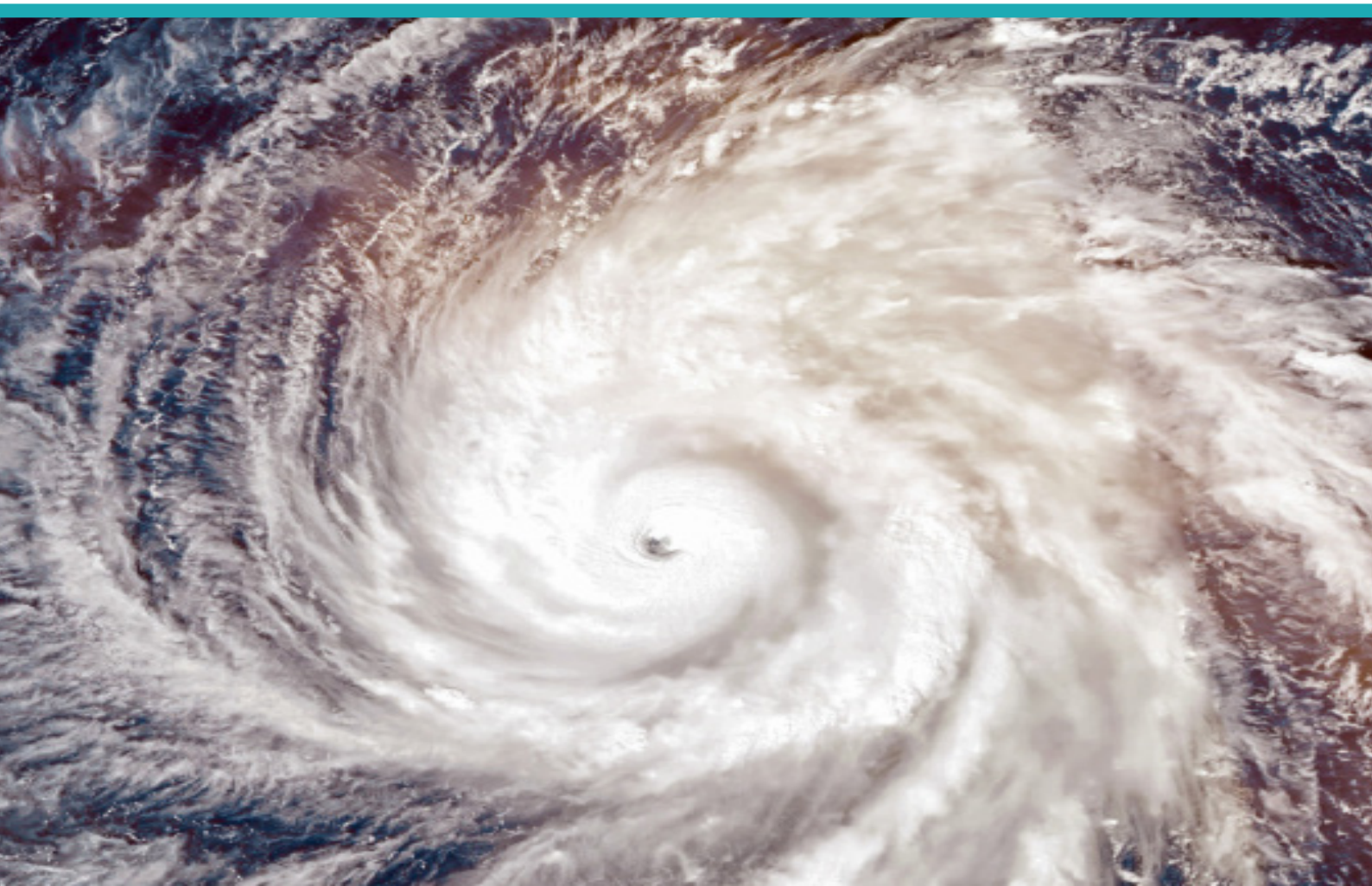
making science work for health

PHG FOUNDATION

Precision health in a changing climate



An urgent need

Climate change is an immediate and escalating global health emergency, undermining decades of public health progress. The increasing frequency of extreme weather, deteriorating air quality, and shifting disease patterns disproportionately harm the world's most at-risk populations, including the elderly, children, and those with pre-existing health conditions [1].

