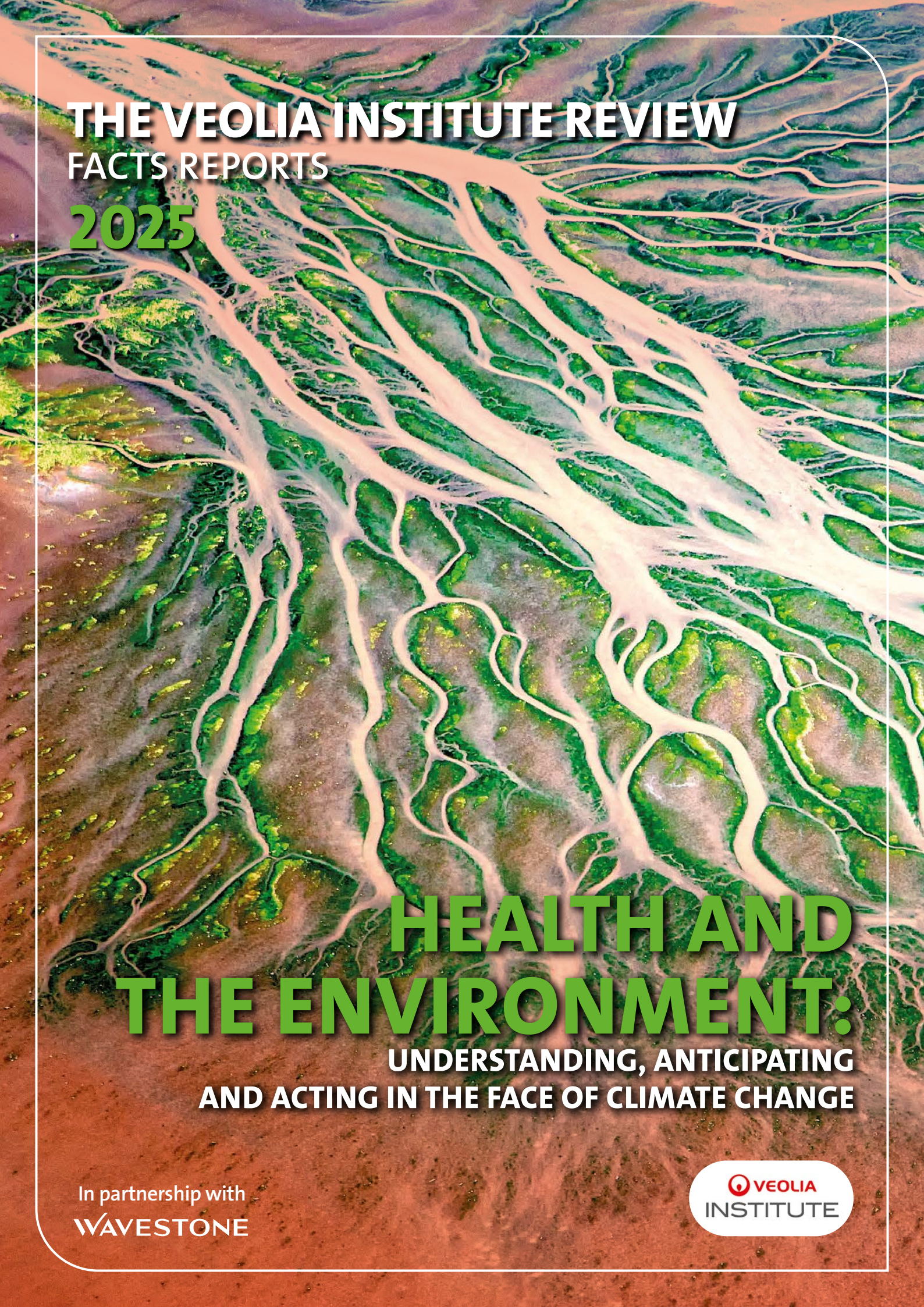

THE VEOLIA INSTITUTE REVIEW

FACTS REPORTS

2025

HEALTH AND THE ENVIRONMENT:

UNDERSTANDING, ANTICIPATING AND ACTING IN THE FACE OF CLIMATE CHANGE

In partnership with

WAVESTONE

VEOLIA INSTITUTE

THINKING TOGETHER TO ILLUMINATE THE FUTURE

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We would like to express our deep gratitude to Amartya Sen, Economist, Nobel Prize 1998, Professor at Harvard, for his invaluable contributions and commitment to the work of the Veolia Institute since its creation in 2001 and until 2023.

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INTRODUCTION

Nicolas Renard - Executive Director, Veolia Institute

The environment and health, health and the environment. The two are inextricably linked, each depending on the other: environmental deterioration harms human health, and when we protect the environment, the environment protects human health. The relationship between the two has long been recognized, as illustrated by the advice from Hippocrates many years ago to avoid building towns in unhealthy locations. The word malaria, meaning bad air in Italian, expresses this causal link between disease and the state of the environment, although it is misleading since malaria does not result from bad air but is caused by a parasite, *Plasmodium falciparum*, transmitted by *Anopheles*, a genus of mosquito.

Air, water, soil and climate all affect our organisms and our lives, from birth to death. As humans, our environment, be it natural, urban or domestic, puts us in contact with innumerable biological, chemical, and physical agents liable to impact our health. The current health crisis could well be interpreted as one of the major ecological crises facing humanity, on a par with pollution, climate change, the depletion of natural resources, and the erosion of biodiversity. Phenomena that all result from human activity, and that all pose a threat to the environment or human health.

Rising death rates caused by heatwaves, more frequent epidemics, declining mental health, poorer air quality, compromised access to water, food insecurity, and so on: in one way or another, every country in the world is feeling the impacts of the climate crisis. To the extent that some are dubbing it "the number-one public health crisis."[1]

Heat kills half a million people every year. And heatwaves, these silent killers, are becoming more numerous and more intense. Europe is the continent that is heating up fastest. A two-degree rise in global temperatures will lead to European cities seeing temperatures as high as 50°C. And who among us knows what life will be like at 50°C?

The effects of climate change on health are evident in many countries, with surges of dengue fever in Brazil, malaria in Chad, and cholera in Zambia and Malawi. In the future, rising temperatures will facilitate the spread of mosquito-borne arboviruses such as dengue, chikungunya and zika, as well as extending their periods of peak activity. This will also help spread other viruses, such as the Powassan virus currently found in North America that can cause severe encephalitis.

In our oceans, rivers and lakes, rising temperatures will encourage the reproduction of protozoans and pathogenic bacteria, leading to new outbreaks of water-borne diseases. Melting permafrost is another factor and a possible health timebomb, releasing viruses and bacteria trapped for tens of thousands of years that, in all likelihood, humans will have no immunity against and antibiotics will be powerless to treat.

Low-income countries will be hit harder by the consequences of climate warming. If we compare cities in Pakistan to Riyadh in Saudi Arabia, all of them will experience equivalent temperature rises by 2050. But the numbers of heat-related deaths will be very different. More people will die in Pakistan because the country has fewer financial resources to allow it to adapt to a hotter planet.

The ability to adapt is critical to both the survival of humans and ecosystems. Changes in the climate are dramatically altering the distribution of rainfall and plant cover. They are also altering the behavior, range and distribution of animals and insects, including pollinators. They threaten ecosystems that have not had enough time to adapt, with direct repercussions on human health. The One Health approach is one solution to these problems. It stresses the interconnected relationships between ecosystem health, animal health, and human health.. Healthy ecosystems have beneficial effects on human health. "We knew already that we live on one planet. We then discovered that there is only one health."[2]

> ***"Human health is a direct expression of the quality of the relationship between people and ecosystems. It will also be the final arbiter of the success or failure of our policies for adapting to climate change."***

In truth, a broad panoply of solutions needs to be tirelessly implemented all over the world if we are to protect human health in the face of climate change. For example, including planted and shaded areas in urban patterns, designing buildings with sufficient thermal mass to provide heat in winter and cooling in summer, using wastewater recycling systems, and, of course, changing our lifestyles.

Particular attention must be paid to medical infrastructure. Unless changes are made, facilities in many countries will be overwhelmed by the impact of climate change on local people. Hospitals have to prepare to receive greater numbers of patients. They need to plan for the increasing scarcity of water, which they use in large amounts. They need to rethink their air conditioning and insulation systems, which are hardly ever designed to deal with extreme heat. And facilities located in coastal areas need to reinforce their protection against cyclones, which will grow in intensity.

Human health is a direct expression of the quality of the relationship between people and ecosystems. It will also be the final arbiter of the success or failure of our policies for adapting to climate change.

1 Vanina Laurent-Ledru, directrice générale de Foundation S - The Sanofi Collective, l'Opinion 28 mars 2024.

2 Bedeau, L. (2024). The Veolia Institute FACTS Report on Environmental Health.

FOREWORD

Philippe Kourilsky
Professor Emeritus at the Collège de France, Honorary Director General of the Pasteur Institute,
Member of the Veolia Institute Foresight Committee

Health and the environment: what has changed in twenty years?

It has now been 20 years since the Veolia Institute and Pasteur Institute first co-organized an international conference on Education, Environment and Health. At the time I felt that the extremely broad theme was hard to delineate and complicated to conceptualize. The molecular biologist I was then struggled to link it to scientifically defined content. A strong emphasis was put on education. The meeting's conclusions remain of great interest and I would encourage everyone to read them.[1] The wide-ranging contents presented in this issue of FACTS illustrate the considerable progress achieved over the past two decades. How can this progress best be described? Where can we imagine it will lead us? Although they necessarily only offer some pieces of the puzzle and are fairly personal, the observations that follow may assist readers in forming their own opinions.

> *"The environment is as much physical as biological, yet the two are inextricably intertwined in the soil, the oceans, and the atmosphere."*

Both terms of the equation – environment and health – have evolved, with a partly common background. The enormous growth in life sciences, characterized by the massive acquisition of relevant data.

Super-fast genome sequencing[2] has changed molecular genetics, a discipline born in the 1980s, out of all proportion. Scientific viewpoints have shifted as a consequence, from the reductionist approaches of molecular biology's early days to an approach that is far more systemic. Other technologies, such as imaging, have also contributed to revolutionizing biology, a science now characterized by its increasing mastery of complexity.[3] Considerable progress has been achieved in our understanding of all the biological systems that make up human beings: the nervous system, immune system, endocrinal system, and so on. The same applies to studies of human pathologies. Simply put, medicine has become more scientific and, as a result, more personalized too. With artificial intelligence used to help analyze, model and exploit this ever-growing mass of data, medicine will undergo further profound changes that we are only just starting to glimpse.

It is not only humankind that has been impacted by this whirlwind of new knowledge. In the 20th century, our knowledge of the environment was constructed on the basis of a handful of model organisms such as beer yeasts, the *E. Coli* bacteria, *C. elegans* worm, *Drosophila* fly, *Arabidopsis* herbaceous plant, and the mouse. Today, our knowledge has expanded to include a wide range of organisms, particularly from the plant world. Not to mention research on fossils and the insights it offers into how species have evolved. Lastly, we are also now delving far deeper into the study of ecosystems that are composed of a great many different organisms.

The environment is as much physical as biological, yet the two are inextricably intertwined in the soil, the oceans, and the atmosphere. A single gram of soil contains close to one billion bacteria, and a milliliter of seawater contains ten million viruses.[4] As for the atmosphere, depending on the location and human activity, it contains thousands or millions of particles that we breathe in and that can carry microorganisms. And let us not forget the now infamous CO_2, produced and absorbed by living organisms as well as being generated by human pollution.

1 The conference program and summary are available here: https://www.institut.veolia.org/en/our-events/international-conferences/education-environment-and-health.

2 The genomes of several tens of millions of people and over 5,000 different species have been fully sequenced, and many more have been partially sequenced. DNA data extracted from fossils, although only partial, is essential to analyzing how species have evolved.

3 Kourilsky, P. (2023). *Mes années Pasteur* [*My Pasteur Years*], Odile Jacob.

4 These viruses essentially regulate plankton growth and are harmless to humans.

As a result, the impact on health of air, water and soil quality is increasingly understood. This deeper understanding of the environment opens the door to innovative new areas for research, such as how to anticipate the emergence of harmful infectious agents using *in silico*[5] models combined with studies of the cascade of characteristics at the origin of potential epidemics.

