affects the efficacy of the specific health protection programme. Dynamic change of the conditions within which implementation research is performed needs to be explicitly considered in order to optimise and adapt the implementation programme to the actual contextual framework of the research. Examples of the seamless integration of participatory implementation research into public health programmes will result from this topic in order to serve as practical guide for widespread use of this approach in tackling environmental health issues.

Title: *Address methodological issues in participatory implementation research to guide the optimal integration of*

implementation research into public health programmes on environmental health challenges

Scope: This topic will address the large spectrum of implementation research types and the respective methodological developments needed to ensure that it can be taken up readily by public health programmes and policy makers in environment and health. Systematisation of practical trials, optimisation of quality improvement procedures, development of mixed methods and adaptation to fit the needs of implementation research in complex environmental health issues as well as fostering participatory processes and citizen science are parts of the subtopics expected to be tackled by this topic. The methodological issues highlighted above would be applied in selected examples of importance for tackling environmental health challenges with a view to develop formal guidance towards the widespread uptake of implementation research into public health programmes in the EU and worldwide. The outcomes encompass methodological guidance, key examples of application with high policy relevance and key performance indicators that fit the use of implementation research in the environmental health field.

Research Goal 5
Develop infrastructures, technologies and human resources for sustainable research on environment, climate change and health

Introduction

The long-term sustainability of a European research effort in the field of environment, climate and health relies primarily on the availability of solid infrastructures, development of new robust and innovative technologies, an adequate legal framework and availability of expert human resources. Building and developing such infrastructures is critical for the feasibility of research programmes in this field and for the effectiveness of interventions and policies. Several gaps have been identified in this field and the corresponding research needs are described below. These include upgrading of epidemiological cohorts into one or more mega cohorts to spearhead research on environment and health, advances in ways to process the resulting data with data sciences, connecting, and harmonizing national nodes of research infrastructures at the European level to analyse big data and gather knowledge all together. This flow would further stimulate development of models, tools and experimental innovations that are necessary to make progress in data sciences related to health and environment. Moreover, these research goals promote the need for implementation of a transdisciplinary research infrastructure for the development of Planetary Health monitoring.

RG5.1 Well-designed and maintained population cohorts and related biobanks

Objective: Establish a coordinated and harmonized infrastructure of population cohorts and biobank capacities of existing and future epidemiological cohort studies in Europe, with the goal to spearhead research in the area of environment, climate change and health.

Relevance

Scientific relevance: The environment, climate, occupation and paid employment are major determinants of population health. Despite ongoing changes in climate conditions and environment, and profound transformations of working life, there is currently limited coordinated European joint research on these factors. Large population-based cohorts are invaluable resources and important infrastructures supporting research in environmental health. Coordinated infrastructures in cohort studies are needed spanning from parent-child cohorts to adult cohorts to capture general environment and occupation exposures throughout the lifetime. Coordinated and harmonized collection methods would produce comparable data, enabling meta-analyses and comparisons with different statistical approaches and would maximise comprehension and optimise societal impact of these investments. Various types of data and methods should be combined to enable exposome type assessment addressing multiple stressors and factors. Longitudinal data is needed, integrating socio-economic, community and gender aspects, as well as new insights into potential resilience factors and effects of behavioural changes. While some large projects have been funded by the EU evaluating environmental exposures, for example projects on air-pollution or exposures in early life, there has been limited funding on coordination of health research and particularly of cohort studies addressing environment, climate and occupation in a wider perspective that captures the complexity of the effects of the wider environment on health.

Policy-relevance: The integration and harmonization of European cohorts and biobanks with information on environment, climate and occupation, will exploit their use and create new potentials for research including the evaluation of new risks, for example infections in relation to the environment. The establishment of a system of large mega-Cohorts may include tens of millions of participants in the EU and will have direct relevance to health impact assessment and the evaluation of policies at the international, national and regional level. The European mega-cohort initiative is closely connected to modern policies for data science and secure use of big data and will be directly related to major ongoing EU initiatives and programmes including: the EU Biodiversity strategy in relation to health at the international and local level; the EU Chemicals strategy and the Zero pollution action plan through an evaluation of the causal links between exposure and health and of wider and long term social impacts; the Farm to Fork strategy through the incorporation of agronomy and nutrition in relation to health; the missions, for example on cancer or on urban health; and the cross cutting clusters on health, digital society/economy, climate energy and mobility, and food, natural resources, agriculture and environment in connection to health.

Research needs

- Coordinate and establish European multimillion mega-cohort collaborations of existing cohorts of men and women in the EU with extensive information on environmental, climate and occupational exposures and employment patterns, including both young and older persons, and harmonize outcome and exposure information. Link the mega-cohort with existing biobanks.
- Create a solid new basis for the conduct of Europe-wide studies on environmental, climate and occupational exposures, and social inequalities in health and wellbeing through modern and secure approaches for data sharing and decentralized analyses.
- Develop modern technological tools/infrastructure for health assessments and forecasts related with the climate and, when possible, use these technologies in cohort studies.
- Building and expanding existing activities: implement an online interactive tool with detailed information on existing data sets and biobanks using data visualization techniques, which will be disseminated freely and widely to researchers, policy makers, patients and the public.
- Develop tools to facilitate the estimation of environmental, climate and occupational exposures, and new exposures such as infections, in population studies by standardisation of existing exposure data, amalgamation of existing exposure resources, and by building exposure assessment procedures with widespread applications including modern approaches for health impact assessment.
- Foster the inclusion of environmental, climate, occupational and social data emerging from new technologies (e.g. Earth observation (satellite) data, massive use of portables and personal sensors), biotechnologies (e.g. omics) and Electronic Health Records.
- Promote linkage of the EU system of mega-cohorts with international networks of cohorts evaluating

environmental, climate and occupational health globally and contribute to an international strategic agenda for more efficient research coordination globally.

Tentative research call areas

Title: *Establishment of a system of mega-Cohorts in the EU with harmonized data and connections to biobanks*

Scope: To integrate and harmonize European cohorts and biobanks with information on environment, climate and occupation, that include tens of millions of participants in the EU and will have direct relevance to health impact assessment and the evaluation of policies at the international, national and regional level. The mega-cohorts should exploit their use and create new potentials for research including the evaluation of new risks, for example infections in relation to the environment.

RG5.2 Development of laboratory capacities for assessment of the chemical exposome and its functional impacts

Objective: Develop a distributed research infrastructure providing sufficient laboratory capacities for assessment of human exposome, i.e. a combination of methods for target and non-target analysis of exposure and effect biomarkers.

Relevance

Scientific Relevance: Chemical contamination of the environment and humans has been recognised as a major driver of environmental toxicity but there are major questions that remain unsolved: How to address the effects of chemical mixtures? How to monitor emerging and novel substances? How to develop early warning systems? How to integrate abiotic environmental contamination with *in vivo*, wildlife and human contamination and how to assess the impact of these contaminations?

There is a need to build research infrastructures providing sufficient laboratory capacities for target and non-target analyses of exposure and effect biomarkers and development of innovative experimental and modelling tools to explore the effects of environment on toxicity outcomes along the Adverse Outcome Pathways perspective. This would also require big data infrastructures and effective governance structures and approaches for integration across sectors, disciplines and multiple stakeholders.

Research infrastructures are instrumental for development of any research field but even more so the cross-cutting domains where there is a need to transfer knowledge from various areas and establish interdisciplinary expertise. They deliver innovative technologies and services, new knowledge and highly skilled experts, i.e. all elements needed to promote excellent science.

Policy relevance: Comprehensive data on current exposures and their effects are needed to initiate transformational changes leading to better protection of the environment. Such data will be important for implementation of current EU strategies (Chemical strategy, Biodiversity, Farm to Fork) and action plans (Zero pollution, Circular economy) as well as all Horizon Europe missions.

Research needs

- Develop sufficient laboratory capacity for widely targeted and non-targeted analyses of exposure and effect biomarkers through the establishment of the distributed European research infrastructure consisting of the national nodes with harmonised analytical and data management approaches and open access to available services.
- Develop high-throughput methods to enable assessment of exposure and effects markers in large-scale studies focusing in particular on long-term effects.
- Develop innovative experimental and modelling tools to explore and predict the effects of environment on toxicity outcomes and to inform societal decisions on (production and/or regulations of) hazardous chemicals with application of results from work along the Adverse Outcome Pathways perspective.
- Develop methodologies supporting early warning systems by taking advantage of improved mechanistic understanding and computational capacities. Relevant approaches would be to further develop mechanistically-driven effect markers such as epigenomics (and other omics) markers as well as integrated computational frameworks in order to support such a goal.

Tentative research call areas

Title: *Development of harmonised laboratory capacities for assessment of environmental and human exposures to legacy and emerging chemicals and their toxic mixtures*

Scope: To address a problem of human external and internal exposures to emerging chemicals and toxic mixtures and resulting effects on human health, we need to develop sufficient laboratory capacities (i.e. equipped with advanced technology and adequate human resources, with harmonised analytical and QA/QC approaches and open access to available resources). This should be achieved through the development of distributed European open-access research infrastructure based on existing and newly established national capacities.

Title: *Development of harmonised data infrastructures enabling open access and analysis of available data from advanced analytical platforms*

Scope: Management, analysis and interpretation of data from advanced (multi-residual, suspect screening and non-target) analytical platforms require extensive IT support including complex data processing pipelines, libraries and advanced tools enabling remote access, federated analysis and integrative assessment of multifactorial exposures.

RG5.3 Innovative big data-based methods and tools to characterize interrelationships between environment and health

Objective: Develop innovative approaches to leverage the rapidly expanding availability of data streams relevant for characterizing interrelationships between global environmental change, proximal environmental exposures, and physical and mental health. Develop new methods and tools for characterizing these relationships using multimodal data streams, artificial intelligence, and other data science approaches.