Current public health responses, while vital, are often reactive and applied at a broad population level, failing to protect those at greatest biological risk. Strategic application of genomics could offer a valuable addition to the ongoing response to climate-related health challenges, complementing and potentially enhancing existing mitigation efforts.

Its use also raises critical questions about equity, responsibility, and the ethical implications of identifying and acting on biological vulnerability with precision, questions that must be addressed as part of any meaningful integration into public health strategy.

To achieve this we recommend:

- Integrating genomics into climate and health strategies
- Building the data infrastructure for a genomics-informed response
- Investing in discovery research for biomarkers and the development of predictive tools
- Prioritising equity and representation in research
- Establishing robust ethical governance for a new era of health data

Purpose

This PHG Foundation position statement is the result of our horizon scan of the climate change and health landscape. In it, we highlight emerging trends, key challenges, and evolving roles at the intersection of climate change, human health and the role of genomics.

Providing insights and strategic considerations, the position statement highlights proactive, evidence-based approaches that support understanding of, and strategies to address, the health impacts of climate change.

Intended for healthcare professionals, policymakers, and stakeholders across clinical and climate sectors, with this position statement we aim to inform decision-making and support the strategic integration of genomics into climate-health responses.

Making genomics part of the climate-health solution

The climate crisis is a health crisis, creating complex and cascading threats to human wellbeing worldwide [1], [2]. As governments and health systems grapple with this challenge, we are underutilising one of the most powerful tools in modern science: **genome-based science**.

Far from being a niche area of research, genomics can offer a fundamental contribution to our understanding of the health impacts of climate change, and our response. Integration of genomics into health discussions and strategy will support the broader drive to tackle health in a changing climate.

Genomics provides the ability to move beyond broad, population-level observations to a precise understanding of why some individuals and communities are more susceptible than others. This knowledge will contribute to unlocking a new generation of proactive and equitable public health responses.

Here we outline how genomics can and should be leveraged as a part of the solution to:

- **Improve risk estimation:** By identifying the genetic factors that mediate susceptibility to climate-sensitive health threats like heat stress, air pollution, and infectious diseases, we can develop more accurate and granular risk models [3], [4].
- **Develop targeted interventions:** A better understanding of risk allows for the design of efficient, evidence-based interventions that direct resources to those who need them most, moving from reactive care to proactive prevention [5].

- **Build climate resilience equitably:** By focusing on the biological mechanisms of vulnerability, we can create responses that are tailored to the specific needs of diverse populations, helping to mitigate the profound inequities of the climate crisis.

By integrating genomic data with environmental and clinical information, we can move beyond generalised responses to a nuanced understanding of individual and subgroup susceptibility as well as more appropriate intervention development. This enables the development of targeted and equitable health interventions that enhance climate resilience.

Epilepsy and heat

The increasing frequency and intensity of heatwaves due to climate change present a significant risk for individuals with epilepsy. For some, rising ambient temperatures are a direct trigger for seizures, a phenomenon particularly evident in temperature-sensitive genetic epilepsy syndromes like Dravet Syndrome. This suggests situations where an individual's underlying genetic susceptibility to seizures remains dormant until unmasked by an environmental pressure, such as extreme heat.

By studying the genomes of individuals who experience heat-related seizures, researchers can pinpoint the specific genetic variants that create this vulnerability. Identifying these gene-environment interactions is a critical first step in developing genomic-informed risk models.

These models will enable clinicians and public health officials to more accurately predict which individuals with epilepsy are at highest risk during a heatwave, allowing for targeted preventative strategies and more personalised care in a warming world.

Understanding genomics can shape response

Climate change does not affect everyone equally. An individual's genetic makeup is a factor that influences their response to environmental stressors [6]. Integrating this knowledge can transform our public health capabilities from reactive to predictive, allowing for more targeted and effective interventions.

Uncovering mechanisms of disease

Genomics can help explain the biological basis for differential health outcomes in the face of climate change. A deeper understanding of the mechanisms of disease allows for a strategic shift from generalised public health advice to personalised, evidence-based interventions. This paves the way for a new, more personalised approach to public health, a concept of the emerging field of precision environmental health [16].