Human beings are closely linked to the environment through their metabolism. A human's intestinal microbiota contains 50,000 billion bacteria divided into several thousand separate species. Although sometimes the subject of excessive media attention, this should in no way mask its importance: the intestinal microbiota is a major metabolic "organ" that mediates between humans and their environment. The other microbiomes (lungs, skin, and mucous membranes) are also invaluable mediators whose roles we are beginning to appreciate. They all play their part in a range of different pathologies.

"I am convinced that the most serious consequences of the current environmental crisis, particularly those resulting from climate warming, will be social. There will be colossal direct and indirect repercussions on human health."

Humans are doubly social beings. On the one hand, we do of course live in societies. And on the other hand, the development of the brain, particularly in childhood, depends on what we perceive and receive from our environment. Certain human characteristics are innate, such as the ability of newborns to count to two or three. Many others, however, are acquired. The ways in which this remarkable organ is formed are as complex as they are multiple. The immediate social environment, as provided by family and educators, is critically important. We can, however, legitimately question the impact of more global environmental changes, whether social or even climate-related.

One example would be the impacts on mental health of wars in Vietnam, Korea, Iraq, Algeria, and, today, Russia's invasion of Ukraine: assessments of their severity are continuously being revised upward. This is all the more important since certain behavioral traits can be transmitted across one or two generations via mechanisms, sometimes called epigenetic,[6] that are still not well understood. From this perspective, the Covid-19 pandemic and the various lockdowns imposed as a result offer an interesting area for study. And how will climate refugees be affected?

It may be argued that the social environment I refer to has little in common with the "real" environment which is rightly the object of such concern to ecologists of all persuasions. But are we really so sure? Stress in all its forms is potentially harmful to human health, as many studies of cancers have shown. It is important to understand how it becomes "imprinted" on the organism via the brain or the microbiome, both of which are connected to the immune system and the other systems that organisms use for regulation and defense. Similarly, the environmental stresses impacting ecosystems point to problems of robustness and resilience that are conceptually relatively similar to those that can affect humans.

Returning to a more conventional ecological vision of the environment, we have undoubtedly witnessed a major change over the past two decades with the worsening of the environmental crisis we now face.

This manifests in four interconnected ways: climate warming, exhaustion of vital natural resources, pollution of every type, and a reduction in biological diversity. All of these can (and will) impact human health as well as that of other physical-biological and social ecosystems. Faced with these challenges, the problems to address will not be simply scientific and technical, they will be ethical too. The environmental crisis is already exacerbating inequalities we have spent decades trying to reduce. Poverty was falling but is now on the rise again.

I am convinced that the most serious consequences of the current environmental crisis, particularly those resulting from climate warming, will be social. There will be colossal direct and indirect repercussions on human health. This is why I argue strenuously for a broader vision of the links between environment and health.

I believe, now more than ever, that ecology must be a moral science.[7]

5 Theoretical research methods, particularly involving computer models, used to predict the likely toxicological, or other, effects of substances (European Food Safety Authority).

6 The study of heritable changes in gene function that do not involve changes in DNA sequence (Merriam-Webster).

7 Kourilsky, P. (2023). *Innovation for Ecological Transformation.* Veolia Institute. https://www.institut.veolia.org/sites/g/files/dvc2551/files/document/2023/11/Veolia_FACTS_25_2023_GB_Web_Interactif_V3%20%281%29.pdf.

Exploring the climate-environment-health nexus:

Insights for informed action

Harvey V. Fineberg
President of the Gordon and Betty Moore Foundation and member of the Veolia Institute's Foresight Committee

Harvey V. Fineberg has been the president of the Gordon and Betty Moore Foundation since 2015 and is a member of the Veolia Institute's Foresight Committee. He previously served as the president of the U.S. National Academy of Medicine (2002-2014) and was the Dean of the Harvard Chan School of Public Health (1984-1997). Prior to joining a philanthropic foundation, he devoted most of his academic career to the fields of health policy and medical decision-making. Dr. Fineberg has co-authored and co-edited several books and is the recipient of various honorary degrees and other awards, such as the Henry G. Friesen International Prize in Health Research.

Human health, the environment, and climate change are intricately linked. The environment, encompassing physical, biological, and social dimensions, profoundly influences our health. Climate change, as a pervasive force, impacts human health directly, for instance through extreme weather events, and indirectly through phenomena like air pollution from wildfires, and alterations to ecosystem services. Our understanding of health has evolved over time from ancient philosophical roots to modern scientific insights. While the environment was gradually integrated into this understanding, climate change remains a pressing concern that is often overlooked in health policies. Addressing climate-related health risks demands a multi-faceted approach, drawing also on practices from Eastern and indigenous cultures that emphasize the interconnectedness of humans and the environment. Collective action and policymaking are essential to mitigate these risks, alongside individual contributions. Effective action entails adopting a preventive mindset and ambitious policies to reduce climate change drivers, mitigate impacts, and promote resilience in human populations. Overcoming the growing distrust of science through education and awareness is also crucial. As societies confront these challenges, it is imperative to envision a future where we not only survive but thrive as a society, embracing sustainability and resilience as guiding principles for a healthier and more equitable world.

From a broad perspective, what are the major factors influencing human health, and in what ways does the environment play a role in these factors?

To begin, it may be valuable to adopt a scheme that was first articulated more than 50 years ago by the Canadian Minister of Health Marc Lalonde. In his proposals, Mr. Lalonde outlined four sources of health and illness. First, our genetic endowment; second, our lifestyle or self-care, which includes the habits we adopt, the foods we eat, and whether we consume alcohol and drugs. Third, the medical care that we receive; and finally, the environment. 'Finally' does not mean the least impactful; the environment is actually a profound source of influence on human health. Our environment encompasses a physical environment, a chemical environment, a biological environment, and a social environment. And all these dimensions have a profound impact on the life-chances, health, and well-being of each of us.

We have varying degrees of control over these four influences on health. Genetic endowment is regarded as a given; it sets the stage, it is the template upon which everything depends, it gives us the potential for the degree of health we can individually enjoy. In the not-too-distant future, even our

genetics might be subject to intervention. Among the first genetic treatments for a specific genetic disease – sickle cell anemia – has been approved by regulatory authorities both in Europe and in the United States. Although its current use is limited due to high costs, it represents a harbinger of a future class of interventions.

Today, we have the most direct control over our lifestyle choices. Yet even these choices are significantly conditioned by our environment. We believe we are choosing what we eat, but our food choices are embedded in the history, the culture, and the living conditions in which we were raised. So even things that we believe to be individual choices have their roots in our social and cultural environment and are shaped by geography and economics.

Medical care is another determinant, but on a population health basis, often less powerful than genetics, lifestyle, and environmental factors. For individuals with specific medical conditions, medical intervention can be critical and enhance the quality and duration of life.

One reason the environment plays a crucial role in our health is its pervasive nature. The environment surrounds us throughout our entire lives. It is the air we breathe, the water we drink, the food we consume, the interactions we experience, the stress, the joys, the exposures to chemicals or infections depending on our work or our place of living, and the susceptibility to homelessness or other sources of disruption in our lives. It is omnipresent and unavoidable. And improving the environment often depends on collective choice rather than individual action.

How does climate change affect the environment, and by extension our health?

When considering climate change, we can differentiate between direct effects and indirect effects on human health. Climate change means that the planet is warming on average though impacts vary greatly by region. Consequently, we observe a series of extreme weather events that can be paradoxical, mixing both increasing droughts and risks of floods due to altered precipitation patterns. As the average temperature rises, these extreme events will become more frequent, directly impacting human health. For example, recent heatwaves in Europe had dire impacts on human health, causing heat exhaustion, heat strokes and death, especially among the elderly or otherwise vulnerable individuals for whom hotter temperatures can be detrimental, and even fatal.

"One reason the environment plays a crucial role in our health is its pervasive nature. The environment surrounds us throughout our entire lives."

The indirect effects of climate change are even more profound. One significant risk that has become evident, for example, is the increased frequency of wildfires, affecting every continent except Antarctica. From North to South America, from Europe to Asia, wildfires have become more and more prevalent. Wildfires are dangerous to a double extent: they cause direct damages, destroying lives, property, and natural environments. And the smoke from wildfires, which generates severe air pollution as fine particulate matter, can be even more detrimental to human health. In many parts of the world, air pollution levels already dramatically exceed safe thresholds due to the burning of fossil fuels, impairing the quality and longevity of life by hastening pulmonary lung disease, heart disease, and other illnesses.

Could you say a few words on the ecosystems and their role for human health? How does climate change affect this relationship?

In a broader context, the concept of ecosystem services encompasses the various ways in which human well-being is supported by the functions of a given ecosystem, such as ensuring air quality or cleaning and filtering water to make it safer for humans. However, these functions are altered by climate change, which indirectly impacts water quality by precipitating biological changes that, for example, lead to the proliferation of algal blooms, thereby compromising water safety.

Additionally, a significant effect of climate change is likely to arise from changes in the ecology of disease vectors. Warmer temperatures will promote spread of mosquitoes to new areas, allowing them to survive at higher elevations than in the past and bringing them into more frequent and extensive contact with human populations.

Looking at the history of medicine, how has the understanding of the interrelationships between health, the environment, and climate change evolved over time within medical theory and practice?

Human understanding of disease and its origin varies across cultures and regions of the world. In the Western tradition, health can be traced back to Aristotle's concept of the four humors, which attributed health and illness to the balance or imbalance of bodily constituents. This paradigm profoundly influenced medical thinking until the Renaissance, when more modern thinkers, partly in arts but also in medicine, began to examine human bodies and understand the origins of pathologies by observing changes in organs and tissues.

Over the last few centuries, the significance of biological threats and environmental hazards emerged. By the mid-19th century, the concept took hold of miasma or amorphous vapors conveying disease. The term 'malaria' means 'bad air' in Italian, highlighting the idea that diseases were somehow conveyed by dangerous vapors. Though scientifically misguided, these notions of the environmental origin of illness laid the groundwork of the modern sanitation movement.

Louis Pasteur (1822-1895)

The field of epidemiology often traces its roots to the work of John Snow during the outbreak of cholera in London in the 1850s. Snow documented the temporal and spatial relation of cases to homes served by a particular source of water drawn from polluted sections of the Thames River. The exact nature of water contamination was not fully comprehended at the time, but it was clearly associated with disease.

The pioneering work of scientists such as Louis Pasteur and Robert Koch in the late 19th century began to identify microorganisms responsible for human and animal diseases. Infectious diseases impose a huge burden on humanity, and various infectious organisms can be transmitted through a wide variety of environmental exposures, including inhaled air droplets (tuberculosis, measles, SARS-CoV-2), food and unpasteurized milk (salmonella, campylobacter, E. Coli), contaminated water (cholera, shigella), sexual relations (HIV, syphilis), blood exposure (hepatitis), insect vectors (malaria), and direct penetration through the skin (hookworm).

Over the course of the 20th century, many other risk factors for disease came into focus, including prior conditions, such as high blood pressure, and lifestyle choices, such as tobacco use. Landmark studies such as the Framingham Heart Study established the connection between diet and risk factors like hypertension for cardiovascular disease. Other studies can be cited, such as the Nurses' Health Study, which followed hundreds of thousands of nurses over time, investigating the relationship between lifestyle factors and outcomes in women's health. The Six Cities Study, followed by the Twenty Cities Study, underscored the link between air pollution, especially small particulates, and life expectancy. The famous Whitehall studies in London examined the life course of civil servants and discerned a relation between social class and risk of premature death. This opened an important era of appreciation of the power of social determinants of health.

It has long been understood that climate and weather, along with other geographic features, affect the distribution of infections and other diseases. Climate change, and the new extremes it produces, has only more recently been recognized as a potent determinant of health. Because climate change is pervasive, its effects were so widespread that they went unnoticed; it was so obvious as to be unseen.

This overview you gave us focuses on the Western world. Are there any specific approaches to environmental health in other parts of the world that offer valuable lessons for us?