Relevance

Scientific relevance: Big data in combination with innovative data science approaches and multi-disciplinary research teams hold important opportunities for characterizing complex interrelationships between global environmental change, proximal environmental exposures and health and to monitor health impacts of interventions. The increasing volume and type of remote sensing data is opening unprecedented opportunities to characterize the composition of space from individual buildings to regional and global scales. Research is needed to develop innovative approaches to combine the strengths of remote sensing with other data sources (e.g., collected through Smart Cities, Internet of Things, low cost sensor networks, sentiment analysis of social media data) to paint a more complete picture, linking objective knowledge about the built, physical, and natural environment with the subjective information on individuals' experience and perceptions of their environment to more fully understand how these interact to affect health. Rapidly evolving technology in small, wearable sensors is generating opportunities to measure environmental exposures, emotional states, behaviours, and physiological responses with increasingly fine resolution. Detailed information can now be obtained on individual's location, their physical activity, mode of transport, environmental exposures (e.g., air pollution, noise, temperature), physiological responses, and emotional status over varying temporal and spatial scales, providing insights into how multiple dimensions of environment affect physical and mental health. These data streams can be combined with multi-omics data to elucidate how external environments are internalized and ultimately shape health outcomes, accounting for the combined effects of multiple exposures.

Policy-relevance: Developments in methods and tools for leveraging increasingly diverse and large data streams can be applied to multiple research areas with relevance to policy at EU, national and local levels. EU policy areas that would have particular benefits from these methodological advances include: The European Green Deal, EU Strategy on adaptation to climate change, ambition towards zero pollution, and missions related to climate neutral and smart cities. Research in this field would also contribute to implementing the EU digital strategy and Destination Earth (DestinE)[84], a major initiative of the European Commission, which aims to develop a high precision digital model of the Earth to monitor, simulate and predict environmental change and human impact in order to support sustainable development.

Research needs

Research is needed to address knowledge gaps regarding the most efficient and valid data analysis methods and tools for integrating diverse data streams related to environment and health. In addition to methods development, research is needed to demonstrate the value of these approaches in specific applications to shed new light on the complex links between global environmental change, proximal environmental exposures, and health. Specifically:

- Development of innovative methods and tools for integrating diverse data streams related to environment and health
- Case studies to demonstrate the validity of new methods and tools
- Demonstration of the added value of new methods and tools to capture complexity of interrelationships between global environmental change, proximal environmental factors, and health beyond traditional methods.
- Demonstration of the value of new methods and tools for monitoring and evaluation of policy action and other interventions.
- Uptake of new methods and tools by stakeholders to maximize impact of innovation in society.

Tentative research call areas

Title: *Advancing data science approaches to characterize health impacts of global environmental change and proximal environmental exposures in population health research.*

Scope: Big data in combination with innovative data science approaches and multi-disciplinary research teams hold important opportunities for characterizing complex interrelationships between global environmental change, proximal environmental exposures, and health and to monitor health impacts of interventions. These data streams can be combined with multi-omics data to elucidate how external environments are internalized and ultimately shape health outcomes, accounting for the combined effects of multiple exposures. Research on data science should develop flexible approaches for the use and analysis of complex data on the

[84] https://digital-strategy.ec.europa.eu/en/library/destination-earth

interrelationships between global environmental change, proximal environmental factors, and health with demonstrated validity. In particular, methods should consider how to improve representativeness of findings.

Title: *Development of innovative methods and tools for integrating diverse data streams related to environment and health*

Scope: The increasing volume and type of remote sensing data is opening unprecedented opportunities to characterize the composition of space from individual buildings to regional and global scales. Research is needed to develop innovative approaches to combine the strengths of remote sensing with other data sources (e.g., collected through IoT, Smart Cities, social media data), linking objective knowledge about the built, physical, and natural environment with the subjective information on individuals' experience and perceptions. Rapidly evolving technology in small, wearable sensors is generating opportunities to measure environmental exposures, emotional states, behaviours, and physiological responses with increasingly fine resolution. Research should demonstrate the added value of new methods and tools to capture the complexity of interrelationships between global environmental change, proximal environmental factors, and health beyond traditional methods and the value of new methods and tools for monitoring and evaluation of policy.

Joint research call area for RG5.3 RG2.1

Title: *Development of new tools and methods to estimate in complex urban environments the exposures, health effects and health impact tools for decision making*

Scope: The urban environment is complex and environmental exposures and health effects and impacts are hard to assess. Furthermore, much data is being generated through routine monitoring, lifestyle, environmental and health apps, remote sensing that is not being used. New method developments are needed to utilize and analyse the current and future conditions such as new statistical techniques to quantify relationships (e.g. mixture of exposures, machine learning), novel equipment to measure the exposures and potential confounders (e.g. apps, wearables, remote sensing) and health effects (e.g. administrative data, new data sources) and new methodology to quantify the health impacts (e.g. microsimulation, ABM). The expected outcome of the work is a range of new methodologies to assess the complex urban environment that have been tested, applied and validated.

RG5.4 Transdisciplinary research infrastructure: Planetary Health monitoring

Objective: Advance research infrastructure for the generation of scientific knowledge on planetary health and the monitoring of trends in the drivers and consequences of environmental change to support consequent policy-measures and corrective actions.

Relevance

Scientific relevance: We live in a new geological epoch – the Anthropocene – characterised by the substantial impact of human activity on the Earth's systems. Transgression of planetary boundaries of these systems pose major but imperfectly understood risks to human health and well-being as well as future development (Rockström 2009[85]; Steffen 2015[86]). Most of these risks are not clearly recognised or monitored, and are invisible to the policy, economic, and social systems that can help mitigate them. Interdisciplinary research is essential to address gaps in evidence on the interconnected pathways linking global environmental changes, e.g., chemical pollution, biodiversity loss, land use change, climate change, as well as to develop and implement effective responses to these changes and their health impacts. One of the key barriers for such research is the lack of integrated and interoperable spatially and temporally resolved data on health outcomes and relevant environmental factors. Integrated monitoring and assessment capabilities are, therefore, crucial to improve the understanding of the risks and emerging hotspots as well as to guide responses. This approach is particularly important where the effects of different environmental changes might interact to influence health outcomes. Recent advances in computational, sensing and communication technologies have created the conditions for a revolution in global-scale planetary monitoring (German Advisory Council on Global Change 2019[87]).

Policy relevance: Most of the health risks arising from global environmental changes are not clearly recognised or monitored, and are invisible to the policy, economic, and social systems that can help mitigate them. Policies and transformations can generate huge health co-benefits, and health is an important aspect for the social acceptability of transformations. Engagement of policy makers and other key stakeholders in a position to influence planetary health should be central to the transdisciplinary research infrastructure and related research efforts. This is illustrated by the Global Environment Outlook GEO-6 of the UN which has allowed a significant step forward in the integration of human health and the health of the planet[88]. Policy makers and other key stakeholders should be engaged in the development of use cases to ensure the uptake of the key messages generated through monitoring and research.

Research needs

Research is needed primarily on data integration and analysis to connect indicators of global environmental changes with data and indicators of human health outcomes as well as on stakeholder needs and usability of the infrastructure for researchers and stakeholders. Data could be gathered from national health registries, existing cohort studies, and other sources. This requires the collection of data from outside, as well as within, the EU. It also requires the collection of environmental data as well as health data. The planetary health monitoring system should integrate existing environmental/health monitoring initiatives in ways that can allow improved attribution of health outcomes to different environmental changes and assessment of the impacts of actions to address such changes. Improved capacities to predict the impacts of global environmental changes on health outcomes is also needed as well as assembling interventions world-wide to adapt to or mitigate these impacts. Specifically, there is need for:

- Analysis and synthesis of strategies for providing data to drive actions that can leverage big course corrections in the way our society operates, triggering and sustaining transition to a low carbon, low environmental footprint economy within a safe operating space for humanity.
- Developing methods to better integrate health outcome monitoring, environmental monitoring and updated data on planetary boundaries. This could include further systematic mapping of existing monitoring efforts against the pathways that link planetary changes with human health.
- Integration of top down (global level) and bottom up (local level) monitoring by using global satellite systems as well as local monitoring at specific sites or settings involving vulnerable populations or high levels of exposures.
- Integration of monitoring with actions to adapt to and/or mitigate environmental change.
- Assessment of the implications of planetary health for health systems (including workforce and financing as well as improving the integration of environmental health services with health services)

[85] Rockström et al, A safe operating space for humanity; Nature, 461 (2009), pp. 472-475

[86] Steffen et al, Planetary boundaries: guiding changing planet; Science, 347 (2015), pp. 1-10

[87] https://www.wbgu.de/en/

[88] https://wedocs.unep.org/handle/20.500.11822/27539

- Approaches and models to predict effects of environmental changes in young and future generations

Tentative research call areas

Title: *Building an integrated planetary health monitoring*
Scope: The building of such infrastructure will enable the effective implementation of several major objectives: trialling and testing the methods for integrated monitoring and assessment of planetary health risks and responses (Belesova et al, 2019 and 2020 [89]); application of planetary health monitoring in a thematic area, e.g., monitoring of health risks of environmental change in a hotspot location; monitoring of an intersection of health risks of two or more interrelated global environmental changes; monitoring of response implementation and effectiveness. Case studies can be developed through engagement with the relevant actors and stakeholders.

[89] Belesova, K., Haines, A., Ranganathan, J., Seddon, J., Wilkinson, P., & Zou, M. (2019). *Designing a Planetary Health Watch: A System for Integrated Monitoring of the Health Effects of, and Responses to, Environmental Change*. https://doi.org/10.17037/PUBS.4654610

Belesova, K., Haines, A., Ranganathan, J., Seddon, J., & Wilkinson, P. (2020). Monitoring environmental change and human health: Planetary Health Watch. *The Lancet*, *395*(10218), 96–98. https://doi.org/10.1016/S0140-6736(19)33042-9

Research Goal 6
Promote research on transformational change in environment, climate change and health

Introduction

The issues raised by chemical pollution and climate change and their impacts on environment and health are so critical and urgent that different types of solutions at different levels and in different sectors are needed, including technological, organizational and societal efforts. Accordingly, research must address these different levels and explore different types of solutions. This research goal aims to leverage transformational change in research to address the challenges at the environment, climate change and health nexus. There is a need to address the existing gross inequality in the health status of populations particularly between as well as within countries[90] and to explore new ways of tackling the challenges linking health, climate change and environment with a renewed focus on health outcomes, universal access to healthcare, and by improving and fostering population health through disease prevention and health promotion.[91]

A new transformational change approach is required to frame these challenges and work towards multidisciplinary solutions that consider socio-economic and social-ecological aspects, including a focus on those who are most vulnerable[92]. This transformational framing and societal change require e.g. Planetary Health and One Health, considering current governance and societal structures that guide policy decisions and their potential to shape the way we live, work and consume. Transformational change towards sustainability can be achieved by increasing participatory co-creation opportunities and capabilities as well as mechanisms and practices in the science-policy interface as prerequisites for more effective and impactful research. This needs to be concrete, target-oriented and time-bound and to foster public engagement, measuring impacts on local social and environmental conditions, as well as on the health and welfare of the participants themselves.