Pollutants and air pollution

The health impacts and biological responses of pollutants in our environment (air, water, food) are modulated by our genes. By understanding these genetic variations, we can predict which populations are at higher risk from specific pollutants and develop strategies to protect them [9].

Air pollution and epigenetic risk

Climate change is intensifying wildfires, leading to a significant increase in air pollution from fine particulate matter like PM2.5. While the cardiorespiratory health risks are known, our individual biological responses are modulated by our genes and epigenetics.

A recent study of Australian twins and families exposed to wildfire smoke demonstrated this connection, revealing that exposure was associated with epigenetic changes, specifically DNA methylation, in several genomic regions. These modifications altered genes involved in critical biological pathways, including inflammatory regulation, which are linked to diseases such as cancer, diabetes, and asthma.

This research highlights how genomics and epigenomics can uncover the precise molecular mechanisms linking climate-related pollutants to disease. By understanding these variations, we can better predict which populations are at higher risk and develop targeted public health strategies to protect them.

Extreme heat

Research is increasingly showing that an underlying genetic "trait" influences heat tolerance [9], [10]. Genomics helps us move beyond simple observation to identify the specific biological pathways that determine why one person can withstand a heatwave while another suffers from heatstroke.

Emerging pathogens

Spillover events of novel pathogens into human populations are becoming more frequent. The application of selective pressures to pathogenic organisms such as changes to environmental temperatures or salinity, incites genetic adaptations that allow pathogens to survive and in some cases thrive in novel environments.

This increases the likelihood of novel pathogens coming into contact with human populations, which has been seen with fungal infections caused by *Candida auris*, with high mortality rates [11].

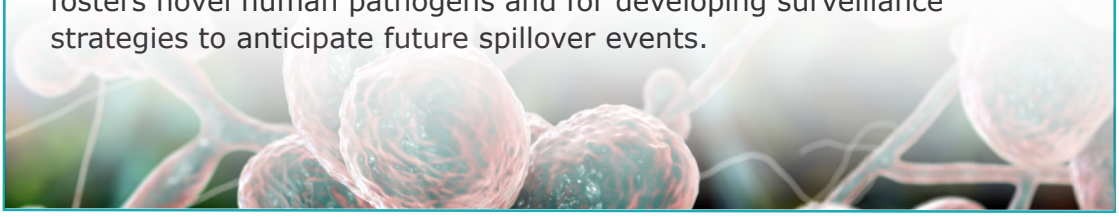
Emerging pathogens and climate-driven adaptation

C. auris has become a human threat. Climate change is shifting the geographic range of known diseases as well as driving the evolution of new ones, as exemplified by the dangerous fungal pathogen *C. auris*. Historically, the temperature difference between the human body and the environment (the 'thermal restriction zone') has protected us from most fungal infections.

However, as global temperatures rise, this natural barrier narrows, exerting selective pressure on fungi to adapt to warmer conditions. *C. auris* has emerged almost simultaneously as a human pathogen in several disparate locations and it has been hypothesised that this is due to climate-driven genetic adaptations.

By using genomic sequencing, scientists can identify the specific variants that enabled this fungus to develop thermotolerance and become a significant, often drug-resistant, threat.

This genomic insight is crucial for understanding how climate change fosters novel human pathogens and for developing surveillance strategies to anticipate future spillover events.



Infectious diseases

Warmer temperatures are expanding the range of disease vectors like mosquitoes and ticks which spread diseases such as Zika, Dengue fever and encephalitis.

The genetic makeup of newly exposed populations that are immunologically naive also becomes a critical factor in predicting disease severity [12], [13].

A classic example is genetic variants that confer the sickle cell trait resulting in protection from severe malaria, which is common in populations with a long history of exposure [14].

Nutritional stress

Climate change disrupts food systems, altering the nutritional content of staple crops. Nutrigenomics shows how these dietary shifts interact with an individual's genetic profile [15], [16]. For example, a person with a common genetic variant that impairs folate metabolism is at much higher risk of deficiency if their local food supply, altered by climate change, becomes poor in folate-rich vegetables [15].