The Western medical tradition incorporates a notion of internal physiological equilibrium or homeostasis, as posited by Claude Bernard in the 19th century. However, other health and cultural systems in the East and in many indigenous communities in the Americas and Australia, emphasize the concept of human harmony with the environment. These communities have lived for eons in equilibrium with their environments, fostering a profound connection and appreciation of the environment as intrinsic to human existence, and seeing humans in connection with the environment. Many of these traditional practices offer thoughtful lessons for us today.

"Because climate change is pervasive, its effects were so widespread that they went unnoticed; it was so obvious as to be unseen."

For instance, prescribed burns to reduce the risk of major, very hot wildfires are a traditional native practice aimed at maintaining forest health. Certain trees, when young, need sunlight to flourish, so a thinner wildland will be more conducive to the next generation's growth than a dense, overgrown, and fuel-laden woodland. Another example is the traditional harvesting of wild rice in the Great Lakes region of Northern America. Native Americans used to limit their harvesting days and return some of the grains to the lake, seeding the next crop. Early Europeans traders wrongly regarded this practice as wasteful, failing to recognize it as a way of maintaining harmony with the environment by giving back to it.

Today, there is a growing recognition of the wisdom in many traditional practices. The outdated ideals of progress in Western civilization, from the Renaissance onward, which emphasized consumption, efficiency, productivity, and control are now reaching their limits in terms of human well-being. Non-Western ideas centered on health, overall well-being, resilience, and survival, have begun to influence the thinking of Western-oriented scholars, thinkers, and leaders in recent decades.

You said earlier that climate change *"was so obvious as to be unseen"*. Why has climate change been a health blind spot for so long? And why do we, as a society, struggle to address it and take appropriate action?

I think there are at least four major reasons. First, while climate change is profound, measurable, and undeniable, its progression is very slow. It is not a matter of a sudden increase in average temperature, although the last decade has been the warmest ever recorded in history. But even that decade spans a full ten years. Throughout the same timeframe, certain individuals may have encountered cold spells in their communities, influencing them to perceive a colder climate despite global trends. Thus, the reality of the average global temperature does not penetrate individual perceptions. This situation echoes the traditional metaphor of the frog that, when put in water that is gradually heated, will not perceive the danger and move. But when put directly in hot water, the frog will immediately react and jump out.

A second reality is that the impacts we are discussing primarily exacerbate existing conditions. Climate change worsens phenomena that are already familiar rather than introducing dramatically different ones. We have always had hurricanes, floods, droughts, and wildfires. Therefore, it is easier to ignore or normalize the increase of these events over time as they do not seem entirely novel.

Third, there are significant political challenges in implementing targeted pain or harm for broader social benefits. For instance, efforts to reduce fossil fuel dependence will face substantial resistance because the global general good and long-term benefits are not perceived as immediately tangible compared to the focused harm faced by those directly affected.

Lastly, I would add that our political systems, for the most part, are designed to respond to crises and emergencies rather than being planful, proactive, and forward-thinking in policy adoption. Urgency and emergency tend to command immediate attention, overshadowing the importance of acting for long-term human value. Therefore, all these factors – slow movement, familiarity, targeted harm, and non-emergent character – contribute to relative neglect and make it challenging to capture public attention and influence policymaking.

What is our real capacity for action, considering the imperceptibility of climate change and the collective nature of environmental health?

Certain aspects of environmental health depend on collective actions, such as the quality of the air we breathe or the water we drink, which are more subject to collective control rather than individual choice. This underscores the importance of collective decision-making in influencing the health and wellbeing of each of us. Only through collective efforts can we diminish dependence on fossil fuels and establish the conditions for healthier air, cleaner water, and sustainable food sources.

But, at an individual scale, we also have the capacity to take meaningful steps. We can reduce personal reliance on fossil fuels, minimize our environmental footprint, and improve our nutrition while promoting sustainable food practices. On this score, numerous initiatives aim to adapt food distribution mechanisms to ensure equitable access, particularly for those who are vulnerable to food insecurity. There is no reason, anywhere on the planet, to have starvation. This is fundamentally a human construct as global food production today is capable of meeting everyone's needs. Amartya Sen, Nobel Laureate in Economics and a former member of the Veolia Institute's Foresight Committee, made a powerful argument regarding the choice of famine, emphasizing not the necessity, but the human-driven factors behind it.

"But, at an individual scale, we also have the capacity to take meaningful steps."

Perhaps most importantly, we have the power to elect officials who will prioritize long-term environmental challenges and understand the far-reaching impacts of climate change. We can appoint representatives who are willing to be in the lead, not merely follow, and who will make the right choices, with foresight, for communities, nations, and humanity.

In 2024, nearly half of the global population will vote in a national election, marking a crucial year for democracy. Amid rising conspiracy theories and a skepticism toward scientific consensus, how can we encourage people to elect officials who support science?

You are delving into a very profound and underlying mega-challenge. By mega-challenge, I mean a huge issue, unbounded by national borders, often interconnected with other mega-challenges, and unsolvable except through multinational action. Climate change, poverty, and pandemics are all mega-challenges. What you are raising now is the public's understanding of and confidence in science and evidence. The doubt becomes pervasive: individuals are questioning evidence and authority, showing skepticism toward science, leading to hesitation or resistance to vaccination and immunization efforts. People continue to doubt climate change and its reality.

This poses a crucial long-term educational and psychological challenge: we must help people understand why science is trustworthy, even amidst uncertainty. Paradoxically, the uncertainty of science is a source of trustworthiness, as it means science is subject to improvement based on evidence over time. We could trace origins of public skepticism in science to the power of social media in amplifying extreme and erroneous ideas and to the reliance of some authoritarian leaders on spreading the 'big lie' to persuade people: the 'big lie' is so outrageous that it must be true, because why else would they say it? These challenges of understanding and confidence are deeply interconnected with public attitudes toward climate change, and this constitutes a mega-challenge of our time.

Given the importance of policymaking in addressing collective approaches to health, how would you envision an appropriate integration of climate-related risks into health policies?

When it comes to integrating climate-related risks into health policies, I would parse the possibilities into three major categories. The first is the imperative to reduce the drivers of climate change and environmental degradation and their impact on health. In other words, we must reduce fossil fuel use, not only because of its climate effect but also due to its dire impact on human health. This also involves tackling issues such as overfishing in the seas, deforestation for cattle and soy production, and degradation of mangrove ecosystems in coastal regions, all of which impact both climate and ecosystem vitality.

Second, we can mitigate the effects of climate change, which means finding ways to manage and control the impacts that are already present. This could include measures like better control of vectors through improved screening of all residences in affected regions, enhanced water purification methods to reduce chemical exposures, and urban planning strategies to mitigate the impacts of wildfires or sea-level rise on urban coastal areas, protecting critical residential infrastructure.

And finally, we need to define and implement resilience strategies aimed at strengthening communities and cities' ability to adapt, survive, and thrive in the face of inevitable change.

Thus, while health policy *per se* remains relatively unchanged by the impacts of climate change, our response to these challenges becomes increasingly urgent and consequential. Ensuring access to care and preventive services, as well as guaranteeing clean air, safe water, and food, become all-the-more vital considering climate change's impacts on human health.

In conclusion, considering our discussion, what should be our priority moving forward as a society?

We urgently need to adopt a preventive mindset rather than a reactive and treatment-oriented one. Investing now to avert calamitous situations in the future is crucial. Framing prevention within the context of human security would be valuable, as it conveys the necessary sense of urgency. Whether we are facing a pandemic like Coronavirus or natural disasters such as floods and wildfires, human security is at risk. Taking action to prevent these threats and enhance security should be the framing that encourages political leaders to adopt policies that diminish the drivers of climate change, mitigate its impacts, and promote resilience in human populations. In doing so, we can ensure that in the future, we not only survive, but truly thrive as a society.


SAVE EARTH
SAVE
YOURSELF
HERE IS ONLY
SOS
PLANET

1 Direct threats to human health as a consequence of the climate emergency

In 2020, the Covid-19 pandemic reminded us of the vulnerability of our health, described by Plato as our "first good". In revealing our interdependencies and highlighting how every aspect of our existence is linked to others, the pandemic gave us a renewed perspective on the history of a civilization whose development has always been marked by public health calamities. It took this crisis for health to once again become a shared concern. Too long seen as a personal matter, it is now viewed as a collective and public issue, global in nature.

Today, however, our health faces a new threat, more silent and more open-ended: climate change. While its impacts have been discernable for several decades and are becoming more intense and frequent, including natural disasters, extreme weather events, and extended periods of drought, its effects on human health are only now starting to be widely identified as a threat to public health. Internationally the issue is gradually being recognized by politicians, scientists and institutions. For example, a whole section of the most recent IPCC report was dedicated to this topic. Similarly, a day was set aside for the first time to examine the issue at the 2023 Dubai climate change conference (COP 28).

The first part of this issue of FACTS explores the direct harm climate change does to our health. The most obvious impacts result from heatwaves. Particularly visible and devastating, they are a reality in an ever growing number of regions around the world. **Pieter VanCamp** explores the effects on the human body of prolonged exposure to extreme heat, from exhaustion to cardiovascular and respiratory diseases, while also stressing the resources the human body has to ward off these dangers.

Looking beyond the day-to-day, **Cyril Cosme** reminds us that climate change impacts every facet of our lives, including our work. But not all workers are impacted equally. A number of factors come into play, such as the country we find ourselves in, the laws that apply there, and whether or not we work outdoors, when defining workers' degree of exposure to health risks resulting from climate change.

The reality is that climate change is profoundly inequitable in terms of its impacts and health risks. And although nobody is unaffected, some groups are far more vulnerable. Understanding this phenomenon requires examining it in two ways: on a geographical scale (global, regional, and local) as well as a socio-economic scale (population groups, local or national culture, and individual characteristics). **Gina Solomon, Matthew O. Gribble** and **Sheri Weiser** provide an analysis of how geographical and social disparities lead to diverse and complex vulnerabilities, while **Virginia Murray** highlights the role of gender inequality in terms of natural disasters, from risk-reduction to management. The world faces an upsurge in natural disasters, which are already having a major impact on forced migration. According to the UNHCR, in the years from 2008 to 2016 they were responsible for the enforced movement of over 21.5 million people every year. **François Gemenne** argues that climate-driven migration is a present-day problem rather than a risk facing us in the future, and that most so-called economic migration should be understood as climate-driven migration. Climate refugees are on a journey which is already littered with obstacles, and which shifts the nature of their vulnerabilities: people leave a situation that threatens their health to be confronted to new hazards elsewhere. The truth is that there is not one vulnerability, but a series of overlapping, interacting, and interlinked vulnerabilities that together form a particularly complex system of risks.

Nevertheless, there is more to health than the physical and biological well-being of humans. Back in 1946 the preamble to the WHO constitution defined health as a "state of complete physical, mental and social well-being [...]." This is where the difficulty lies when studying the direct impacts of climate change on health, since some impacts are invisible, intangible and poorly understood – while their effects are markedly harmful. **Annamaria Lammel** examines the rise in eco-anxiety, a phenomenon particularly prevalent among younger generations who fear for their futures in the face of climate uncertainties. In response to this growing psychological malaise, **Bruno Rousseau** suggests eco-therapy as a solution, an approach centering on ties with nature as a way to calm climate-related anxieties, ease people's minds and reconnect with nature and the living world.

Environmental health, climate change, and equity:

Understanding geographic vulnerabilities

Gina Solomon: Chief of the Occupational, Environmental and Climate Medicine (OECM) Division at the University of California San Francisco (UCSF),

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Sheri Weiser: Professor of Medicine at UCSF, co-founding Director of the University of California Center for Climate, Health and Equity

Gina Solomon is chief of the Occupational, Environmental and Climate Medicine (OECM) Division at the University of California San Francisco (UCSF). She previously served at the Natural Resources Defense Council, the California Environmental Protection Agency, and the Public Health Institute. Dr. Sheri Weiser is a Professor of Medicine at UCSF, co-founding Director of the University of California Center for Climate, Health and Equity, whose research focuses on the intersections of food insecurity, extreme weather HIV, and chronic diseases, aiming to improve health outcomes in vulnerable populations. Matthew Gribble, Associate Chief for Research in OECM at UCSF, addresses issues related to tribal partnerships, oceans and human health, and climate change and health equity.