Fundamental research should support increasing preparedness for future acute events and crises, the building of an ethical society and addressing human rights and inequalities for a healthy, fair, inclusive and resilient society. Research should also tackle the challenges of effective and comprehensive communication of results and solutions as well as dealing with risks and uncertainty. Education and training strategies must take advantage of innovative tools and approaches to trigger and nourish the wide involvement of scientists and citizens in research. This creates a culture that values, encourages and rewards robust cross-sectoral research partnerships that are simultaneously intrinsic and responsive to societal challenges.

While societal transformational change is put forward in this RG, this does not mean that the burden of change should fall on citizens alone. Clearly international, regional, national and local authorities have a critical role in initiating and supporting the change processes at various scales and in the prevention of, as well as mitigation and adaptation to the environmental crisis as stated in many proposals of this agenda.

[90] (https://www.oecd-ilibrary.org/docserver/3c8385d0-en.pdf?expires=1629893015&id=id&accname=guest&checksum=FF3C2B666B70649B36761EF6D0F7D0DF

[91] EU4Health 2021-2027 – a vision for a healthier European Union.

[92] WHO, Environmental Health Inequalities in Europe (2012) https://www.euro.who.int/__data/assets/pdf_file/0010/157969/e96194.pdf

RG6.1 Preparedness to prevent and combat future environment and health threats/challenges

Objective: Improve prevention, preparedness, response and population resilience for future health crises and environmental threats.

Relevance

Scientific relevance: COVID-19 has revealed important gaps in preparedness and response to emerging infectious diseases, which have had serious public health consequences. Similar lessons have been drawn from other environmental crises, including the accidents at the Chernobyl and Fukushima nuclear power plants and ship and oil rig catastrophes, e.g. the BP Deepwater Horizon oil rig disaster in the Gulf of Mexico, 2010. Besides emerging infectious diseases and nuclear accidents, public health and environmental crises can be caused by a number of agents/factors, either natural or human-made, including chemical, biological, radiological and nuclear (CBRN) threats and climate change including flooding, heat waves, droughts or forest fires. Active and passive epidemiological and exposure surveillance are of paramount importance for early detection, prevention, and timely response to emerging threats, as well as for the evaluation of the impact of protective measures taken in response to a threat. This includes monitoring exposures and disease trends, understanding health effects, including mental health, of the exposures and those of different types of response, conducting health impact assessment and modelling the likely impact of different scenarios of responses in order to provide the scientific evidence needed for public health policy decisions. Stakeholder involvement, including citizen science, is a key tool to ensure adequacy and acceptability of the research and policy to the needs of affected populations. Immediate research efforts are therefore needed to investigate innovative tools for surveillance and response, including improvement of epidemiological surveillance at the city, regional, national and European levels. At the local level there should be implementation of measures found to be effective in responding to different crises. There is also a need to develop innovative global networks that could share scientific research on prevention, preparedness and response to environmental and health threats, including the animal-human interphase, and to promote awareness in the general population.

Policy-relevance: The COVID-19 pandemic has highlighted the need for sound data on which to base policy decisions and a fluid connection between public and environmental health scientists and decision makers when responding to any kind of health and environmental crises. Policy decisions should be based on evidence to guide their actions on the response to emergency threats, thus research findings on different health threats/findings should be quickly incorporated into policy-decision processes. Strengthening coordination and collaboration among research and innovation institutions and policy-making authorities should be further promoted. Development of a global network of agencies and research institutions focused on prevention, preparedness, surveillance and response to health threats and challenges is needed. Activities should be aligning with the EU4Health[93] programme which addresses prevention, preparedness & response to cross-border health threats. This program aims to build the European Health Union applying lessons learned from the COVID-19 response.

Research needs

The fundamental needs are related to research on innovative tools that will provide better prevention, surveillance and response to health threats and challenges as well as processes for better collaboration and coordination of research and innovation into policy-making decisions and awareness.

- Research and develop new tools and core integrated protocols for preparedness, surveillance, monitoring, and emergency response that can be adapted rapidly to different threats.
- Investigate the use of disseminated surveillance networks for different health threats and challenges, building upon and strengthening existing infrastructures and expertise in the Member States.
- Develop clear routes for decisions and communication - including stakeholder involvement.
- Investigate the feasibility of new animal-health surveillance systems with cross-border collaborations.
- Research on pathways for strengthening the capacity to react or adapt to a crisis, including emergency response plans.
- Development of a legal framework for collaboration (including data sharing) among different Member States agencies and research and innovation organizations and with other international organizations in case of public health and environmental crises. This includes having a unified access to databases across the different levels involved in crisis response.
- Develop and assess suitable models to evaluate different impacts of crisis (environmental, health, socioeconomic…), of surveillance and of different policy measures and feed into public health policy and decision making.

[93] https://ec.europa.eu/health/funding/eu4health_en

- Repurposing of existing population-based cohorts as surveillance platforms.
- How to optimise population knowledge, understanding and compliance to serious societal threats - through stakeholder involvement and novel communication strategies and models.

Tentative research call areas

Title: *Epidemiological intelligence for preparedness, response and resilience*

Scope: The COVID Pandemic has highlighted the limitations of existing registries for rapid identification of exposures and risks and for evaluation of the health impact of responses to any type of crises. Innovative approaches are needed to ensure linkage and interoperability of different data sources (e.g. air pollution and waste water monitoring systems, disease registries) and access to information updated in real time, coupled with HIA and modelling platforms. One concrete objective would be to bring together European cohorts as a means for surveillance in the case of an environmental and health crisis

Title: *Integrating health in city planning for emergency preparedness, response and resilience*

Scope: The objective is to define approaches and tools for translating and implementing lessons learned in emergencies into city planning. This requires the identification of evidence-based cost-effective strategies for responding to health and environmental crisis at the local level.

RG6.2 Transformational change

Objective: Develop transformational research designs to tackle complex research questions and to investigate obstacles to and drivers of transformational change and the approaches for the implementation of transformational policies and practices to achieve healthier and sustainable societies.

Relevance

Scientific relevance: Transformational change can be defined as a philosophical, practical and strategic process to effect profound change. Research in this field will contribute to answering important questions on which type of change is needed and how it will address the environmental and climate challenges, how to start acting, how to achieve implementation of solutions and how to achieve profound changes that are required to reach healthier and sustainable societies. Implicitly, transformational change approaches work towards solutions in the environment and health nexus and need to consider socio-economic and social-ecological aspects, focusing on the most vulnerable. Improved co-creation opportunities and capabilities as well as mechanisms and practices in science-policy interface are prerequisites for more effective and impactful research.

Policy-relevance: Examples of transformational change in human history include the agricultural and the industrial revolution. Today, transformational change is required to specifically address current and future environmental, social and health issues and to achieve the required fundamental individual, societal, cultural, economic and political shifts to reach aims such as the SDGs or the Paris Agreement; hence it needs to be concrete, target-oriented and time-bound. Profound changes in systems and in behaviour are at the basis of the European Green Deal and related EU strategies; thus research on transformational change supports their implementation across all topics.

Research needs

Identifying and implementing the most relevant transformational change addressing the environmental and climate impacts on health is an overarching research issue to achieve healthier and sustainable societies and social change. More holistic and transdisciplinary research approaches (including social, behavioural, political and legal sciences) will support transformational change and implementation towards sustainability, addressing societal needs relevant in the environmental health field. This also entails improving data and knowledge sharing and tools for monitoring and awareness raising. Participatory research and implementation science is suggested to understand and integrate transformational processes in research, policy and practice. Transformational research is required at the local, regional, national and international levels to provide results to decision makers and the public along the way.

- exploring the philosophical and ethical dimension of transformational change as a response to major environmental and climate crises.
- addressing transformational change as a key dimension of holistic research and implementation concepts such as Planetary Health or One Health to stimulate its application and related research.
- framing and investigating the case for transformational action and social change in order to re-prioritize accordingly the agendas across sectors towards sustainability.
- defining approaches and tools for translating and implementing scientific evidence into policies and profound societal and behavioural transformational change processes and technological innovations supporting sustainability and green transition on national and local level, taking benefit of living labs, testbeds or other relevant approaches and platforms.
- understanding and integrating transformational processes in research, policy and practice to achieve profound changes, e.g. in the area of circular economy; in the health sector to facilitate a shift towards better incorporation of prevention and health promotion as well as the pathway towards zero emission health services; and in research to promote more integrated, holistic, collaborative and participatory approaches.
- understanding drivers and health impacts in socio-economic, cultural and social-ecological settings and the interlinkages and complexities between climate change, biodiversity loss and environmental degradation to inform pathways for transformational change towards a healthy and climate resilient living environment for all.
- investigating the drivers and barriers to transformational change (including stakeholders' resistance), how it can be triggered and achieved, including scientific and participatory approaches to promote behaviour change at individual, collective, societal and cultural levels and change of mind-sets towards sustainability.

Tentative research call areas

Title: *Transformational change in healthcare: linking environmental quality with population health and rebalancing the prevention-treatment dichotomy in healthcare towards strengthened prevention while addressing equity of access and efficiency demands for societal good*

Scope: The Covid-19 pandemic has highlighted the socioeconomic disparities and inequity in access for many to

healthcare services. In general, the health sector is more focused on providing cost-efficient health care than promoting prevention and providing equitable access for all. There is a clear deficit in the research emphasis and investment given to disease prevention, health promotion and the implementation of equitable access to universal healthcare for all, including primary/community-based care. This call seeks to address the long identified problem in healthcare systems to re-orientate focus towards health promotion and disease prevention linked to a healthy environment while also balancing equity of access to healthcare systems based on need and the demands for efficiency through a transformational approach to research. This call seeks to promote research on effective ways leading to better incorporation of environmental health and health prevention as an integral part of the healthcare ecosystem, including the use of new technologies. Comparison of different health systems across the world can be valuable as well as feasibility and intervention studies.

Title: *How to achieve healthier and sustainable societies: drivers and barriers of transformational change, including behavioural change and cultural shifts*

Scope: The scope of the call should be limited to the EU Green Deal and its strategies, to define the content areas (e.g. food systems, pollution, climate change mitigation). Strong participation of social sciences is required. The call seeks to investigate the main drivers and barriers to transformational change (including stakeholders' resistance), how it can be triggered and achieved, how to promote behavioural change at individual, collective, societal and cultural levels and change of mind-sets towards sustainability. It also includes the development, design and implementation of effective interventions and citizens' participation.