Syndemic exposures

Beyond single threats, populations often face a syndemic, where multiple stressors interact to compound and amplify health risks. For instance, the combination of extreme heat, high humidity, and air pollution creates a synergistic effect that can overwhelm the body's defenses. Research now shows that such concurrent exposures can trigger persistent inflammatory responses.

Genomics is critical for identifying the genetic variants that make some individuals more susceptible to this chronic inflammation, leading to more severe consequences like cardiovascular and respiratory disease.

A technological tipping point

The ambition to integrate genomics into the climate-health response is now feasible because we are at a unique technological tipping point. A convergence of breakthroughs in molecular technologies, environmental sensing, digital connectivity, and computational power has created an opportunity to capture and analyse the complex interplay between our genes, our health and our rapidly changing environment.

High-resolution environmental sensing

We can now measure the environment with remarkable granularity. Satellite remote sensing provides continuous global coverage of atmospheric conditions and land use, while drones offer high-precision data for specific locales [17].

At the community level, the Internet of Things (IoT) has enabled vast networks of low-cost sensors monitoring air quality, temperature, and water contaminants in real time [18].

At the individual level, wearable devices can now track personal exposure to pollutants, UV radiation, and other environmental factors, providing a direct link between a person's immediate surroundings and their physiological state [19].

Advanced computational power

The sheer volume and complexity of data generated by genomic sequencing and ubiquitous environmental sensing are beyond the capacity of traditional analysis [20].

The emergence of artificial intelligence (AI) and machine learning (ML) are critical enablers that allow us to make sense of these massive, disparate datasets [21]. Subtle patterns and complex, non-linear interactions between thousands of genetic variants and a lifetime of environmental exposures can be detected with these advanced computational tools [20].

These techniques are transforming our ability to build predictive models of gene–environment interactions, particularly at the population level, though their reliability and utility at the individual level remain subject to ongoing evaluation [22].

A critical caveat - the environmental cost of technology

Embracing these powerful technologies also requires us to proceed with caution. The data-intensive approaches that underpin modern genomics and AI have a significant environmental footprint of their own [23], [24]. Data centres, which are essential for storing and processing vast datasets, consume enormous amounts of electricity and water for cooling, contributing to the very carbon emissions we seek to mitigate.

The explosion in AI is projected to dramatically increase this energy demand [23]. Therefore, a core principle of this work must be sustainability, which requires development and adoption of green computing practices and sustainable data infrastructure to ensure that the tools we use to address the climate-health crisis do not inadvertently make the problem worse [25].

The ethical frontier

The use of genomics to identify at-risk subgroups and unlock discoveries that could be of benefit for the entire population raises ethical challenges that demand careful consideration.

Focusing on at-risk groups raises questions about where the responsibility for mitigating health effects should land, what costs it is reasonable to require at-risk individuals themselves to bear, and what should fall on groups and public authorities. Ways will need to be found to ensure that these questions are brought to the surface and addressed in context and ahead of implementation.

It forces us to confront classic public health dilemmas: under what conditions can treating people differently benefit everyone, rather than enabling some to enjoy freedoms for which others bear the cost, through stigmatisation,

discrimination or disadvantage? And how much cost ought people be willing to carry for the benefit of their fellows?

The challenge is to harness the power of precision approaches for universal benefit while safeguarding individuals. It requires a framework where the identification of a particular type of vulnerability is seen not as a tool for division, but as an essential way to achieve more effective and equitable public health for everyone in a changing climate. This will require a robust and inclusive dialogue to ensure these advancements serve the common good.

These ethical dimensions must be actively and openly addressed as we move forward.

A call for a smarter, more targeted response

The climate-health crisis demands a multifaceted response that leverages every effective tool at our disposal. Genomics offers an additional lens to understand who is most at risk and why, and, when responsibly applied, offers the prospect of smarter and more equitable interventions.

We must invest in the research, infrastructure, and ethical capacity to integrate genomics into health responses to climate change. We can then move beyond a reactive posture and begin to build a truly climate-resilient health future for all.

Realising the potential of genomics in the climate-health response will require a collaborative effort from all sectors. While global and national responses to climate change have a complex political context, this must not delay urgent investment in research, evidence, and policy action.