Although climate change is affecting the entire planet, local effects differ in both nature and severity according to geography. Some geographic differences are readily apparent – such as the inherent vulnerability of coastal areas to sea level rise – whereas others are emerging. Geographic vulnerabilities are modified by the built environment and by disparities in the ability to adapt to climate change, further complicating the risk across the globe. The complex interactions of climate threats, local geographic and social vulnerabilities, and adaptation can best be explored at the regional level through examples relevant to other regions facing similar issues. This article will describe general principles of geography and climate change risk and explore how these play out using four examples: harmful algal blooms in Alaska, loss of glaciers in Peru, sea level rise causing increased drinking water salinity in Bangladesh, and HIV and food insecurity in Kenya related to extreme weather. The magnitude of the threat to humans from climate change will be significant, and geographic vulnerability is in many ways immutable, but much can still be done by humans to either increase or reduce risk. Lessons from one region can inform strategies in areas across the globe that share similar geographic vulnerabilities.

INTRODUCTION

Health status and lifespan are influenced by geography due to interactions between geographic and social factors, including economics, history, culture, development and migration. Climate change acts as a "threat multiplier", exacerbating vulnerabilities. For example, an area prone to flooding faces higher catastrophic flood risk in the setting of climate change. Feedback loops among climate change, regional climate vulnerability, economic capacity, food and water insecurity, infectious diseases, and migration amplify impacts on human health. Further, human action can either ameliorate or exacerbate these vulnerabilities. The failure of the levees resulting in the flooding of New Orleans in the United States after Hurricane Katrina in 2005 is an example of adaptive failure on a major scale. Understanding geographic vulnerabilities and their interaction with social vulnerabilities and adaptation measures is crucial for developing informed local, regional, and global strategies to protect health and the environment.

OVERVIEW OF GEOGRAPHY, CLIMATE CHANGE AND HEALTH

Shifts in the planetary system

Climate change is driving large-scale physical changes across Planet Earth. The melting of the glaciers has caused a change in the tilt of the Earth's axis increasing earthquake and volcano risks. Ocean currents are affected by warming sea-surface temperatures, with potential impact on local climates. Higher carbon dioxide concentrations in the atmosphere lead to more acidic oceans, as it diffuses into the water and dissociates into carbonic acid. Thus, we are racing toward a world of warmer, more acidic oceans; evolving geological hazards; and changing currents affecting local climates.

The world's ongoing physical and biological changes will interact to produce additional hazards. For example, heavy rains may promote vegetation that is a fire risk in the next drought; and plants dying during droughts may have reduced ability to hold soils in place affecting mudslide risks when it rains again. These changes can result in invasive species and zoonotic disease risks, alter pollen composition, increase poisoning risks (venomous animals, molds, and toxin-producing algae), and create other hazards for people living with nature. An understanding of this complex set of issues requires knowledge of global climate zones and regional factors.

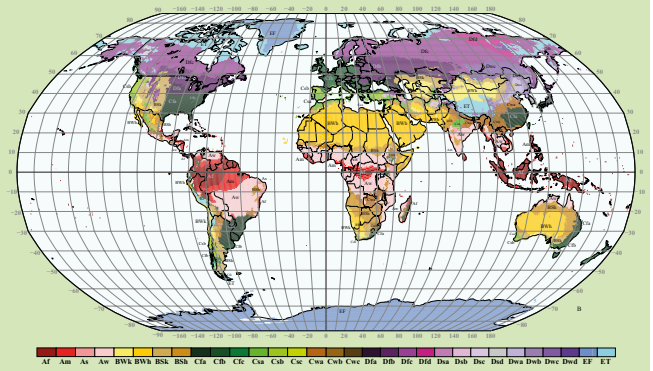
"Climate change is driving large-scale physical changes across Planet Earth."

Global climate zones

German climatologist Wladimir Köppen (1846-1940) divided the world's climates into categories based upon temperature and latitude. These categories have been modified into the Köppen-Geiger climate classification system, which divides the globe into six classifications: A: tropical, B: dry, C: moist subtropical, D: moist continental, E: polar, and H: highland (mountain) climates. Each of these zones can be further classified according to precipitation and temperature patterns.[1] The three-letter combination resulting from the classification system characterizes local climate zones worldwide. ***(Figure 1)***

Widely separated regions of the globe may share the same climate. For example, Mediterranean-type ecosystems (Csa and Csb climate zones), with their characteristic climate of mild, wet winters with hot or warm, dry summers, exist in the Mediterranean, California, Chile, South Africa and South Australia. These areas, although distant from each other, share similar weather, vegetation, and climate vulnerabilities. Lessons from one of these regions may be relevant to the others.

Figure 1: Global climate zones



Source: Köppen-Geiger climate classification. From Kottek, M., J. Grieser, C. Beck, B. Rudolf, and F. Rubel, 2006: World Map of the Köppen-Geiger climate classification updated. Meteorol. Z., 15, 259-263.

The world's climate zones are shifting. Shrinking of the polar icecaps and polar movement of the permafrost line have been well-documented. Desert regions, including the Sahara, are growing, as are drier continental regions. For example, the line between the arid Western climate and the moist Eastern continental climate in the United States has moved about 140 miles eastward since 1980,[2] resulting in shifts between areas where wheat (a more drought-tolerant crop) and corn can readily grow. Farmers can adapt to these shifts with added irrigation, up to a point. Eventually, shifting climate zones will be challenging for farmers to adapt to, as plant hardiness zones are indicated to be moving northward globally at about 13 miles per decade,[3] and invasive plant and insect species also move northward, threatening crops and ecosystems.

The effect of geography on climate vulnerability extends beyond climate zones. Geographic predictors of vulnerability also include elevation above sea level, location relative to the coast and to rivers that may flood. Dike or levee systems can significantly reduce the risk of flooding in these areas, but can also result in secondary harm (e.g., loss of river deltas, increased coastal erosion), as well as increased sediment run-off resulting in "dead zones", both of which are observed today in Coastal Louisiana and the Gulf of Mexico. Engineered systems may also fail catastrophically, resulting in massive loss of life and damage.

1 See details of all categories here: Kottek, M., Grieser, J., Beck, C., Rudolf, B., & Rubel, F. (2006). World map of the Köppen-Geiger climate classification updated. *Meteorologische Zeitschrift, 15*(3), 259–263. https://doi.org/10.1127/0941-2948/2006/0130.

2 Seager, R., Feldman, J., Lis, N., Ting, M., Williams, A. P., Nakamura, J., Liu, H., & Henderson, N. (2018). Whither the 100th Meridian? The Once and Future Physical and Human Geography of America's Arid–Humid Divide. Part II: The Meridian Moves East. *Earth Interactions, 22*(5), 1-24. https://doi.org/10.1175/ei-d-17-0012.1.

3 These maps, based on the average annual minimum temperature of any location, establish predictions about what crops can over-winter successfully in different regions, helping growers determine which perennial plants are most likely to thrive at a location.

Location of a community relative to the wildland-urban interface, related to human incursion on natural areas, is a predictor of risk from wildfires; percentage of ground surface that is paved is a predictor of both flood risk and heat vulnerability. Although communities in similar climate zones share comparable risks from climate change, actual risk can vary significantly based on other local geographic factors and the built environment.

Global geographic impacts of climate change

Climate change is already causing widespread harm to public health, and the impacts will become more severe over the coming decades. It primarily manifests as extreme events, ranging from heat waves to fires, major storms and floods. These events cause direct and indirect health effects through population displacement, conflict over resources, and mental health problems. Although climate change affects everyone, its specific impacts differ, both in nature and in magnitude, by geography. Examples of these disparate impacts across the globe are shown in ***Figure 2***, while specific impacts across the European sub-continent are shown in ***Figure 3***.

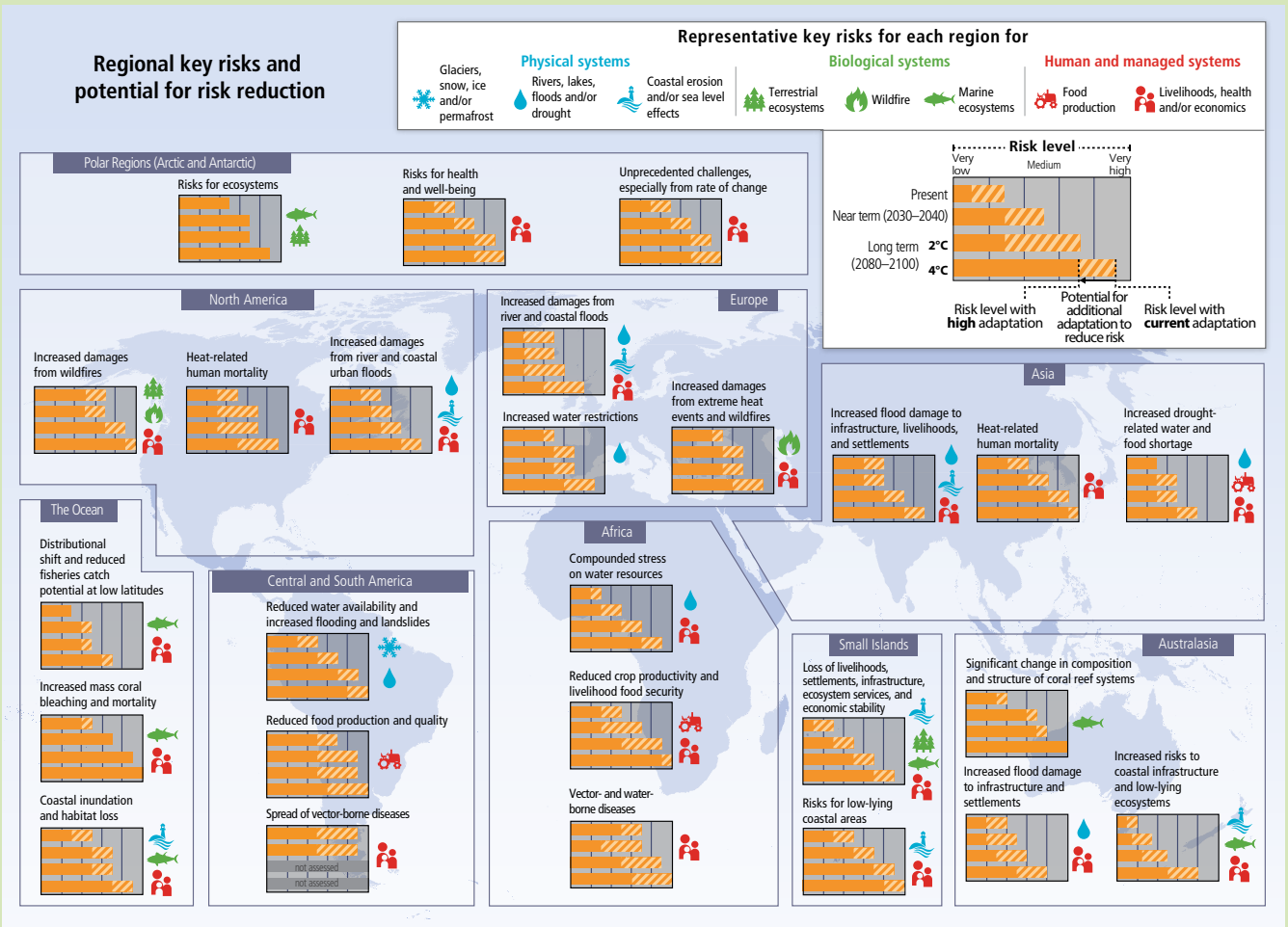
- *Heat:* The most direct effect from climate change is from heat. Average temperatures are rising globally, and extreme heat events will become common. From 2000 to 2019, approximately 489,000 heat-related deaths occurred each year, with 45% of these in Asia and 36% in Europe.[4] Besides, 60% of global episodes of health-threatening temperatures were made more than twice as likely to occur by human-caused climate change.[5] Some areas of the globe, mainly in South Asia and the Persian Gulf, already experience temperatures in excess of the "noncompensible heat threshold"[6] at least once per decade. The areas at risk are predicted to expand to encompass as much as 25% of the globe with 2.0 degrees Celsius of warming.

4 World Health Organization: WHO. (2024, May 28). *Heat and health.* https://www.who.int/news-room/fact-sheets/detail/climate-change-heat-and-health.