RG6.3 Socioeconomic factors and the environment, environmental injustice, equity, sustainable economic growth

Objective: Identify inequalities arising from environmental factors and their interaction with social and economic factors as well as approaches and solutions to address these issues and environmental justice.

Relevance

Scientific Relevance: Environmental conditions vary across populations within and between countries and they play a significant role in health and well-being [94]. Disadvantaged subgroups within populations are often exposed to higher environmental risks, higher health risks and have less access to environmental and health benefits. The environmental risks include higher exposure than the general population to air pollution and noise, but more specifically also crowded and poorly maintained housing, poorly controlled high and low indoor temperatures, and lack of safety in public spaces. Despite improvements in environmental conditions in most European countries, associated socioeconomic inequalities persist or tend to increase between and within countries whereas it is also apparent that each country has a specific portfolio of inequalities' [95]. Inequalities in environmental opportunities and burdens are expressed and interconnected at various levels along dimensions of ethnicity, gender [96], income (and work), as well as in urban environments (see also RG 2), and are often manifest in and exacerbate health inequalities. Environmental injustice is a significant issue with the most vulnerable populations in our society being hardest hit by environmental stressors.

The spatial coincidence between social vulnerability and exposure to multiple adverse environmental factors was highlighted by the European Environmental Agency (2020), which also concluded that while policies to improve environmental quality are in most cases delivering positive outcomes for the general population, vulnerable groups are being left behind[97]. Yet, there are still many knowledge gaps in this field that may delay needed policies. For example, while effects on health and mental development from crowded and otherwise dismal housing, especially among children, was systematically investigated in many countries a century ago, there is a lack of research on physical and mental health effects from current substandard housing/residential areas, which gives an uncertainty concerning the urgency of these issues for decision makers. In addition, the climate change challenges and COVID-19 pandemic represent a convergence of crises illustrating growing inequalities in environmental impacts and healthcare access. Environmental burdens associated with pollution, resource scarcity and extreme events accentuate socioeconomic inequalities which have been underestimated and yet projected to increase under current development trajectories [98]. A more precise assessment of environmental injustice and of the relationship between the environment and socioeconomic factors is needed to develop relevant solutions.

Policy relevance: Environmental and health injustice is addressed by a number of policies across different sectors. The case for equity of access to resources for all is addressed by UN Sustainable Development Goals and Europe's *Zero-Pollution Action Plan* (2021) by prioritising investments which increase access to nature and reduce exposure to pollution in low-income and marginalised communities. The *EU Biodiversity Strategy* [99] acknowledges the need to ensure sustainable corporate governance for business and social justice, fairness and inclusiveness for all. The current *European Pillar of Social Rights Action Plan* (2021)[100] addresses change towards a greener, fairer and more inclusive future.

Research needs

The imperative is to orient research in environment and health to take account of human rights, vulnerability and inequalities (i.e. disadvantaged position in the society in terms of i.e. income, gender, sexuality, ethnicity, minority-status, neurodivergence, disabilities) and differences in time (age) and space (e.g. regions, cities). There is a need to:

- Explore how the different risk-factors and their combinations (accumulation) in the nexus affect people in different situations and how these factors and processes can produce and maintain social disadvantages and increase vulnerability. How does social disadvantage translate into environmental disadvantage (taking into account the exposure differential for different groups as some have a higher exposure to risks and less to environmental goods) and how can this be disconnected?
- Create new knowledge on societal and social structures and mechanisms leading to differential exposure to environmental and social stressors and interplay between environmental conditions and gender inequalities, basic service inequalities, education and work-related inequalities. Paying particular attention to housing-related inequalities through assessment of the role that housing quality plays in increasing exposure to environmental stressors. How much of health inequality is explained by environmental factors? What is the comparative

[94] WHO, Env EEA Report No 22/2018 Unequal exposure and unequal impacts: social vulnerability to air pollution, noise and extreme temperatures in Europe
[95] WHO, Environmental Health Inequalities in Europe (2012) https://www.euro.who.int/__data/assets/pdf_file/0010/157969/e96194.pdf
[96] COM (2020) 152, A Union of Equality: Gender Equality Strategy 2020-2025
[97] Healthy environment, healthy lives: how the environment influences health and well-being in Europe — European Environment Agency (europa.eu)
[98] WHO (2019) Environmental health inequalities in Europe. Second assessment report. Copenhagen: WHO Regional Office for Europe; 2019.
[99] COM (2020)380. EU Biodiversity Strategy for 2030: Bringing nature back into our lives
[100] European Parliament (2021), European Pillar of Social Rights Action Plan

degree of variability of exposure to different environmental risk factors in countries and at the local level? Include social, legal, and economic sciences and take into consideration the vulnerability, variability, and susceptibility of human societies as well as the different ways they interact with animals and ecosystems.

- Strengthen implementation research to identify potential barriers and best practices to drive policy development towards ensuring equity and environmental justice. How can the impact of different levels of vulnerability be measured and factored for policy formulation?
- Improve understanding of the impact of socioeconomic factors, as well as issues such as environmental injustice and equity, in order to improve co-creation capacities of both the researchers and key stakeholders involved in projects (see RG6.6).
- Utilise participatory research with under-represented groups to address societal needs through citizen science where the public contributes to data gathering to monitor local environments, in order to address environmental injustice where there is disproportionate exposure of certain populations to environmental hazards. Foster public engagement and measure impacts on local social and environmental conditions, as well as on the participants themselves. Identify levers for and barriers to socio-ecological systems' health and resilience.
- Further develop and implement an economical model (see doughnut economy; economy of well-being for example) that fits within planetary boundaries, including innovative financing mechanisms.
- Producing a knowledge base on ways to transform the economy to prevent environmental degradation, biodiversity loss and unsustainable use of resources, e.g. through sustainable food production and circular economy approaches.

Tentative research call areas

Title: *Influence of demographics on increased vulnerability to environmental stressors*
Scope: Exploration of the relationship between demographics and increasing vulnerability to environmental stressors (increased sensitivity and reduced resilience); studies should focus on differences in environmental exposure and vulnerability for disadvantaged subgroups (in terms of i.e. income, age, gender, sexuality, ethnicity, minority-status, neurodivergence, disabilities) and across time and space (e.g. regions, cities).

Title: *Heterogeneous data analysis in the environment, health and socio-economic nexus*
Scope: Undertaking analyses of different types of data - social and demographic status, health and environmental quality - to identify interlinkages and complexities between climate change, biodiversity loss and environmental degradation and the socio-economic health impacts. (including research on mental health effects, food and water security, equity, environmental justice, health inequalities, migration and displacement, vulnerable groups and minorities). For example, this could include quantifying the unequal distribution of environmental risk factors across populations and link to health inequalities.

Title: *Revisiting and transforming unsanitary housing and residential areas in the 21st century. Meeting the challenges from coinciding environmental degradation, climate change, migration and increasing social inequalities*
Scope: European policies need to efficiently secure the need for healthy living conditions for vulnerable populations, especially in urban areas. These actions need to be based on up-to-date findings of the impact of coinciding multiple environmental risks and population vulnerabilities, including health effects (mental and somatic), behavioural effects, effects on life chances (including educational achievement and employment), and citizen voice. Current evidence for different transformational strategies needs to be critically summarized from the perspective of the concerned populations and increased individual and collective resilience to multiple increasing challenges. New case-studies may be included.

RG6.4 Ethical, philosophical and political aspects

Objective: Address the ethical, philosophical and political dimensions of transformational change at the nexus of environment, climate change and health.

Relevance

Scientific relevance: The merit of values, morality and social norms extends beyond personal opinion and the conduct and customs of societies in that it must be judged against how well they serve to enhance the philosophy of a deeper ecology and true environmental sustainability. The evidence for a deeper embeddedness of ethical reasoning and sustainability as a philosophy in guiding research orientation and political action as it relates to the nexus of environment, climate change and health remains elusive, yet the need becomes ever more pressing as cosmetic greening of actions will do little to delude the natural course of real-world systems. This underscores the imperative for governments to engage with a deeper ethical and philosophical outlook grounded in empirically based understandings of sustainability in relation to human and natural systems. There is a need to understand the value framework of individual, institutional, community and governance structures as they relate to the dissemination, integration and implementation of research outputs. This represents an important gap in understanding and an area requiring re-focused effort and support in order to maximise the benefits of the broader EU research programme. Another consideration is that the ethics, philosophy and politics of research are central to research implementation, yet they are closely dependent on the social, cultural, political and economic structures within which the very questions of research are raised. This creates a complex circular reference or feedback system where the two perspectives are deeply interwoven and even interdependent. Addressing this challenge requires careful disaggregation of the factors and dynamics which define value systems, morality, behavioural norms, conditioning and cultures (Meyer et al. 1997[101]; Meyer and Jepperson 2000[102]). It is these factors and dynamics that establish the models and standards which act as a reference for all actors in modern society and the nature and outputs of research. This forms a second focus for research directed at the ethical, philosophical and political character of society itself.

Policy Relevance: A sustainable future addressing the environment, climate change, health nexus cannot be achieved by relying solely on initiating a 'bottom-up' approach, rather a macro-political and macro-institutional approach to sustainability in governance, policy and research is required (Boulton, 2010[103]; Prothero, et al., 2011[104]). This builds upon the ethics of Planetary Health and the Statement of Principles set out in the Canmore Declaration of 2018, which itself builds upon the 1986 Ottawa Charter for Health Promotion. Thus there is a need for policy and regulatory frameworks to be inter-connected and adaptable in order to handle conflicting objectives in economics, politics, ethics and social justice. Key research platforms that reflect current philosophical aspirations at the environmental, climate change and health nexus include: the EU Strategic Plan 2020-2024 (DG Research and Innovation); the EU Green Deal, particularly where it addresses climate action, pollution, biodiversity and carbon leakage; Horizon Europe with its missions on climate change, societal transformation, healthy waters and cancer; and the 'One Health' programme tackling environmental health at the animal, human and environment interface.