Read our recommendations below

Recommendations

We call upon funders, policymakers, researchers, and leaders in healthcare, academia, and industry to recognise this emerging field and work together to build the necessary research capacity, data infrastructure, and capacity for ethical reflection.

Integrate genomics into climate and health strategies

Formally recognise genome-based sciences as essential tools in climate-health policy to better understand biological vulnerabilities and inform public health interventions. This integration will contribute to developing predictive tools that can guide adaptive strategies and strengthen the resilience of our health systems.

- Call for governments, global health agencies, and research funders to incorporate genomics into major climate and health initiatives.
- Catalyse a shift in research priorities to focus on the biological mechanisms that mediate the health impacts of environmental stressors.

Build the data infrastructure for a genomics-informed response

Create secure, interoperable data ecosystems that link genomic, 'omic, clinical, and high-resolution environmental data to serve as a foundation for precision public health [26].

The power of genomics is unlocked when it is integrated with other data sources. Fragmented data systems are a major barrier to progress; a unified infrastructure is essential for advancing risk estimation and enabling targeted interventions [27]. Achieving this will require coordinated investment and collaboration across sectors, disciplines, and borders.

- Support the development and adoption of harmonised data standards to allow for the pooling of data from multiple sources, increasing statistical power and accelerating discovery [27].
- Expand data collection in large-scale, longitudinal biobanks to include granular environmental exposure data alongside health and genomic information [28]. Programmes like Born in Bradford (UK), UK Biobank, and the All of Us Research Program (USA) have started to link genomic and health data to meteorological and pollution metrics [27], [29], [30]. This enables projections of disease burdens under future climate scenarios.
- Invest in building this research infrastructure within climate-vulnerable regions to ensure the equitable development of context-specific solutions.

Invest in discovery research for biomarkers and the development of predictive tools

Building upon association studies toward targeted research that uncovers the biological mechanisms of climate-related health risks. These insights are necessary to move beyond correlation and build predictive models that shift public health from reactive care to proactive prevention. This will support the development of predictive tools for climate-sensitive diseases and inform adaptive healthcare strategies [29].

- Prioritise research aimed at identifying robust biomarkers of environmental stress and individual susceptibility.
- Invest in the development and validation of predictive tools that can forecast disease risk for individuals and communities under future climate scenarios.
- Harness emerging technologies, such as wearables and portable sensors, to enable personalised, real-time exposure monitoring.

Prioritise equity and representation in research

Support and fund the co-development of population-level programmes to develop research infrastructure in climate-vulnerable regions prioritising equity, ethical engagement and the empowerment of underrepresented populations to shape globally relevant science. This will:

- Correct the severe underrepresentation of non-European ancestry populations in genomics research, ensuring that findings and interventions are relevant across diverse global contexts.
- Generate context-specific insights into disease vulnerability and resilience, reflecting the unique interactions between genetic, environmental, and social factors in different populations and settings.
- Advance global understanding of disease mechanisms by supporting inclusive, ethically engaged genomic research that reflects the full spectrum of human genetic diversity and is shaped by the priorities of participating populations.

Establish robust ethical governance for a new era of health data

Develop a comprehensive international governance framework to ensure the ethical use of integrated climate-health data and safeguard public trust.

The integration of genomic and environmental data requires anticipatory and agile governance to guide the ethical production and application of knowledge, ensuring that data use promotes equitable benefit and protects the rights and interests of individuals and communities [31].

- Ensure data are robust enough to support legal and policy accountability, providing clear evidence to link climate change to specific health outcomes and drive effective action.
- Promote dynamic co-creation and co-development research models that treat participants as partners, ensuring transparency and giving individuals agency over creating data and how their data are used [32].
- Convene an international consortium to establish clear legal and ethical principles around data use and sharing, consent, and robust protection against discrimination and stigmatisation [33].