5 Lancet Countdown: Heat-Related mortality. (2023, November 15). https://www.lancetcountdown.org/data-platform/health-hazards-exposures-and-impacts/1-1-health-and-heat/1-1-5-heat-and-sentiment.

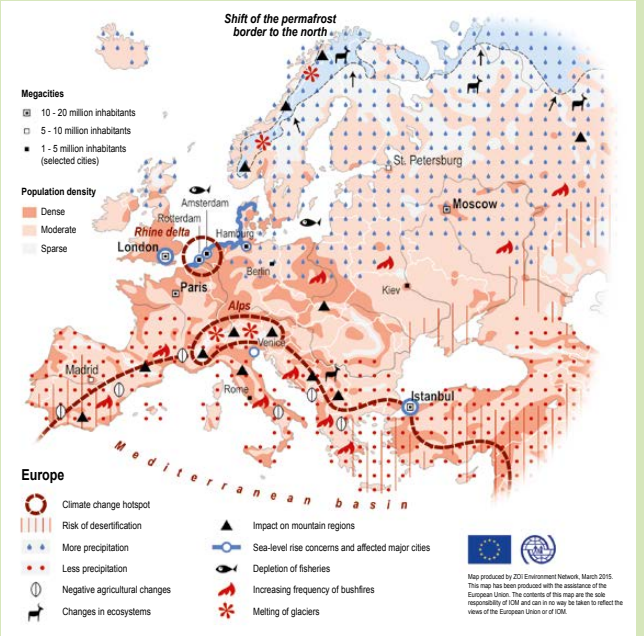
6 This threshold is a combined calculation of temperature and humidity that is predicted to cause death after six hours of unmitigated exposure.

Figure 2: Regional risks of climate change worldwide



Source: IPCC, 2014: Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, R.K. Pachauri and L.A. Meyer (eds.)]. IPCC, Geneva, Switzerland, 151 pp.

Figure 3: Climate change across the European sub-continent



Source: IOM UN Migration, https://environmentalmigration.iom.int/resources/europe-and-africa.

- *Extreme Weather and Coastal Damage:* Increased heat causes turbulence in the earth's atmosphere. This energy can manifest as dramatic weather fluctuations, including more violent storms. Sea level rise will result in inundation of low-lying coastal areas, destruction of coastal wetlands and mangroves, and erosion of coastal bluffs, especially during high tides and storm surges. Tropical cyclones are projected to become more powerful due to warming oceans. Taiwan, Japan, the Philippines, Southeast China, Southern India, Mexico, the Caribbean, the Southeastern U.S. and Northwest Australia, already vulnerable to these major events, are all the more exposed to severe storms.
- *Wildfires:* A warming climate places enormous stress on many species of trees, as weather conditions become too warm and either too wet or too dry for the climate to which the forests are adapted. Stressed trees are more susceptible to fungal infestations and pests. The combined stresses of heat, drought and infestations kill large numbers of trees, while so-called "ladder fuels" such as grasses and shrubs become more prevalent. Forest stress is fueling fires in places ranging from Australia and Indonesia to Canada.
- *Water Insecurity:* Today, 2.4 billion people live in water-stressed countries.[7] The water stress in parts of Southern and Central Asia and North Africa is already critical. Within the next few years, 1.8 billion people are likely to face critical water scarcity and two-thirds of the global population is expected to be in water-stressed countries. Drought can lead to malnutrition and dehydration, which can impair immune response and increase susceptibility to infections.
- *Flooding:* Flooding can increase the spread of water-borne illnesses like cholera and cause direct injury and death. At least 15% of all deaths related to natural disasters are due to floods, which are particularly harmful for elderly and disabled people who are less able to evacuate before a major storm. Testing after flooding in Louisiana and Texas revealed toxic petroleum chemicals, heavy metals, and pesticides in the sediment left behind in flooded neighborhoods.
- *Food insecurity:* Nearly one in three people globally did not have access to adequate food in 2020. Of these, nearly 40% faced severe food insecurity.[8] Roughly half of people experiencing food insecurity are in Asia, one-third are in Africa, and 11% are in Latin America and the Caribbean. A recent study[9] based on data from 83 countries found that every 1°C increase in local average temperature over time led to a 1.6% increase in moderate to severe food insecurity.
- *Migration:* Climate change is expected to drive the largest mass movement of people in human history. While estimates vary, it is predicted that approximately 200 million people in climate-vulnerable areas of the world will be forced to migrate by 2050.[10] A feedback loop can emerge wherein the inability to meet food and other basic needs forces people to migrate, and the challenges arising from displacement, including homelessness and poverty, amplify hunger further. Migration also places political stress in 'receiving' geographic areas, which can result in political instability and conflict.
- *Inequality:* Climate change amplifies existing disparities, leading those who contribute the least to greenhouse gas emissions (GHG) to suffer first and worst from its harmful health effects. These populations have greater exposure due to deprivation and injustices like racism and colonialism. Countries with the highest per-capita GHG emissions (i.e., the greatest consumers), including the U.S., Canada, Australia, and Russia, also have the lowest mortality linked to climate change. Meanwhile, Southern American and African countries, which have some of the lowest per-capita emissions, suffer some of the highest climate-related mortality rates.

> *"60% of global episodes of health-threatening temperatures were made more than twice as likely to occur by human-caused climate change."*

7 Nations that withdraw 25% or more of their renewable freshwater resources to meet water demand (Water Scarcity | Land & Water | Food and Agriculture Organization of the United Nations. (s. d.). https://www.fao.org/land-water/water/water-scarcity/en/).

8 Food and Agriculture Organization, International Fund for Agricultural Development, United Nations Children's Fund, World Food Programme, & World Health Organization. (2021). *The state of food security and nutrition in the world 2021: Transforming food systems for food security, improved nutrition and affordable healthy diets for all.* Food and Agriculture Organization. https://doi.org/10.4060/cb4474en.

9 Dasgupta, S., & Robinson, E. J. Z. (2022). *Attributing changes in food insecurity to a changing climate.* Scientific Reports, 12(1). https://doi.org/10.1038/s41598-022-08696-x.

10 International Organization for Migration. (2023, October 9). *IDM second session 2023 - Think about tomorrow, act today: The future of human mobility and climate change.* International Organization for Migration. https://www.iom.int/international-dialogue-migration-2023-think-about-tomorrow-act-today.

GEOGRAPHIC CASE STUDIES

Harmful algal blooms in Alaska

Paralytic shellfish poisoning (PSP) is an acute syndrome that has a range of presentations from mild (e.g., tingling around the lips), to moderate (e.g., temporary paralysis of the limbs), to severe (e.g., paralysis of the lungs resulting in death). PSP is caused by a type of harmful algal bloom (HAB) that occurs worldwide in temperate waters and is worsening as oceans warm. Shellfish are filter-feeders and accumulate the toxin, resulting in potential poisoning of animals and humans that consume them. This problem is of particular concern for Alaska's native communities as they rely on traditional foods such as butter clams and have been subject to recent outbreaks of PSP.

In response to the growing health threat, native communities around the Gulf of Alaska have banded together to provide scientific leadership on PSP prevention. The Southeast Alaska Tribal Ocean Research Consortium (SEATOR) coordinates efforts across the Gulf of Alaska to monitor for toxin risks, and the Sitka Tribe of Alaska Environmental Research Lab provides toxin testing services both for the larger monitoring program and for individual community members who want their shellfish tested for safety.

At a global level, the Intergovernmental Oceanographic Commission (IOC) has a Harmful Algal Blooms Programme that coordinates global scientific knowledge-sharing to advance community resilience (developing solutions such as early warning systems). While HABs are natural, their occurrence is a function of nutrients and temperature. Many HABs are problematic due to oxygen depletion from decaying algae, causing massive fish kills. Others produce toxins that can devastate fish, birds and marine mammals, and harm humans. HABs affect coastal areas and island nations worldwide ***(Figure 4***).

Figure 4: **Harmful algal blooms worldwide**

Source: IOC-UNESCO Harmful Algae Information System, https://data.hais.ioc-unesco.org/.

Loss of glaciers and water scarcity in Peru

The Cordillera Blanca has the largest area covered by glaciers in the tropics. This mountain range has lost almost half of its glaciated area since the early 20th century. Catastrophic and unpredictable flooding from melting and failure of ice dams that hold back the nearly 900 glacier lakes in the region have caused massive damage and killed livestock and people. Most worrisome is the fact that the peak flow from melting glaciers has already passed, meaning that there will be decreased flow in glacier-fed streams, which threatens the availability of fresh water for agriculture, livestock and drinking water.

Populations in Peru have been moving from inland mountain and jungle areas to the coast, where 70% of the population now lives. These migrants are ending up in large shanty towns on the outskirts of Lima, the capital city. These shanty towns, housing 1.3 million inhabitants, have no water, sewage or electricity. Water deliveries occur sporadically from tanker trucks, and residents must pay to obtain a small amount of water, which is often contaminated, and has been associated with outbreaks of cholera, dysentery, hepatitis, typhoid fever and diarrheal disease. Sufficient water is often not available for food preparation or hygiene.

In coastal South America, some communities are collecting water from coastal fog, an ancient practice used by the Incas. Today they use "fog catchers" that are made of inexpensive nylon, propylene or polyethylene mesh that catch fog droplets and collect the water in a reservoir for filtering. Depending on location and weather conditions, these fog collectors can be very effective, collecting about 20L of fresh water per square meter of cloth per day. Today, over 2,000 fog catchers have been installed in Peru by the NGO *El Movimiento Peruanos sin Agua*.[11]

Sea level rise and salinity in drinking water in Bangladesh

Much of the world population lives near the ocean, where climate change threatens water supplies. Surface waters and groundwater are impacted by storm-surge flooding. In unconsolidated coastal aquifers, intrusion of salty ocean water into the drinking water supply is a major problem, especially where there is over-pumping of groundwater wells. Coastal subsidence can couple to saltwater intrusion, greatly increasing the salinity of groundwater supplies.

Since salt intake is a major risk factor for hypertension, this could be an important dimension of the cardiovascular harm of climate change. The Government of Bangladesh and the United Nations International Children's Emergency Fund (UNICEF) attempted to address increasing drinking water salinity in southwest coastal Bangladesh by introducing managed aquifer recharge to some communities.

11 The Peruvians Without Water Movement.

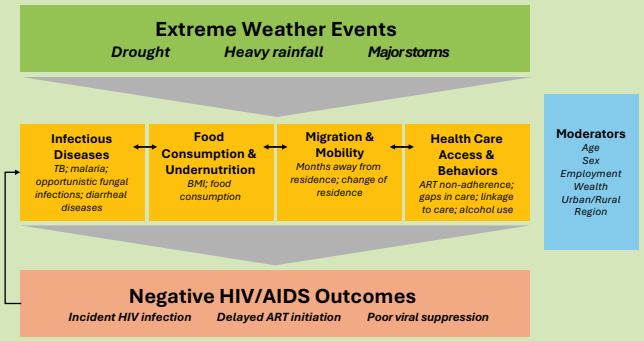
The experiment was only partially successful, illustrating the limitations of engineered solutions. While the provided water was less salty than untreated groundwater, the drinking water source that had been previously consumed by some participants was fresher (rainwater and pondwater) than the provided alternative, but it is also vulnerable to surface inundation.

Drought, food insecurity and HIV in Kenya

Kenya has been suffering increasing frequency of drought and excessive rains in the setting of climate change. This is especially problematic in the counties in the Nyanza region, bordering Lake Victoria in western Kenya, which also have the highest prevalence of HIV/AIDS in the country and made up nearly half of HIV cases nationwide in 2018.[12] Despite unreliable rainfall patterns, the region is dependent on agriculture, and few income-generating alternatives exist. Drought and excessive rains in Kenya have been found to worsen HIV health along four key pathways: increased incidence of infectious diseases, food insecurity/undernutrition, migration and mobility, and alterations in health care access and behaviors ***(Figure 5)***.