Ethical, philosophical and political considerations are linked and directly applicable to the EU Biodiversity Plan, the EU Chemical strategy, the Circular Economy action plan and the Zero pollution action plan. Likewise, they underscore all the SDGs (United Nations, 2015) and are linked to the recommended research and action initiatives of the Ostrava declaration (WHO Regional Office for Europe, 2017). Access to health as a human right is fundamentally dependent on ecological and environmental determinants and the concept of Planetary Health. It is an imperative of shared values that health is recognised as a state of complete physical, mental, social and ecological well-being, including an ability to thrive personal health involves also planetary health.

Research needs

Research regarding the role of ethics, philosophy and politics in transformational change, human health, climate change and planetary health are relevant for all RGs and respective research areas in this research agenda. In particular, there is a need to:

- Increase understanding on how values which define ethical and philosophical outlooks and political expediencies can be shaped by cultural norms, institutional inertia and powerful actors that fashion the output observed and experienced.
- Develop research models that address the issue of responsibility towards future generations.

[101] Meyer, J.W., Boli, J., Thomas, G.M. and Ramirez, F.O., 1997. World society and the nation-state. American Journal of sociology, 103(1), pp.144-181.
[102] Meyer, J.W. and Jepperson, R.L., 2000. The 'actors' of modern society: The cultural construction of social agency. Sociological theory, 18(1), pp.100-120.
[103] Boulton, J., 2010. Complexity theory and implications for policy development. Emergence: Complexity and Organization, 12(2), p.31.
[104] Prothero, A., Dobscha, S., Freund, J., Kilbourne, W. E., Luchs, M. G., Ozanne, L. K., and Thøgersen, J. 2011. Sustainable consumption: Opportunities for consumer research and public policy. Journal of Public Policy & Marketing, 30(1): 31-38.

- Develop methods to support efficient research while taking into consideration participant privacy and data management within current and ongoing research, especially within the context of GDPR (General Data Protection Regulation). Generating a unified "base standard" for data management is needed as a starting point for future considerations.
- Develop a new more holistic conceptual framing which defines a culture of ethical sustainability, including equality and vulnerable population groups and which shifts social institutions, societal norms and governance systems towards a deeper ecological philosophy; consider neglected components of bioethics such as environmental and biodiversity ethics, social sciences ethics, and the ethics of various legal concepts, such as human rights, the rights of indigenous people, environmental justice, and animal rights and include the ongoing ecocide.
- Address the environmental efficacy of corporate environmental and social responsibility including co-creation and participatory research to address societal needs (e.g. the polluter pays and pays true and full costs based on impacts on health and environmental sustainability).
- Evaluate the ethical and philosophical context of production and consumption patterns including the health effects of over exploitation of resources, unsustainable food production and land-use, environmental injustice, migration and social displacement.
- Address the ethics and philosophy of sustainability at the interface of environment and health. This needs to be seen as a 'Grand Challenge' requiring 'Grand Governance' where the meaning and role of the citizen is elevated beyond paternalistic platitudes. This should include the meaning of values and citizenship and a new form of governance reflecting a deeper sustainability model.

This research approach recognizes the need to develop evidence-based knowledge on values, social norms and political systems that underscores responsible and impactful research and its translation into policy. Research should assess how sustainability, human health and Planetary Health can be seen as fundamental rights, defined by our values, morality and philosophy, and enshrined in new structures so that governance is moved to design policies that have the necessary traction to ensure implementation.

Tentative research call areas

Title: *Evaluate socio-political structures that shape transformational change at the environmental climate change health nexus.*
Scope: Address social groupings, political models, governance systems and related enablers and blockers of transformational change towards sustainability. To develop systems and tools that can help shape how society responds to the Global Challenges and human health and welfare. To help advance multidisciplinary and cross sectoral understanding of social norms, values and behaviours at the individual, institutional and governance level in the context of equity, environment and health.

Title: *Develop a new holistic conceptual framing which defines a culture of ethical sustainability, including equality and vulnerable population groups and which shifts social institutions, societal norms and governance systems towards a deeper incorporation of philosophy and ethics.*
Scope: Investigate the factors shaping society and governance, what and who controls the questions asked, and how to link transformation towards sustainability with social institutions, societal norms and governance systems.

Title: *Develop research models on the responsibility towards future generations.*
Scope: How to best introduce into all decision making the consideration for the long term outcomes and how this will affect the well-being of the next generations. Targeted topics could be considered such as dealing with water scarcity, food sufficiency, cultural issues, etc. Advantages and risks of such a concept and related tools should be assessed.

RG6.5 Science communication and science–policy-society dialogue

Objective: Improve dialogue and understanding between science, stakeholders and policy by effective and comprehensive communication of results and solutions as well as risks and uncertainty to various audiences across disciplines and stakeholder types to foster trustworthiness, counter misinformation and build capacities and skills.

Relevance

Scientific relevance: A gap exists in uptake of the scientific findings by stakeholders, in knowledge co-production, in adjusting policies based on new scientific findings, and in monitoring of results including risks and uncertainties in the environment and health field due to deteriorating trust in authorities, communication source fragmentation and insufficient understanding across disciplines linked to unclear communication. More creative science communication to the public, specialists and policy makers is needed as well as opportunities for dialogue and co-creation to (re)build citizens' and stakeholders' trust in science, promote interest in research and to ensure that scientific knowledge translates into policy and practice. Moreover, building on lessons learned from communication during COVID-19 pandemic, innovative ways of translating complex scientific concepts into easy-to-understand and trusted information are urgently needed.

Policy-relevance: Currently, strong links to communicating science, risks and urgency for effective science-policy interface are underlined in the EU Chemicals Strategy, in the Zero Pollution Action Plan and also indirectly in the Circular Economy Strategy. It is expected that frameworks supporting "zero pollution" actions, green transition and environmental sustainability including communication tools and green skills will be established or updated (EU Competence Framework(s), Pact for Skills), Knowledge Centre for Biodiversity, Education for Climate Coalition).

Research needs

Successful science- policy-society dialogue is a continuous and sustained process to jointly interpret evidence and to agree on key outcomes and it needs to be improved, strengthened and intensified. Current communication challenges require inclusion of social, cultural, political and economic dimensions, adaptation to multidirectional communication, counter-fragmentation of communication channels, and new capabilities and cross-disciplinary methods. In particular, there is a need for:

- Improving inter-disciplinary communication within research projects: among scientists, with stakeholders as well as between stakeholders in order to increase awareness and understanding.
- Identification of and building skills and capacities for efficient risk communication comprising scientific, social, cultural, political and economic dimensions to integrate knowledge and efficiently and comprehensively communicate risks and solutions building on lessons learned from COVID 19 communication challenges.
- Establishment of multi/inter/trans-disciplinary approaches and partnerships engaging stakeholders and citizens in science in order to better support a healthy and green transition and environmental sustainability and opportunities for joint/collaborative action.
- Identification of gaps in communication and/or disclosure within the environmental health field using qualitative approaches to identify key barriers and opportunities relating to open communication among stakeholders.
- Address misinformation, science denial, doubts and dealing with uncertainty, including research on motives, framing and role of media and digital platforms.
- Investigate the application of citizen outreach, engagement and more profound forms of citizen science to promote awareness and behaviour change and improve science communication in the environmental health field.

Tentative research call areas

Title: *Improving Risk communication effectiveness by applying societal values*

Scope: It has been demonstrated that values and cultural backgrounds play an essential role in the perception of information related to climate and environment (and health) in general. Research would address how best to solve communication challenges (counter the spread of misinformation, who are trusted information sources, analyse and bridge gaps between expert and public perceptions and missing capacities and skills for risk communication) in risk communication building on lessons learned from COVID 19 communication challenges.

Title: *Engaging science–policy-society stakeholders for environmental sustainability*

Scope: Multidimensional partnership engaging science–policy-society stakeholders to produce new tools and networks for advancing efficient communication in the environmental health field combatting lack of trust, fragmentation of communication channels and building opportunities for action for environmental sustainability. There is a need to investigate especially the science- to-policy interface to improve the translation of research results into policy. Research is also needed on how to best include

stakeholder communication and input in a broader risk governance framework and how to introduce and implement measures that may appear unpopular at short-term but bring benefits in long-term.

Title: *Engaging and empowering citizens to promote awareness and behaviour change towards sustainability*
Scope: Legislative and regulatory changes are effective in bringing changes for better protection of human health, but it is well-established that these processes are often gradual and take a long time. To stimulate behaviour, change at individual and community level, citizen engagement and new communication strategies and tools should be developed to involve and raise awareness of the public. Research and capacity building in this area should support citizens' readiness to make informed decisions and promote transformation towards sustainable choices. Increased understanding of citizens' perceptions of risks, attitudes and opinions would further facilitate stimulating behaviour change in the environment health field i.e. in the context of consumer products and chemicals and choices on more sustainable and healthy lifestyles and diets.

RG6.6 Transformational change in education, training and research

Objective: Develop educational strategies and research designs enabling the next generation of scientists, professionals and citizens to tackle current research and societal challenges and support informed decision making in the environment, climate and health domains.

Relevance

Scientific relevance: Transformational change is impossible without appropriate human resources in all relevant sectors including science, education, management, policy, and decision making. Without it, new knowledge and technology cannot be created, transferred and/or applied. The rapid pace of scientific progress requires continuous knowledge updates and multi-, inter- and transdisciplinary understanding and skills. The challenge for education is to combine on one hand the needs for increased specialization and on the other hand interdisciplinarity and the ability to integrate systems thinking and cope with complex, interlinked challenges. We need to encourage trans-disciplinary science education and develop advanced educational programs at the undergraduate and graduate levels bridging and connecting several domains together (chemistry, biology, physics, public health, statistics, informatics etc.) in order to address environmental health challenges. The research sector itself should take into consideration these transformational changes and new research culture and framework are needed.

Policy relevance: Adequate education is currently required at all layers of societies to be able to address the major environmental, climate and health issues that we are currently facing and that will be even more acute in the future. Education is therefore a critical component of transformational change. The European Green Deal emphasises the role of education and training and the importance of engaging with learners, educators and the general public on the tremendous environmental challenges. Commission Communication on Achieving the European Education Area [105] by 2025 also highlights education and training for green transition and sustainable development. Moreover, the upcoming Council recommendation on education for environmental sustainability will promote cooperation and development of stronger policies on education for environmental sustainability, climate education, biodiversity and related topics, addressing all ages and levels of education.