References

[1] World Health Organisation, WHO, 'Climate change'. WHO, Oct. 12, 2023. [Online]. Available: https://www.who.int/news-room/fact-sheets/detail/climate-change-and-health

[2] World Ecomonic Forum, WEF, 'Heightened heatwave risks for the elderly, and other health stories'. WEF, Jul. 17, 2025. [Online]. Available: https://www.weforum.org/stories/2025/07/heightened-heatwave-risks-older-persons-health-stories/

[3] F. Cui et al., 'Air pollutants, genetic susceptibility and risk of incident idiopathic pulmonary fibrosis', Eur. Respir. J., vol. 61, no. 2, p. 2200777, Feb. 2023, doi: 10.1183/13993003.00777-2022.

[4] M. Q. Ren, J. B. Kazman, P. A. Abraham, D. Atias-Varon, Y. Heled, and P. A. Deuster, 'Gene expression profiling of humans under exertional heat stress: Comparisons between persons with and without exertional heat stroke', J. Therm. Biol., vol. 85, p. 102423, Oct. 2019, doi: 10.1016/j.jtherbio.2019.102423.

[5] J. E. DeVoe, N. Huguet, S. Likumahuwa-Ackman, A. Bazemore, R. Gold, and L. Werner, 'Precision Ecologic Medicine: Tailoring Care to Mitigate Impacts of Climate Change.', J. Prim. Care Community Health, vol. 14, p. 21501319231170585, Dec. 2023, doi: 10.1177/21501319231170585.

[6] PHG Foundation, 'Environmental human genomics'. Accessed: Aug. 12, 2025. [Online]. Available: https://www.phgfoundation.org/research/environmental-human-genomics/

[7] S. Dolley, 'Big Data's Role in Precision Public Health.', Front. Public Health, vol. 6, p. 68, 2018, doi: 10.3389/fpubh.2018.00068.

[8] Canadian Lung Association, 'How air pollution is messing with our genes'. Accessed: Aug. 12, 2025. [Online]. Available: https://www.lung.ca/how-air-pollution-messing-our-genes

[9] Y. Hosokawa, R. L. Stearns, and D. J. Casa, 'Is Heat Intolerance State or Trait?', Sports Med. Auckl. NZ, vol. 49, no. 3, pp. 365–370, Mar. 2019, doi: 10.1007/s40279-019-01067-z.

[10] N. Sambuughin et al., 'Genetics of Exertional Heat Illness: Revealing New Associations and Expanding Heterogeneity', Int. J. Mol. Sci., vol. 25, no. 20, 2024, doi: 10.3390/ijms252011269.

[11] J. H. Ellwanger and J. A. B. Chies, 'Candida auris emergence as a consequence of climate change: Impacts on Americas and the need to contain greenhouse gas emissions.', Lancet Reg. Health Am., vol. 11, p. 100250, Jul. 2022, doi: 10.1016/j.lana.2022.100250.

[12] CDC, 'Vector-Borne Diseases', Climate and Health. Accessed: Aug. 12, 2025. [Online]. Available: https://www.cdc.gov/climate-health/php/effects/vectors.html

[13] Center for Science Education, 'Climate Change and Vector-Borne Disease'. Accessed: Aug. 12, 2025. [Online]. Available: https://scied.ucar.edu/learning-zone/climate-change-impacts/vector-borne-disease

[14] H. Turner, H. Carr, and C. Babb de Villiers, 'Host genomics: lessons for infectious diseases'. PHG Foundation, Dec. 2024. [Online]. Available: https://www.phgfoundation.org/wp-content/uploads/2024/12/Host-genomics-lessons-for-infectious-disease.pdf

[15] M. Bulut, E. Karakas, and A. R. Fernie, 'Adjustments of plant primary metabolism in the face of climate change', J. Exp. Bot., p. eraf116, Mar. 2025, doi: 10.1093/jxb/eraf116.

[16] J. Steluti et al., 'Genetic Variants Involved in One-Carbon Metabolism: Polymorphism Frequencies and Differences in Homocysteine Concentrations in the Folic Acid Fortification Era', Nutrients, vol. 9, no. 6, p. 539, Jun. 2017, doi: 10.3390/nu9060539.