> *"Droughts and excessive rains in Kenya have been found to worsen HIV health along four key pathways: increased incidence of infectious diseases, food insecurity/undernutrition, migration and mobility, and alterations in health care access and behaviors."*

Figure 5: Associations between weather extremes and HIV/AIDS



Source: Lieber M, Chin-Hong P, Whittle HJ, Hogg R, Weiser SD. The Synergistic Relationship Between Climate Change and the HIV/AIDS Epidemic: A Conceptual Framework. AIDS Behav. 2021 Jul;25(7):2266-2277. doi: 10.1007/s10461-020-03155-y.

- *Increased infectious diseases:* People living with HIV reported more infections from cold and wet living conditions during floods, increased diarrhea outbreaks from contaminated flood waters, and increased incidence of malaria from stagnant waters during both floods and drought.
- *Undernutrition:* Extreme flooding and drought worsened food insecurity and diet quality. These changes were documented to contribute to weight loss in all age groups and stunting in children.
- *Migration and mobility:* Migration drives poor HIV outcomes through reduced access to services, and lower adherence to treatment. In Kenya, floods were a major contributor to migration due to destroyed crops, homes and infrastructure.
- *Health care:* Participants reported that infrastructure damage (e.g., roads) from storms and flooding undermined their ability to access medical facilities, which led to treatment non-adherence, and negatively impacted their health.

Climate-adaptive regenerative agriculture holds promise as a way towards sustained improvement of household income and HIV health in Kenya. In the Nyanza region across 16 health facilities, we carried out an intervention that included a farming loan to purchase agricultural implements, a human-powered water pump, seeds, and fertilizers, and training in financial management and sustainable agricultural practices. Among over 700 participants living with HIV, the study found improvements in household food security, measures of women's empowerment, mental health, social support, and physical health status. The researchers also saw reductions in intimate partner violence and HIV stigma. Among adolescents living in the household, there was improved nutrition and sexual and reproductive health, and children under five exhibited improved growth and development.

CONCLUSION

Complex interactions between global climate zones, topography, other local geographic factors, the built environment, economic and social factors result in different climate threats, vulnerabilities and potential solutions across the globe. Successes in one region may translate to other regions that face similar climate threats. Although engineered solutions can work to address some threats in some regions for some period of time, they have the potential for catastrophic failure. Solutions that build on local practices, further local traditions, and provide economic benefits can improve both health and resilience. Because climate change is a threat-multiplier, it tends to exacerbate existing social and economic inequities. Efforts to address climate change should therefore also focus on improving equity and protecting health.

12 National Aids Control Council, & Tum, P. K. (2018). *Kenya HIV Estimates Report 2018.* https://nsdcc.go.ke/wp-content/uploads/2018/11/HIV-estimates-report-Kenya-20182.pdf.

Can the human body cope with extreme heat in a changing climate?

Pieter Vancamp
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Pieter Vancamp is a neurobiologist and physiology specialist affiliated with the French Research Institute for Agriculture, Food, and Environment (INRAE). He obtained his Ph.D. from the Catholic University of Leuven in 2018, and his expertise in scientific research spans three international laboratories. In recognition of his contributions to neuroendocrinology research, he was honoured with the Early Career Research prize by the French Society for Neuroendocrinology in 2023. Beyond his academic pursuits, Vancamp has contributed to numerous articles tailored for a diverse readership, with a particular focus on the effects of heat on the human body, aiming to raise awareness and foster understanding among the general public.

The scorching summer of 2022 left a devastating trail of 61,000 lives lost across Europe,[1] illustrating the human body's vulnerability to extreme heat. But amidst this tragedy arises a compelling question: how does the human body defy incineration under the assault of a 40°C summer sun? What arsenal of defences does it wield to brave such extreme conditions? Let's discover an incredible journey through the body and its perfectionated physiology to safeguard our survival regardless of the temperature's merciless whims. It is a breathtaking showcase of nature's ingenuity.

Yet, even the most formidable defences have their breaking points. When does this finely tuned orchestra falter, and how does the scorching heat transform from a mere discomfort to a lethal threat? In the light of climate change, these questions loom large. With record-breaking temperatures signalling the onslaught of more frequent and severe heatwaves, one cannot help but wonder: can our bodies endure the relentless march towards a hotter world? And how can we best anticipate to protect ourselves and our peers?

INTRODUCTION

Climate change is a stark, undeniable reality. The seemingly modest rise of 1.5°C in global temperatures has already wrought significant changes, such as the intense heatwaves that have hit the European main lands over the last years. In France, for example, out of 47 heatwaves experienced since 1947, 22 have occurred since 2010.

These events highlight the profound impact of extreme heat on human health. The 2003 heatwave that swept across Europe and caused over 70,000 additional deaths, remains vividly remembered.[2] A global analysis attributes 37% of heat-related fatalities between 1991 and 2018 to climate change.[3] Future projections suggest even more extreme heatwaves and increased heat-related illnesses and mortality, particularly if global temperatures were to climb above the 2°C threshold.

Beyond the death tolls, heat exposure affects everyone. Symptoms of heat distress range from minor discomforts to more serious illnesses. How does the human body endure extreme heat? Let's delve into the mechanisms through which our body deals with intense warmth, and discover at what point things take a turn for the worse.

1 Ballester, J.,et al. (2023). *Heat-related mortality in Europe during the summer of 2022.* Nature Medicine, 29(7), 1249-1259. https://doi.org/10.1038/s41591-023-02419-z.

2 Robine, J. M., et al. (2008). *Death toll exceeded 70,000 in Europe during the summer of 2003.* Comptes Rendus Biologies, 331(2), 171–178. https://doi.org/10.1016/j.crvi.2007.12.001.

3 Vicedo-Cabrera, A. M., et al. (2021). *The burden of heat-related mortality attributable to recent human-induced climate change.* Nature Climate Change, 11(6), 492-500. https://doi.org/10.1038/s41558-021-01058-x.

THE PERFECT TEMPERATURE

The human body stands as a masterpiece of nature's design. Within its confines, billions of cells work in harmony tirelessly, ensuring our seamless journey through each day, allowing us to focus on life's more significant endeavours. Yet, this intricate choreography is contingent upon optimal conditions for cells and their enzymes to function. One critical parameter for our mental and physical well-being, and fundamental to survival, is a core temperature of precisely 36.8°C. There is no margin for error. Recall the discomfort experienced when even a slight increase of 1 or 2 degrees is displayed on the thermometer during your body's battle against an unwelcome viral or bacterial intruder.

That however, is a temperature increase governed by the body, called fever. It is for our own good. During prolonged periods of extreme heat or strenuous physical activity on the other hand, there is a risk of the temperature escalating uncontrollably, above levels that are tolerable for cells, threatening the proper functioning of vital organs. If our core temperature were to exceed about 43°C, mere minutes would stand between life and death due to the incineration of cells and proteins on a microscopic scale.

Fortunately, over millions of years of evolution, our bodies have developed sophisticated physiological defence mechanisms to keep their internal temperature stable, regardless of external conditions. This inherent ability, known as thermoregulation,[4] is indispensable for our daily survival, and it is our physiological armour to resist violent heatwaves.

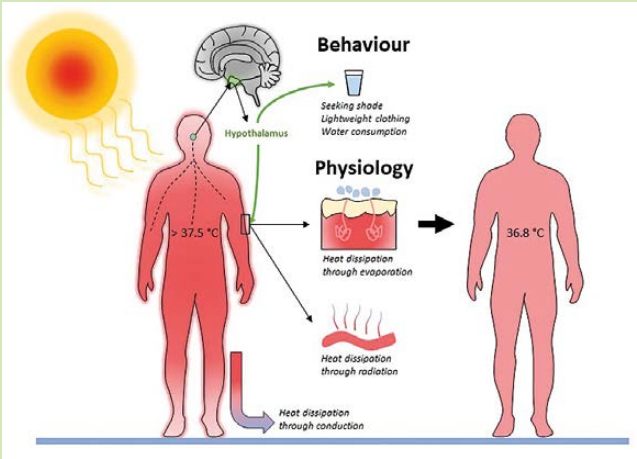
OUR BODIES REACTING TO HEAT - SWEATY FOREHEADS AND RED CHEEKS

The primary mechanism for cooling is sweating. When the core temperature increases, the hypothalamus, a specialized brain centre overseeing the body's vital functions, jumps into action. It controls the activation of somewhat 2-4 million sweat glands distributed throughout our skin, producing the salty substance. As sweat evaporates, it absorbs heat from the skin, thus aiding in the body's cooling process. Covering an expansive two square meters, heat dissipation by sweating via the skin is the principal way of keeping our core temperature at its precise equilibrium of 36.8°C. Sweating profusely can result in a significant loss of fluids, up to a liter per hour, causing the typical sweaty foreheads and armpits, the body locations where sweat glands are densely present.

> *"One critical parameter for our mental and physical well-being, and fundamental to survival, is a core temperature of precisely 36.8°C."*

Fluid loss also triggers a response in the kidneys with as primary goal to reduce unnecessary water loss. This is partly governed by the hypothalamus sending a special hormone called *anti-diuretic hormone*, stimulating the kidneys to recuperate water from urine being produced. As a consequence, the urine gets more concentrated, and turns from lightly yellow into dark yellow, an important sign your body needs a water refill! Alcohol consumption inhibits the production of this hormone, and therefore aggravates fluid loss in hot conditions. Hence the advice to reduce consumption at the warmest hours of the day.

Figure 1: Principal mechanisms by which the human body maintains a core temperature of 36.8°C when exposed to intense heat



Source: Pieter Vancamp.

In tandem with sweating, vasodilation occurs, wherein blood vessels near the skin's surface expand, facilitating the release of heat to the surrounding environment through radiation. There is another sign of the body fighting to keep our inside at the magical 36.8°C: red cheeks and flushed foreheads. Some hormones such as adrenaline, released when you're nervous, also expand blood vessels, and give you red cheeks as well. Additionally, a shallower and more rapid breathing pattern enables the exchange of heat for cooler external air.

Lastly, our brain also prompts us, often subconsciously, to help cooling down the body and minimize exposure to heat. Fluid loss triggers a behavioral reflex to drink more. Other adaptations comprise actions such as seeking shade and donning lightweight clothing. Molecules produced in our bodies' extremities during intense heat travel through the bloodstream and function as messengers to inform the hypothalamus it's time to refrain from strenuous physical exertion. That's why we have a feeling of general fatigue when it is hot outside. Taking a lukewarm shower or lying on a chilled surface, behaviours also often observed in animals, are other ways of efficiently guiding heat

4 Cramer, M. N., et al. (2022). *Human temperature regulation under heat stress in health, disease, and injury.* Physiological Reviews, 102(4), 1907-1989. https://doi.org/10.1152/physrev.00047.2021.

away from the body. Additionally, modern technology offers us some welcomed assistance: air conditioning, for example, accelerates the evaporation of sweat, enhancing our comfort in high temperature environments.

THE BODY'S LIMITS TO WITHSTAND HEAT

During a heatwave, these highly efficient physiological mechanisms (we can tolerate virtually every climate and live anywhere on planet Earth!) may become overwhelmed or less effective due to the prolonged and intense heat exposure. In the face of extreme hot conditions, the body's resilience is tested, with particular strain placed on two vital organs: the heart and the brain.[4]

The demand for sweating to cool the body may exceed the body's capacity to produce sweat or evaporate it efficiently. Loss of fluids and salts can lead to dehydration and electrolyte imbalances. The latter can precipitate painful muscle cramps. Fluid loss combined with prolonged dilation of blood vessels can lead to a drop in blood pressure, compromising blood flow to vital organs. This loss prompts the heart to intensify its efforts, beating faster and more forcefully to maintain circulation. But it can only work with what it has in hand, and if fluid levels do not return to normal, the strain on the heart can worsen, and its functioning deteriorate.

"In a 2016 study, researchers found that young, healthy students were more than 10% slower and less accurate on cognition tests when they were exposed to a warmer indoor environment during a heatwave."

Consequently, reduced oxygen delivery to the brain ensues, manifesting in symptoms such as dizziness, weakness, fainting, and cognitive impairment. Before we hover into the danger zone, however, heat can already negatively affect our mental performance. Even moderate heat exposure during prolonged periods can reduce work efficiency, and increase the rate for errors. In a 2016 study, researchers found that young, healthy students were more than 10% slower and less accurate on cognition tests when they were exposed to a warmer indoor environment during a heatwave.[5] That is because nerve cells, the cells in the brain that help us to think and act, consume enormous amounts of energy and oxygen. In too warm conditions, they have difficulties regulating this energy expenditure, and start to misfire signals to their neighboring cells, resulting in unclear communication to our bodies.