Research needs

The development of a more ambitious and relevant education (e.g. integrative and multidisciplinary) should incorporate current capacities, use existing university clusters and networks and available European resources to further increase Pan-European relevance and impact. Existing programmes such as Erasmus or Marie-Sklodowska-Curie fellowships and networks should be used for training and capacity building in environmental health sciences, in addition to developing regional competencies and more targeted efforts. However, the education on environmental challenges and global changes, human health impacts and needs for transformational changes must be embedded into the general education curricula at all levels as all citizens are expected to contribute to transformational changes. In short:

- Advanced educational programs at all levels (research scientists, professionals, citizens) combining the science areas relevant for addressing environment, climate and health, promoting trans-disciplinary science and holistic perspectives.
- Develop training of professionals in the environment, climate and health fields to update their knowledge in the fields of their expertise
- Revise education systems to support interdisciplinarity towards systems thinking and tackling complex issues; ecology, evolution and biomathematical modelling, climate change and health, sociology, political economy and political ecology needs to be included in health and environmental sustainability education curricula and programs.
- Improved training opportunities both in science and the interaction with relevant societal actors considering life-long learning (EU, national authorities and private sector).
- A Pan-European programme for training and capacity building in environment, climate and health which may be built on currently available programmes, including e.g. Erasmus and Marie Sklodowska Curie Actions.
- Investigating the most relevant tools and (participatory) approaches for a balanced education of citizens in the environment and health field.

Tentative research call areas

Title: *Education networks for a healthy, green and sustainable future in the EU*

Scope: Joint graduate and undergraduate programmes in environmental health sciences should be developed within the clusters of European universities to complement new interdisciplinary programmes**.** In addition, Marie Sklodowska Curie actions and other relevant tools (RISE, Widening) should

[105] https://ec.europa.eu/education/resources-and-tools/document-library/eea-communication-sept2020_en

be used to further enhance opportunities for international training and capacity building as well as for building stronger bonds to the private sector.

Title: *Investigating and developing citizens education approaches and tools in the field of environment and health*
Scope: Sharing the essential knowledge to understand the scientific fields involved in environment and health and to better appreciate the significance and the limitations of findings in this area. Address school education, traditional and digital media, fablab, etc.

Title: *Transformational change in the research sector: multidisciplinary, flexible and open research designs*
Scope: A new EC framework is suggested to call for investigating and applying emergent transformational research designs and management approaches. The scope of content areas is broad, as these research designs can be developed for and applied to many different research areas. It needs to include environment, health and social scientists. Research projects are expected to be large and include groups from different disciplines. In some cases, stakeholders and citizens can be included in research design and implementation. Along these lines, there is a need for a new education and training strategy that can enable the citizens to take an active role in research. The design and management of such transdisciplinary research projects should nevertheless be flexible and allow new questions and issues to emerge at the horizon during the process, potentially leading to substantial changes of the research itself and ultimately the established research culture. This requires innovative research guidelines and supervision as well as review mechanisms to foster and share transformational research approaches and practice which implies innovation and transdisciplinary teams. This may also change the way scientific careers are organized and how researchers are evaluated, recruited and promoted. The benefits and risks of such research organization for the quality and efficiency of research should be assessed.

Annexe 1 - Glossary: working definitions for the project

Abiotic Matrices

Non-biogenic matrices like air, water, soil, sediment, i.e. opposite to biogenic matrices which refer to everything in the global biosphere including everything building up the plants, organisms etc.

ABM

Agent-based models (ABM) consist of interacting agents (frequently people) and an environment that they inhabit. This type of modelling allows a powerful and flexible approach for simulating complex systems l biosphere including everything building up the plants, organisms etc.

Antimicrobial Resistance (AMR)

Antimicrobial Resistance (AMR) occurs when viruses, bacteria, fungi and parasites change over time and no longer respond to medicines. Consequently, antibiotics and other antimicrobial medicines become ineffective and infections become increasingly difficult or even impossible to treat. Antimicrobial resistant organisms are found in people, animals, food, plants and the environment (including water, soil and air), and they can spread from person to person or between people and animals or via food of animal origin. WHO has declared AMR as one of the top 10 global public health threats facing humanity. Misuse and overuse of antimicrobials are the main drivers in the development of drug-resistant pathogens. HTTPS://AHPSR.WHO.INT/PUBLICATIONS/I/ITEM/GLOBAL-ACTION-PLAN-ON-ANTIMICROBIAL-RESISTANCE

Biodiversity

Biological diversity means the variability among living organisms from all sources, such as terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part, including diversity within species, between species and of ecosystems. (CONVENTION ON BIOLOGICAL DIVERSITY, USE OF TERMS: HTTPS://WWW.CBD.INT/CONVENTION/ARTICLES/?A=CBD-02)

Blue space/green space

Green space terms used in the Agenda are natural areas, parks etc., with green vegetation. Blue spaces are recreational water spaces, such as sea shores, lakes, rivers and so on.

Climate

Regularly defined as the average weather or as the statistical description in terms of the mean and variability of relevant quantities over a certain period of time (typically 30 years), as defined by the World Meteorological Organization. The relevant quantities are most often surface variables such as temperature, precipitation and wind (Intergovernmental Panel on Climate Change. Glossary. In: Special report: global warming of 1.5°C.) GENEVA: WORLD METEOROLOGICAL ORGANIZATION, UNITED NATIONS ENVIRONMENTPROGRAMME;2018 (HTTPS://WWW.IPCC.CH/SR15/CHAPTER/GLOSSARY/) (HTTPS://WWW.IPCC.CH/SR15/, ACCESSED 14 AUGUST 2019)

Climate change

The UNFCCC in Article 1 defined climate change as "a change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods" (UNFCCC). The World Meteorological Organization describes climate change as "a statistically significant variation in either the mean state of the climate or in its variability, persisting for an extended period (typically decades or longer)". (FREQUENTLY ASKED QUESTIONS (FAQ) [WEBSITE]. GENEVA, WORLD METEOROLOGICAL ORGANIZATION; 2019; HTTP://WWW.WMO.INT/PAGES/PROG/WCP/CCL/FAQ/FAQ_DOC_EN.HTML)

Climate change adaptation

In human systems, the process of adjustment to actual or expected climate and its effects, in order to moderate harm or exploit beneficial opportunities

Climate change mitigation

A human intervention to reduce emissions or enhance the sinks of greenhouse gases. In climate policy, mitigation measures are technologies, processes, or practices that contribute to mitigation, for example renewable energy technologies, waste

minimization processes, public transport commuting practices (Intergovernmental Panel on Climate Change. Glossary. In: Special report: global warming of
1.5 ºC. Geneva: World Meteorological Organization, United Nations Environment Programme; 2018 (https://www.ipcc.ch/sr15/chapter/glossary/ (https://www.ipcc.ch/sr15/, accessed 14 August 2019).

Circular economy

Aims to redefine growth, focusing on positive society-wide benefits, thus moving beyond the current take–make–waste extractive industrial model. It entails gradually decoupling economic activity from the consumption of finite resources and designing systems to exclude creation of waste. Underpinned by a transition to renewable energy sources, the circular model builds economic, natural, and social capital and is based on three principles: design out waste and pollution, keep products and materials in use, and regenerate natural systems (59). Scientific research is needed, however, to ensure that the actual environmental impacts of the circular economy work toward sustainability. Korhonen J, Honkasalo A, Seppälä J. Circular economy: the concept and its limitations. Ecol Econ. 2018;143:37–46

Communicable disease VS non-communicable disease

Communicable diseases or transmissible diseases, are illnesses (such as cholera, hepatitis, influenza, malaria, measles, or tuberculosis) that result from the contact with infected individuals or their body discharges and fluids (such as respiratory droplets, blood, or semen), ingestion of contaminated waters or foods, or contact with contaminated surface or objects or by direct or indirect contact with disease vectors (such as mosquitoes, fleas, or mice).
On the contrary, a non-communicable disease is a disease that can't be transmitted by any of previously cited contacts (such as diabetes).

Merriam-Webster Dictionary

Doughnut economy https://www.kateraworth.com/doughnut/

Economy of well-being

Refers to a policy orientation and a governance approach, which aims to put people and their wellbeing at the centre of policy- and decision-making. Taking wellbeing into account in all policies is vitally important to the EU's economic growth, productivity, long-term fiscal sustainability and societal stability. Wellbeing contributes to economic growth (Council of the European Union 2019, 11164/19)

Eco Health

Eco Health is the health of the eco-systems.

Ecocide

Ecocide is defined as damage or destruction to the environment or ecosystem caused by natural processes or by human activity. **Ecocide thus includes all major environmental disasters, but primarily refers to anthropogenic (human-caused) impacts.** It leads to a significant deterioration of the global commons or the Earth's ecological system, upon which all living beings in general and humankind in particular are fundamentally dependent for survival (www.endecocide.org/en/what-is-ecocide/).

Ecosystem services

The benefits people obtain from ecosystems. According to the original formulation of the Millennium Ecosystem Assessment (IPBES, 2019), ecosystem services were divided into supporting, regulating, provisioning and cultural. https://ipbes.net/global-assessment

Energy transition

The energy transition is a pathway toward transformation of the global energy sector from fossil-based to zero-carbon by the second half of this century. www.irena.org

Environmental justice

Environmental justice (EJ) is the fair treatment and meaningful involvement of all people regardless of race, colour, national origin, or income with respect to the development, implementation and enforcement of environmental laws, regulations and policies. WWW.EPA.GOV

Fablab

Fab lab (originally fabrication laboratory) is a place/environment to play, create, learn, mentor and invent, on a local basis available to users (entrepreneurs, students, teachers, artists, small businesses and anyone who wants to create something new). A fab lab shares common tools and processes and wakes up the innovative spirit of its users. HTTPS://EN.WIKIPEDIA.ORG/WIKI/FAB_LAB

Genetic resources

Material of plant, animal microbial or other origin containing functional units of heredity of actual or potential value. Genetic resources are important to humans because they provide a pool of genetic diversity that has commercial value and may promote food security (Convention on biological diversity. NEW YORK: UNITED NATIONS; 1992 (HTTPS://WWW.CBD.INT/DOC/LEGAL/CBD-EN.PDF, ACCESSED 13 APRIL 2019)

Global Ocean

The vast body of water that covers 71% of the Earth's surface and includes all marine water (apart from the two inland seas, Black and Caspian). The global ocean is geographically divided into distinct named regions with boundaries that have evolved over time for a variety of historical, cultural, geographical and scientific reasons. Historically, there are four named oceans: Arctic, Atlantic, Indian and Pacific. However, most countries now recognize the Southern (Antarctic) Ocean as the fifth ocean. HOW MANY OCEANS ARE THERE? IN: OCEAN FACTS [WEBSITE]. SILVER SPRING (MD): NATIONAL OCEAN SERVICE; 2018 (HTTPS://OCEANSERVICE.NOAA.GOV/FACTS/HOWMANYOCEANS.HTML, ACCESSED 13 APRIL 2019).