[17] Survey Operations, 'How Technology Is Improving Environmental Monitoring'. Accessed: Aug. 12, 2025. [Online]. Available: https://www.survops.co.uk/how-technology-is-improving-environmental-monitoring/

[18] W. Abdullah, A. R. Alsewari, and M. de Oliveira, 'Special Issue: Advanced Sensing Technology for Environment Monitoring', Sensors, [Online]. Available: https://www.mdpi.com/journal/sensors/special_issues/814AU944Q3

[19] 'Wearable Tech For Environmental Monitoring'. Accessed: Aug. 12, 2025. [Online]. Available: https://www.meegle.com/en_us/topics/wearable-technology/wearable-tech-for-environmental-monitoring

[20] E. Pesheva, 'Turning to Artificial Intelligence to Disentangle the Exposome'. Accessed: Aug. 12, 2025. [Online]. Available: https://hms.harvard.edu/news/turning-artificial-intelligence-disentangle-exposome

[21] E. Wójcik-Gront, B. Zieniuk, and M. Pawełkowicz, 'Harnessing AI-Powered Genomic Research for Sustainable Crop Improvement', Agriculture, vol. 14, no. 12, p. 2299, Dec. 2024, doi: 10.3390/agriculture14122299.

[22] S. Wu, Y. Xu, Q. Zhang, and S. Ma, 'Gene–environment interaction analysis via deep learning', Genet. Epidemiol., vol. 47, no. 3, pp. 261–286, Apr. 2023, doi: 10.1002/gepi.22518.

[23] G. Samuel and A. M. Lucassen, 'The environmental impact of data-driven precision medicine initiatives', Camb. Prisms Precis. Med., vol. 1, p. e1, 2023, doi: 10.1017/pcm.2022.1.

[24] STAX Engineering, 'The environmental impact of data centers'. Accessed: Aug. 12, 2025. [Online]. Available: https://www.staxengineering.com/stax-hub/the-environmental-impact-of-data-centers/

[25] G. Samuel, F. Lucivero, and A. M. Lucassen, 'Sustainable biobanks: a case study for a green global bioethics', Glob. Bioeth., vol. 33, no. 1, pp. 50–64, Dec. 2022, doi: 10.1080/11287462.2021.1997428.

[26] R. N. Salas, T. H. Friend, A. Bernstein, and A. K. Jha, 'Adding A Climate Lens To Health Policy In The United States', Health Aff. (Millwood), vol. 39, no. 12, pp. 2063–2070, Dec. 2020, doi: 10.1377/hlthaff.2020.01352.

[27] Australian Health Ministers Advisory Council, 'National Health Genomics Policy Framework 2018–2021'.

[28] Kaiser Permanente Division of Research, 'Research Program on Genes, Environment and Health'. Accessed: Aug. 12, 2025. [Online]. Available: https://divisionofresearch.kaiserpermanente.org/research/research-program-on-genes-environment-and-health/

[29] UK Biobank, 'Using the UK biobank data to identify the potential environmental risk factors on diseases'. Accessed: Aug. 12, 2025. [Online]. Available: https://www.ukbiobank.ac.uk/projects/using-the-uk-biobank-data-to-identify-the-potential-environmental-risk-factors-on-diseases/

[30] National Institute of Environmental Health Sciences, '"All of Us" program advances diversity, environmental health research'. Accessed: Aug. 12, 2025. [Online]. Available: https://factor.niehs.nih.gov/2024/10/feature/2-feature-all-of-us

[31] K. W. Doxzen, L. Signe, and D. M. Bowman, 'Advancing precision medicine through agile governance'. Accessed: Aug. 12, 2025. [Online]. Available: https://www.brookings.edu/articles/advancing-precision-medicine-through-agile-governance/

[32] The White House, 'Precision Medicine Initiative'. Accessed: Aug. 12, 2025. [Online]. Available: https://obamawhitehouse.archives.gov/node/333101

[33] S. Calluori, K. K. Heimke, C. Caga-anan, D. Kaufman, L. E. Mechanic, and K. A. McAllister, 'Ethical, Legal, and Social Implications of Gene-Environment Interaction Research', Genet. Epidemiol., vol. 49, no. 1, p. e22591, Feb. 2025, doi: 10.1002/gepi.22591.

Authors: Chantal Babb de Villiers and Hayley Wilson

Advisory group: Pete Mills, Susan Mitchell, Laura Blackburn, Rebecca Bazeley

November 2025

DOI: https://doi.org/10.61599/zwse7