More severe neurological manifestations such as confusion and fainting, coupled with an accelerated heart rate, dark urine, red cheeks and sweating, are hallmark indicators of heat exhaustion, a condition that increases the risk of heat-related illnesses and raises warning sign for worse to come if not acted upon.

The situation can deteriorate swiftly. When someone experiences heat exhaustion, immediate action is imperative. The person must be escorted to a cool, shaded area, encouraged to hydrate, take up electrolytes (often abundantly found in sport drinks), and provided with methods to lower body temperature, such as cool water or ice packs – most efficient in places where large blood vessels pass, such as in the armpits and inner legs.[4] Vigilant monitoring for escalating symptoms – such as a changed personality or vomiting – is essential. Without intervention, the body's core temperature may escalate to perilous levels, compromising vital organs' functionality. In extreme cases, the fluid reservoirs being empty, the person typically ends up not sweating anymore, despite the extreme heat.

Eventually, the body reaches a tipping point where it can no longer withstand the stress, resulting in organs shutting down, one after another. This progression marks the onset of a heat stroke, demanding urgent medical attention for any hope of recovery. It is not surprising that, during heatwaves, a surge in hospital admissions for heat-related illnesses can be observed. For instance, on hot days when the temperature exceeded 31°C, the Royal Hobart Hospital in Australia noticed a threefold increase in the relative risk of hospital admissions (study conducted for the years 2003-2010).[6]

WHY WE ARE NOT ALL AFFECTED IN THE SAME WAY

Heat can place significant stress on the body's innate ability to regulate temperature, heightening the risk of heat-related health complications. However, susceptibility varies among individuals; some people seem unaffected by the heat and seem like they could run a marathon, while others can hardly leave their home to face the burning sun. In addition, geography matters: sun and heat exposure are not the same in southern Spain or on the cool Belgian coast. Hence, what determines an individual's susceptibility?

Broadly, two factors dictate one's tolerance to heat.[4] Firstly, environmental conditions play a pivotal role. Elevated humidity, for instance, hinders the evaporation of sweat, which is crucial for cooling the body. Canadian researchers in 1965 have devised the Humidex,[7] an informative table that gives an idea of the perceived temperature by integrating both outside temperature and humidity levels. For example, at outdoor temperatures of 30°C and 70% humidity, the humidex equals 41, a dimensionless number indicating

5 Cedeño Laurent, J. G., Williams, A., Oulhote, Y., Zanobetti, A., Allen, J. G., & Spengler, J. D. (2018). Reduced cognitive function during a heat wave among residents of non-air-conditioned buildings: An observational study of young adults in the summer of 2016. *PLoS medicine, 15*(7), e1002605.

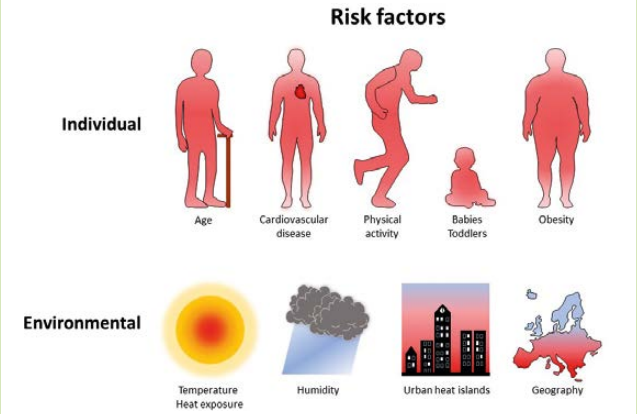
6 Watson, K. E., Gardiner, K. M., & Singleton, J. A. (2020). The impact of extreme heat events on hospital admissions to the Royal Hobart Hospital. *Journal of public health (Oxford, England)*, 42(2), 333–339.

7 Centre canadien d'hygiène et de sécurité au travail (CCHST), *Indice humidex et le travail.*

'great discomfort, avoid exertion'. Looking at the table, that level of discomfort corresponds to a temperature of 39°C in dry conditions (20% humidity).

Other environmental factors include the way we are exposed to heat based on our living environment: urban areas with high levels of concrete and asphalt, the so-called *urban heat islands*, can cause nighttime temperatures to remain elevated due to the retained heat from buildings and pavement. This reduces the body's ability to dissipate heat during the cooler nighttime hours, prolonging exposure to heat stress.

Figure 2: Individual and environmental risk factors dictating one's tolerance to heat



Source: Pieter Vancamp.

Individual factors inherent to each person's physiology also play a crucial role. Age, in particular, is a significant determinant. Statistics consistently reveal that more than two-thirds of the heat-related fatalities occur among individuals aged 65 years or older. Due to the global aging population, researchers expect an even sharper rise in heat-related fatalities in the future.[8] Particularly vulnerable as well are toddlers and infants. They share a common trait with the elderly: their thermoregulatory systems are not as efficient as those of healthy adults. They may need reminders to stay hydrated, as their cognitive functions, including awareness of thirst, may not be responsive. However, a significant number of people under the age of 75 are victims, signifying no one is completely exempt from any risk.

"Statistics consistently reveal that more than two-thirds of the heat-related fatalities occur among individuals aged 65 years or older. Due to the global aging population, researchers expect an even sharper rise in heat-related fatalities in the future."

Heat-related mortality is also higher among women. Data collected during the 2022 summer heatwave in Europe shows 56% more heated-related deaths victims among women than men, but this is probably due to women's life expectancy being longer than men's.

Engaging in strenuous physical labor or vigorous activity is strongly advised against during the hottest hours of the day. Such activities can elevate internal metabolism by up to 10-fold, resulting in the generation of excessive heat—an outcome particularly undesirable in hot conditions. In recognition of this risk, Spain has recently amended its legislation, banning individuals from performing heavy-load work in the afternoon whenever the national weather institute AEMET issues an alert for extreme high temperatures.[9]

Additionally, individuals diagnosed with cardiovascular conditions, often the elderly, are particularly vulnerable. Their capacity to compensate for fluid loss is markedly reduced compared to healthy adults, resulting in diminished resilience to heat stress.[4] Moreover, those with metabolic diseases, notably obesity, are at heightened risk from heat exposure. Increased corporal mass augments heat storage capacity, while the presence of more fat tissue in the skin acts as insulation, hindering heat dissipation to the surroundings.

ANTICIPATING WHAT IS TO COME

It is clear, heat can strain the body's natural thermoregulatory mechanisms, leading to increased risks of heat-related health issues, particularly among vulnerable populations such as the elderly, infants, and individuals with pre-existing health conditions. Hence it is no surprise that models predict an increase in heat-related mortality worldwide due to more intense heat waves coupled to climate change.[10] Even typical behavioral adaptations such as seeking shade or wearing lightweight clothing may provide inadequate relief from the heat. Southern countries are particularly affected, rendering some regions uninhabitable. Climate models based on empirical data predict that a 2°C increase in global temperatures above pre-industrial levels could frequently create conditions that surpass human heat tolerance for billions of residents in the Middle East, India, eastern China, and sub-Saharan Africa.[11] Already now India faces a 30-fold higher risk of experiencing extreme heat waves. Considering humidity as an aggravating factor, by 2050, the country is expected to be one of the first where weather conditions become incompatible with human survival. Such evolutions are also likely in several countries of the European continent.

8 Falchetta, G., et al. (2024). Global projections of heat exposure of older adults. *Nature Communications*, 15(1), Article 47197. https://doi.org/10.1038/s41467-024-47197-5.

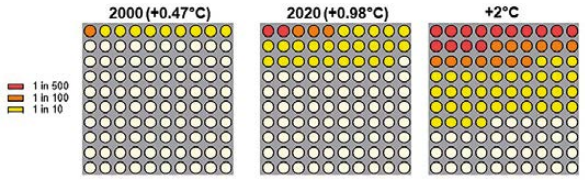
9 20minutos. (2023, May 10). El Gobierno prohibirá este jueves trabajar al aire libre cuando haya olas de calor extremo [The government will ban outdoor work during extreme heat waves this Thursday]. *20minutos*. https://www.20minutos.es.

10 Gasparrini, A., et al. (2017). Projections of temperature-related excess mortality under climate change scenarios. *The Lancet Planetary Health*, 1(9), e360-e367. https://doi.org/10.1016/S2542-5196(17)30156-0.

11 Vecellio, D. J., et al. (2023). Greatly enhanced risk to humans as a consequence of empirically determined lower moist heat stress tolerance. *Proceedings of the National Academy of Sciences*, 120(42), e2305427120. https://doi.org/10.1073/pnas.2305427120.

As an example, if climate change persists at its current pace, alarming reports warn that numerous regions of the Southern Spanish mainland may transform into arid deserts, potentially inflicting irreversible damage on the local ecosystem.[12]

Figure 3: Expected occurrence of extreme heat-related events in a warmer climate as exemplified for Paris, France[13]



Source: Pieter Vancamp, based on data from Lüthi *et al.*, 2023 - *Nature Communications* - Rapid increase in the risk of heat-related mortality.

Although native people residing in warmer climates for generations may possess physiological adaptations and are thus more protected, they too become increasingly vulnerable the more weather events get extreme. Adaptive physiology has its limits, even to the fittest individuals. To escape life-threatening weather conditions, human populations, like other large mammals, often migrate to cooler regions, leading to significant political consequences. For example, the increased frequency of extreme heat, hurricanes, droughts and crops losses in Latin American countries is driving more people towards the United States than ever before.[14] As a consequence, in addition to standard measures like reducing greenhouse gas emissions to mitigate climate change, proactive steps must be taken at the international level to anticipate and safeguard populations over the coming years. Fortunately, there is no need for panic, as collective efforts have demonstrated a swift ability to innovate and implement solutions aimed at protecting our communities.

CONCLUSION

The last years have given us a foretaste of how extreme heatwaves take their toll on human life. Future projections suggest climate change will make these even more severe and frequent, posing a significant threat to public health. Amidst these challenges, it is crucial to recognize the remarkable adaptability of the human body. When not pushed beyond its limits, it can endure prolonged periods of intense heat.

A key takeaway is the importance of listening to our body's physiological signals (e.g., thirst, reddening skin). By heeding these cues, we can better care for vulnerable individuals (e.g., the elderly, pregnant women, pets). Adopting simple strategies, such as scheduling running sessions during cooler morning hours, can help mitigate individual risks associated with heat exposure.

In the meanwhile, only an international collaborative and coordinated effort can put the brakes on global warming and curb associated risks. Scientists and policymakers are actively engaged in raising public awareness, devising prevention plans, and implementing educational initiatives to prepare for anticipated challenges. Past experiences provide valuable lessons. For instance, since 2006, France has implemented heat warning systems to proactively address heat-related health issues.[15] Thoughtful urban design can also play a key role in combating extreme heat. Initiatives such as integrating green spaces to absorb heat and installing water fountains – as seen in preparation for the Olympic Games in Paris – provide accessible means to support the body's thermoregulation. These simple yet effective measures safeguard human physiology during future heatwaves, minimizing unnecessary loss of life.

12 Guiot, J., & Cramer, W. (2016). Climate change: The 2015 Paris Agreement thresholds and Mediterranean basin ecosystems. *Science*, 354(6311), 465-468. https://doi.org/10.1126/science.aah5015.

13 This figure represents the expected evolution in the occurrence of extreme heat-related events-in terms of mortality-for Paris, France in 2000 and 2020 (with average temperatures respectively up +0.47 and +0.98°C compared to the pre-industrial period (1850-1899)) and compares it to a potential +2°C increase in temperatures above pre-industrial average (limit set by the 2015 Paris Agreement). Extreme heat-related events that occurred once every 500 years in in the year 2000 would on average occur 14 times per 100 year in a world that is 2°C warmer.

14 Lakhani, N. (2021, November 1). "'So many have gone': Storms and drought drive Guatemalans to the US border." *The Guardian*. https://www.theguardian.com/world/2021/nov/01/guatemala-storms-drought-climate-migrants.