Health co-benefits

The positive health effects that a policy or measure aimed at one objective might have on other objectives, thereby increasing the total benefits for society or the environment.

High-throughput methods

High-throughput methods are recent scientific experimentation methods relevant to the field of chemistry and biology, in which hundreds of thousands of experimental samples are subjected to simultaneous testing under given conditions. Using robotics, data processing/control software, liquid handling devices, and sensitive detectors, high-throughput screening methods allow a researcher to quickly conduct millions of chemical, genetic, or pharmacological tests. Through this process one can rapidly identify for example active compounds, antibodies, genes that modulate a particular biomolecular pathway. As such, the methods are also used to answer complex questions such as assessment of exposure and long-term effects.

IoT

"Internet of Things" is a system of interrelated computing devices, mechanical and digital machines, objects, animals or people that are provided with unique identifiers and the ability to transfer data over a network without requiring human-to-human or human-to-computer interaction." (google definition)

Living labs

Living lab or living laboratory represents an experiential environment defined by a territory (i.e. city, agglomeration, region etc.), with users interacting with their environment and social ecosystem and by iterative process design/explore/refine their own future in real-life scenarios.

One Health

Operational definition: One Health is an integrated, unifying approach that aims to sustainably balance and optimize the health of people, animals and ecosystems. It recognizes the health of humans, domestic and wild animals, plants, and the wider environment (including ecosystems) are closely linked and inter-dependent. The approach mobilizes multiple sectors, disciplines and communities at varying levels of society to work together to foster well-being and tackle threats to health

and ecosystems, while addressing the collective need for clean water, energy and air, safe and nutritious food, taking action on climate change, and contributing to sustainable development. https://www.who.int/news/item/01-12-2021-tripartite-and-unep-support-ohhlep-s-definition-of-one-health

Planetary Health

Our definition of planetary health is the achievement of the highest attainable standard of health, wellbeing, and equity worldwide through judicious attention to the human systems—political, economic, and social—that shape the future of humanity and the Earth's natural systems that define the safe environmental limits within which humanity can flourish. Put simply, planetary health is the health of human civilisation and the state of the natural systems on which it depends. (Horton, R. et al. 2014, From public to planetary health: a manifesto, The Lancet, Vol 383, p 847)

Salutogenesis

Salutogenesis refers to the origins of health, in contrast to the origins of disease (pathogenesis), which have been traditionally more focused on in medical science. Combining multiple ideas, disciplines and meanings, salutogenesis takes into account a wide range of positive human experiences and resources in how they promote health and coherence.

SES factors

SES, socio-economic status, is an economic and sociological combined total measure of a person's work experience and of an individual's or family's economic and social position in relation to others. Factors used include income, education, and occupation. SES is often used to describe differences in society as a whole, such as differences among geographic areas, student populations, or social groups. The measure is often used to both explain and predict the development in several areas, such as study results, health status, or income differences.

Smart Cities

There is no sole definition of what a smart city is but there are a number of common components. A smart city is a place where traditional networks and services are made more efficient with the use of digital solutions for the benefit of its inhabitants and business. Smart cities make active use of the Internet of Things and open data to optimise the flow of energy, people and data. A smart city goes beyond the use of digital technologies for better resource use and less emissions and refers to smarter urban transport networks, upgraded water supply and waste disposal facilities and more efficient ways to light and heat buildings.

Sustainable development

Sustainable development is defined by the United Nations as development that meets the needs of the present without compromising the ability of future generations to meet their own needs. It calls for concerted efforts towards building an inclusive, sustainable and resilient future for people and planet. For sustainable development to be achieved, it is crucial to harmonise three core elements: economic growth, social inclusion and environmental protection. These elements are interconnected and all are crucial for the well-being of individuals and societies. https://www.un.org/sustainabledevelopment/development-agenda/

Sustainable food production

Food producers make the best use of nature-based, technological, digital, and space-based solutions to deliver better climate and environmental results, increase climate resilience and reduce and optimise the use of inputs (e.g. pesticides, fertilisers). https://ec.europa.eu/food/system/files/2020-05/f2f_action-plan_2020_strategy-info_en.pdf (chapter 2.1.)

Transformation towards a low-carbon society

Profound changes to infrastructures, production processes, regulation systems and lifestyles, and extends to a new kind of interaction between politics, society, science and the economy (WBGU, 2011)

Transformational Change

Transformative Change is a philosophical, practical and strategic process to effect revolutionary change within an organisation, i.e., culture transformation. It is a systems approach applied to broad-based change to catalyse rapid shifts in the mental constructs inhibiting solutions to complex problems or in the organisation's culture that prevent it from realising its full potential. It seeks to discover and integrate personal and organisation development as an overarching approach to

rapid change at all levels of systems. It seeks to impact the mental constructs inhibiting solutions to complex problems or to completely shift the equilibrium of the organisation to create a new culture.

RISE

Research and Innovation Staff Exchange (RISE) is a tool of Horizon 2020 research programme that funds short-term exchanges of personnel between academic, industrial and commercial organisations throughout the world. The tool is open to all research areas and supports the secondment of staff members for one month to one year. The seconded staff then returns to their home institution to pass on the acquired knowledge.

Testbeds

Any device, facility, or means for testing something in development

Stakeholder

Individuals representing one or more disciplines, sectors, or types of organisations in the health-environment-climate nexus that can either impact the success and execution of the HERA research agenda or are impacted by it.

Superblocks, 15-minute city

Introduced in 2016, the “superblock” scheme (superilles in Catalan; supermanzanas in Spanish) transforms nine city blocks into so-called ‘superblocks’, where traffic is only allowed around the perimeter and priority is given to pedestrian areas, low-speed zones and recreational green spaces.

The Superblocks program is a policy for transforming the streets of the city, recovering for the citizens a part of the space currently occupied by private vehicles. The objective is to achieve a healthy public space, greener, fairer and safer, which favours social relations and the local economy. The transformation of the cities to address the major crises has led to the development of the concept of the city of 15 minutes. This initiative promotes an urban reconfiguration that makes proximity the key to improving the quality of life.

Widening

This term stands for **Widening Participation and Spreading Excellence** actions under Horizon Europe (EU Research and Innovation Programme, funding programme) that contribute to building research and innovation capacity for countries lagging behind. The actions will strengthen participating countries' potential for successful participation in transnational research and innovation processes, promote networking and access to excellence by upgrading their research and innovation systems, making them stronger and allowing the EU as a whole to advance together.

White spaces

We named "white spaces" research areas where during the survey there were very few research gaps identified, and also few scientists working on the particular research area with a focus on health. An example is biodiversity loss and health. While there are research efforts regarding biodiversity loss, much less is being performed regarding a link to human health.

Sources

http://www.clevelandconsultinggroup.com/services/transformative-change.php

Intergovernmental Panel on Climate Change. Glossary. In: Special report: global warming of 1.5 ºC. Geneva: World Meteorological Organization, United Nations Environment Programme; 2018 (https://www.ipcc.ch/sr15/chapter/glossary/ (https://www.ipcc.ch/sr15/, accessed 14 August 2019

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How many oceans are there? In: Ocean facts [website]. Silver Spring (MD): National Ocean Service; 2018 (https://oceanservice.noaa.gov/facts/howmanyoceans.html, accessed 13 April 2019).

Korhonen J, Honkasalo A, Seppälä J. Circular economy: the concept and its limitations. Ecol Econ. 2018;143:37–46

WBGU (2011)

WHO (2020) Factsheet: Antimicrobial resistance: https://www.who.int/news-room/fact-sheets/detail/antimicrobial-resistancé

Annexe 2 – Summary of the HERA consortium prioritisation survey

The HERA Consortium participants carried out rating of the research goals, including one set of ratings per partner institution. The rating was given in terms of relevance of the research goals a) in short-term, b) in long-term, c) urgency to act based on societal needs as well as d) rating related to the current call area suggestions. The results of the HERA internal survey are presented in the Excel Prioritisation Tool as shown on the HERA website.

Although the results need to be interpreted with caution, preferences were quite visible among the various Research Goals (RGs), where the highest importance was indicated to:

RG1.1 Health and climate change
RG1.3 Health and biodiversity loss
RG2.1 Healthy urban environments
RG3.1. Exposure to chemicals including legacy chemicals, emerging chemicals and mixtures
RG4.2 Develop tools and methodologies for integrative environmental health risk assessment
RG5.1 Well-designed and maintained population cohorts and related biobanks
RG6.6. Transformational change in education, training and research

The RGs listed above are not ranked/listed in the order of importance, but reflect the order of the RGs and which RGs stand out as highly important. The participants rated only the areas where they felt they had expertise. In general, this meant often 7-12 responses per RG.Due to the small number of responses, median values were not calculated. The call area suggestions ratings are not considered in this summary due to potential biases in selection and writing of the call area descriptions.

HERA criteria (modified from Kogevinas, 2017) were used in the prioritisation, including:

- Novelty: Will research in a specific area increase understanding, produce new knowledge, new approaches?
- Importance to People: Will the life and well-being of many populations be positively affected? Are there specific populations at high risk? How urgent and important are future risks? Magnitude of the problem/benefits
- Importance to the environment at a large/planetary scale
- Impact: Will research in a specific area produce knowledge that meaningfully informs health/environmental policies?
- Sustainable Development Goals: Will research produce new innovations and promote SDGs?

Scientific aspects based on identified research gaps and their summaries				
Topic/Sub-topic and Research needs, objective and short summaries.	COMMENTS Please insert your name/s and organisation: … In case the RG topic is beyond your expertise/comfort, please state that for the RG where that is valid. Please add any thoughts/reflections you may have as an assessor.	Relevance of the research needs in short-term (1-5, 5 most relevant). Insert a short explanatory comment on your rating.	Relevance of the research needs in long-term (1-5, 5 most relevant). Insert a short explanatory comment on your rating.	Promote scientific preparedness to handle environment and health urgencies. Please insert a short verbal assessment of the RG (no rating).

Political/policy aspects based on key EU strategy documents related to environmental health and Horizon Europe							
How are the research needs linked to the EU Biodiversity strategy?	How are the research needs linked to the EU Chemicals strategy?	How are the research needs linked to the Zero pollution action plan?	How are the research needs linked to the circular economy action plan?	How are the research needs linked to the Farm to Fork strategy?	Links to Horizon Europe (HE) Missions (use a-e, see the note)	Cross-cutting the clusters - planetary health (use A-F or multiple e.g. A,C)	Urgency to act based on societal needs (1-5, 5 is most urgent). Insert a numerical rating and a short explanatory comment related to your rating.

Interpretive aspects based on stakeholder input on knowledge/research needs and further interpretation on potential calls to respond to the knowledge/research needs			
Stakeholder input via WP3	Has there been a call in this area recently (H2020, Horizon Europe)?	Suggested title and scope of a potential call area	Insert a numerical rating (1-5) + provide a short explanatory comment on your rating. Title A in Column Q Title B in Column R Title C in Column S Title D in Column T

Figure 6: Overview of the excel prioritization tool

Limitations and discussion

The response rate was quite low as around half of the HERA partners filled in the ratings. The excel tool was aimed at HERA partners who are experts in this area, and an overview of the tool is depicted in the figure 1. It must be noted that the result of the prioritisation is dependent on the tool structure as well as on the structure of the agenda and the formulation of the research goals. This inevitably leads to more visibility to some areas of research, unlike an inventory of all possible research needs or their linear representation if such approaches would have been pursued. Due to the strategic nature of the agenda, the prioritisation was mainly done at the RG level, not between the RGs, meaning that the choice of options under each RGs affects what is possible to prioritise in the first place. However, based on the indicative results, it is worth noting that in RG1, several RGs were rated slightly higher in general than in the other RGs. For this reason, two RGs are lifted from RG1.

Interestingly, the prioritisation seems to align somewhat with the international topical discussions related to climate change, biodiversity loss and pollution, the three planetary crises that should be tackled (UNEP, 2021).

In terms of RG4 and RG6, it was noted both in the editorial group discussions as well as by some assessors that these themes are cross-cutting and could be integrated across various calls for proposals.

References

Kogevinas M. (2017): Setting priorities in environmental health research. Environ Epidemiol 1:e001. doi: 10.1097/EE9.0000000000000001

UNEP (2021): For people and planet: the United Nations Environment Programme strategy for 2022–2025 to tackle climate change, loss of nature and pollution. https://www.unep.org/resources/policy-and-strategy/people-and-planet-unep-strategy-2022-2025 (accessed 20 January 2022)

Further information: A HERA deliverable: Report/guidelines on principles and transparent criteria for prioritization of research and policy needs (2021). Elina Drakvik and Åke Bergman https://cordis.europa.eu/project/id/825417/result

Annexe 3 - Public Consultation on the HERA Agenda 2020-2030

Summary

Public consultation was organized in October 2021 via Google Forms to enable all interested stakeholders, organizations and citizens to give their opinion on the Agenda in an inclusive and transparent manner. The public consultation was announced through social media and emails targeting experts in academia and research institutions, NGO's, the general public, Ministries of Health and Environment.

The responses collected are summarized here, taking into account major relevant ideas. Most of the responses came from individuals and a small proportion from organizations (Figure 7).

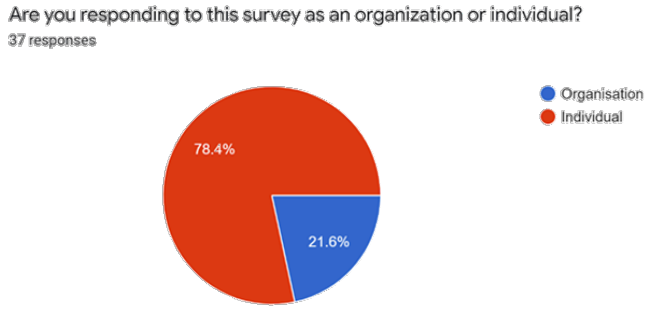

Figure 7: type of respondent to the public Consultation

General questions

To the question: "What are your key take-aways from the Agenda?", participants to the survey generally leaned towards research goals related to climate change and biodiversity loss, air quality and to the need for holistic approaches, solution oriented and implementation research.

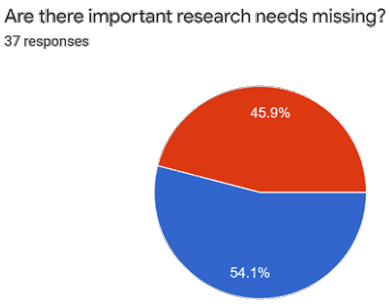

Figure 8: Response to the lack of research needs

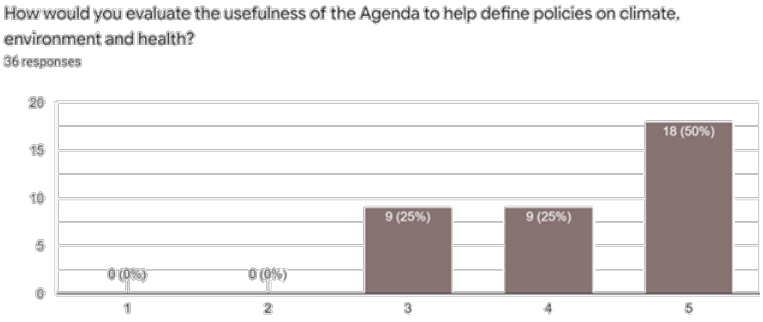

Figure 9: Evaluation of the usefulness of the Agenda rated 1 to 5 (not useful to very useful)

To the question: "Are there any parts of the Agenda that are inessential or unimportant, and if so, which are they?", participants highlighted the potential redundancy of the Agenda with itself and existing initiatives (planetary health watch, resource watch initiative, Global Burden of Disease Initiative).

In general, participants considered that the agenda was useful to very useful (Figure 2). A small majority found that there were research needs that were missing (Figure 3) and provided suggestions, for example, focus on development of early warning systems, and one suggested an effort to monetize pollution and exposure impacts.

To the question: "What do you think is the biggest hurdle in addressing this research need?", participants mostly agreed on financing and political will as a hurdle as well as communication, knowledge management and the lack of flexible tools and transdisciplinary research teams.

Research goals focused questions

To the question: "Do you have specific comments on Research goal 1 "Climate change and biodiversity loss – reduce effects on health and the environment" and if so, what are they?", some participants wished for more focused research calls. Several participants highlighted the need for research in ecosystem services. Others suggested the use of sectoral impact models taking advantage of Copernicus and large inter-comparison exercises at an international scale.

Several participants talked about the effects of climate change on the lifecycle of plants, including on biological airborne compounds such as pollen, ragweed and molds leading to allergies and asthma as well as applications of food allergens requiring research to understand dietary effects.

To the question: “Do you have specific comments on Research goal 2 “Cities and communities – promote healthy lives in sustainable and inclusive societies” and if so, what are they?”, participants suggested research goals tied to salutogenesis and health promotion across activity spaces and settings, rather than the mere mitigation of stressors.

To the question: “Do you have specific comments on Research goal 3 Chemicals and physical stressors – prevent and eliminate harmful chemical exposure to health” and if so, what are they?”, participants had various suggestions: research on natural toxins because fluctuations in bacteria and fungi due to climate changes will lead to increased exposure to natural toxins; “Safe-and-Sustainable-by-Design” concept; considerations of the life-long exposure and research on cocktail effects of chemicals existing in daily consumer products.

To the question: “Do you have specific comments on Research goal 4 “Improve health impact assessment of environmental factors and promote implementation research” and if so, what are they?”, participants suggested to diversify the portfolio of approaches and discipline contributors to include biological and chemical scientists/sciences in addition to social scientists. One participant specifically talked about the development of a specific Patient Reported Outcomes for environmental interventions aiming to protect public health.
For the question: “Do you have specific comments on Research goal 5 “Develop infrastructures, technologies and human resources for sustainable research on environment, climate change and health” and if so, what are they?” participants suggested to base development of new approaches on the existing methodology and merge currently available capacities rather than creating new ones. This was also a suggestion for Research Goal 4.

To the question: “Do you have specific comments on Research goal 6 “Promote research on transformational change in environment, climate change and health” and if so, what are they?”, participants proposed an improvement of the communication on transformational change which tends to be quite abstract. They suggested to develop and work from concrete examples and build the analysis and conclusion around these. Related to this response is the suggestion from another participant of a new education and training strategy that can enable the citizens to take an active role in research, involve all the stakeholders in research (industry included) for a multi-sectoral cooperation. The need to train professionals and update their knowledge in the fields of their expertise was highlighted.

Conclusions

HERA Consortium welcomed the feedback from the public consultation. Despite an extensive circulation of the Agenda and the public consultation announcement only 37 responses were received. All the suggestions made by the participants were discussed within the core editorial group and some adjustments were made to incorporate the inputs from the consultation where possible or to fine-tune some of our proposals in the agenda. Participants highlighted the potential redundancy of the Agenda with itself and existing initiatives (planetary health watch, resource watch initiative, Global Burden of Disease Initiative), but this was an expected outcome of the way we designed the Agenda. Major changes, such as new call areas, were not added at this stage. The suggested call areas already provided should be seen as examples effectively combining expressed research needs and challenges rather than interpreted as a fully exhaustive list.

Contributors

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ANSES - The French Agency for Food, Environmental and Occupational Health & Safety
AUTH - Aristotle University of Thessaloniki
BCS - Bureau for Chemical Substances
CNRS - The National Center for Scientific Research
ESHI - The Environmental Sustainability and Health Institute
HEAL - Health & Environment Alliance
HMGU - Helmholtz Zentrum München
INRAE - French National Institute for Agricultural Research
INSERM - French National Institute of Health and Medical Research
ISGlobal - Barcelona Institute for Global Health
IT - Inserm Transfert SA
JSI - Jožef Stefan Institute
LSHTM - London School of Hygiene & Tropical Medicine
MU - Masaryk University
MUW - Medical University of Vienna
RIVM - National Institute for Public Health and The Environment
SU - Stockholm University
SYKE - Finnish Environment Institute
TUDublin – Technological University
UAVR - University of Aveiro
UU - Utrecht University
VITO - Flemish Institute for Technological Research
WHO - World Health Organization

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