15 Pascal, M., et al. (2006). France's heat health watch warning system. *International Journal of Biometeorology*, 50(3), 144–153. https://doi.org/10.1007/s00484-005-0003-x.

Dhaka Bangladesh 30 April 2024,
40 degrees Celsius. In such a situation,
at-risk drivers take a rest in the shade to relieve the heat.

Understanding, anticipating and managing health risks linked to climate migration

François Gemenne
Political scientist and researcher, specialist in climate policies and international and lead author for the 6th Assessment Report of the IPCC

François Gemenne, a specialist in climate policies and international migration, is a professor at HEC Paris where he is the academic director of the "Sustainability and social innovation" master's degree. He is a lead author for the 6th Assessment Report of the IPCC and a senior research associate at the University of Liège, where he heads the Hugo Observatory, a research lab focusing on environmental deterioration and migration. Recipient of a Fulbright scholarship to pursue research at Princeton University, he has also authored several books, including **L'écologie n'est pas un consensus [Ecology is Not a Consensus]*, (Fayard, 2022) and* On a tous un ami noir [We All Have a Black Friend]*, (Pluriel, 2022).***

In this interview, François Gemenne discusses the specific challenges facing climate refugees, who are often wrongly differentiated from economic refugees. These migration movements are driven by sudden disasters (storms, floods, etc.) and incremental changes (rising sea levels, soil impoverishment, etc.) that are heightening the vulnerability of certain regions. Health problems, whether physical or mental, are omnipresent at every stage of these refugees' journeys – all the more when they are women – from the moment the disaster strikes to when they arrive in a new host country.

Constructing policies to adapt to and manage these new flows requires taking account of a number of subjective factors. People's perceptions of the effects of climate change often have a greater influence on their choice to leave than objective reality. Health, associated with push factors that encourage people to leave, such as the appearance of new diseases, and pull factors that draw refugees toward certain locations, such as access to healthcare, is embedded in a complex web of factors behind the decision to leave. Given this reality, countries can decide to consider and organize these flows in terms of an adaptation strategy, instead of a failure to adapt. Migration can improve the health and security of refugees, but also more broadly the health and security of people in host and home countries.

How would you describe the phenomenon of climate migration? What is the nature and scale of displacements caused by this phenomenon?

We tend to think of the phenomenon of climate migration as a future risk, leading us to neglect the realities of today. However, the scale of climate-related displacements is already striking: in 2023 alone there were over 26 million internal displacements caused by climate disasters, according to the IDMC.[1] This sizeable number considerably exceeds the number of people fleeing conflict and other forms of violence. It is also necessary to add to this figure all those who become refugees as a result of slower and more gradual changes such as rising sea levels or soil impoverishment. None of the statistics account for this kind of displacements.

And yet we continue to treat climate change and the enforced migration it brings in its wake as distant threats, spatially as well as temporally. The fact is that a large proportion of economic refugees arriving in France today are actually climate refugees: very often these are people no longer able to earn enough from farming in their homeland because of transformations brought

1 Internal Displacement Monitoring Centre. (2023). Global report on internal displacement 2023. IDMC. https://www.internal-displacement.org/global-report/grid2023.

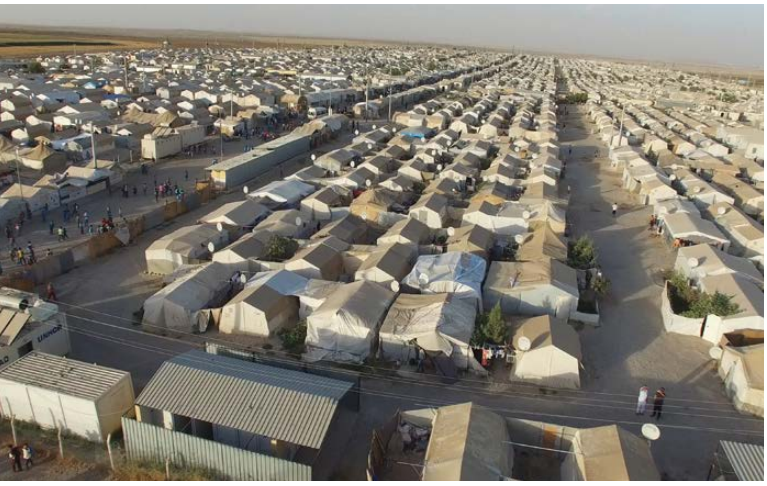
about by climate change. Inevitably, climate and environmental factors intertwine with economic factors. This distinction between economic and climate reasons for migration is a wholly western, not to say artificial, construct since our wages and income in western countries do not depend on environmental conditions and unforeseen climate events.

Three regions of the world are particularly exposed to this phenomenon. Southeast Asia, the most densely populated region in the world, is also currently the most exposed to climate risks. In sub-Saharan Africa, where over half of all families rely on subsistence farming, the effects of climate change are leading to a massive rural exodus as people can no longer earn anything from their farming activities. Lastly, small island states, although home to fewer people, face submersion risks that threaten their very existence.

Why are climate refugees particularly vulnerable to health problems?

Climate change has profound repercussions for the health of climate refugees at every stage of their journeys. The impacts in their home countries are devastating: lack of water, soil impoverishment, destruction of healthcare infrastructure, etc. These factors have a direct impact on people's health, giving them no option but to migrate. Once they leave, their migration routes are littered with health obstacles. Migrants are forced to live in precarious conditions with limited access to water, food, basic care or decent housing. Refugee camps in particular speed up the propagation of infectious diseases due to poor sanitation conditions, lack of access to care, and overcrowding. Lastly, many refugee camps are located in parts of the world already heavily impacted by climate change. Iran, for example, hosts more migrants than any other country in the world but is one of the most water-stressed of all countries, afflicted by years of drought and appalling water management. Bangladesh hosts over 900,000 Rohingya refugees, but climate change has increased the devastation that cyclones and floods cause there.[2] Every year, torrential rains during the monsoon season trigger floods and landslides that threaten to sweep away the refugee camps.

"Aside from the physical risks, the mental health of climate refugees remains very largely ignored. Following an extreme climate event, 25% to 50% of victims experience psychological troubles such as depression or post-traumatic stress disorder."



Aside from the physical risks, the mental health of climate refugees remains very largely ignored. Following an extreme climate event, 25% to 50% of victims experience psychological troubles such as depression or post-traumatic stress disorder.[3] This adds to difficult journeys that can expose refugees to further stresses. Many refugees, women in particular, are victims of smuggling and trafficking networks, exposing them to violence, forced labor, and rape which impact their mental health and physical well-being. This is why some migrants arrive on Europe's shores with injuries or burns, or clear signs of sexual violence. Furthermore, climate refugees may also be subjected to intense pressure from their families to supply regular income once they arrive in a host country. These traumas underline the importance of appropriate health care, physical as much as mental.

You mentioned the specific risks faced by women. What is it that makes them more vulnerable during migration journeys? Are they also more restricted in their ability to decide whether to stay or go?

I am not always at ease with the way that women are said to be vulnerable. It is more that they are exposed to vulnerabilities that men do not face, which are above all the result of economic and social constructs. Climate disasters tend to exacerbate gender inequalities and fuel the factors driving violence. Women and children are, according to UN Women, often the first victims of natural disaster, fourteen times more likely to die than men.[4] They are also more likely to be victims of sex trafficking. Families who are left with no source of income following a climate disaster find themselves with no choice other than to sell their daughters to sex traffickers or force them into marriage so that they receive a dowry. In Bangladesh, for example, there is an established link between flooding that occurred between 1998 and 2004 and the rising number of child marriages recorded in the country.[5]

Eventually, migration is itself a gendered phenomenon. Men are more likely to migrate as it is easier for them to find work, or because migration is dangerous. But this discrepancy leads to a modification and imbalance in gender relations. Women who stay behind will have to shoulder more tasks and responsibilities.

2 UNHCR. (2024). UNHCR and partners rush support to Rohingya refugees affected by deadly landslides in Bangladesh. https://www.unhcr.org/news/briefing-notes/unhcr-and-partners-rush-support-rohingya-refugees-affected-deadly-landslides.

3 Centre Virchow-Villermé, Matlin, S. A., Depoux, A., Gemenne, F., Philibert, A., El Aouad, R., Kowalski, C., & Flahault, A. (2016). Climate change, human migration and health: Bridging from dialogue to action. Charité – Universitätsmedizin Berlin.

4 UN Women, Women's Resilience to Disasters – Concept Note. https://wrd.unwomen.org/sites/default/files/2021-11/WRD%20Concept%20Note_November%202021_v8.pdf.

5 University of Cambridge, Extreme weather and climate events likely to drive increase in gender-based violence.

When women decide to migrate, sexual violence seems to be an almost inevitable part of their migration: two in three women experience sexual violence or rape, especially by smugglers. Enduring these acts of violence or rape becomes almost a bargaining counter, a condition for their passage. Sexual violence, just like in every other lawless or conflict zone, is an omnipresent feature of the migration journeys of climate refugees.

You study the influence of climate change on migration as part of the Habitable project.[6] Are the reasons leading people to migrate rooted in the consequences of climate disasters and the gradual impacts of climate change on habitability?

When you study these questions it is important to take account of the points of view of displaced people themselves. To migrate is a decision made by people, meaning it is necessarily a reaction to subjective factors. In our studies we observe that people's perceptions of the impacts of climate change do not correspond to the reality of impacts observed in the field. The decision to migrate is primarily influenced by subjective perceptions: people leave because they feel that it rains less, when in reality it rains more. These perceptions will weigh more heavily than objective reality when deciding whether to migrate.

Habitability, or habitability thresholds, are defined using climate models that, for example, will judge certain regions no longer habitable once a threshold temperature is reached. Climate policies, where they exist, will therefore mostly rely on climate models arbitrarily setting habitability thresholds that fail to reflect reality or people's perceptions. This shows that it is crucial for climate policies to take into account subjective perceptions of the impacts of climate change reflecting, in particular, the cultural influence on risk perception.

6 Habitable, a project coordinated by the Hugo observatory at the University of Liège, is the biggest research project in this field, with a 6.7-million euro budget and 22 partner organizations from 18 countries.

How can this learning be translated in health terms?

Perceptions on health when making choices about whether or not to migrate and move are an important dimension, with two distinct aspects. On the one hand, health itself should be considered, with all the problems associated with climate change such as communicable diseases and mortality, even excess mortality. There has been a fivefold increase in the number of climate disasters over the past 50 years, leading to a sharp rise in the number of deaths, 90% of them in developing countries.[7] On the other hand, we need to look at the question of access to health systems and adaptations to health infrastructure, which also influence migration decisions.

This phenomenon, in both its dimensions (health and access to healthcare), is a tangible reality. Senegal is one example, east Africa is another: in Kenya and Ethiopia, malaria is becoming entrenched in regions previously spared from the disease, such as the high plateaus of Ethiopia and northern Kenya, leading local people to move to areas free from the disease or equipped to treat them. The appearance or propagation of diseases leads to new migratory flows motivated by two types of factors: push, encouraging people to leave, and pull, attracting them toward certain areas, particularly regions where they believe they will enjoy better access to care and health provision. This means that in small island states like Tuvalu, many women decide to give birth in Australia or New Zealand where they will have access to better health facilities and their children will gain New Zealand or Australian citizenship, a form of life insurance in case their island were to disappear beneath the waves. Similar dynamics are operating within countries: we observe countless migration movements from rural areas to urban locations where people, lacking necessary resources to survive, hope to find a better quality of life and improved healthcare. This highlights how challenging it is to distinguish migration reasons, as they are deeply interconnected and mutually influence one another. No single factor on its own is sufficient to explain the choices made by migrating people. It is not only the quality of medical care that encourages migrants to settle in a country, but a combination of objective and subjective factors that together shape their decisions.

7 United Nations. (2021). Climate and weather-related disasters surge five-fold over 50 years, but early warnings save lives. UN News. https://news.un.org/en/story/2021/09/1098662.

Do migration flows represent major health and security challenges for states?

It all depends on how the migration flows are handled. There is no doubt that disorganized or unsupervised flows will create additional demographic pressures on already scarce resources, potentially leading to security risks. Many regions around the world that host migrants driven by climate change are located in developing countries where health resources are already inadequate for meeting the needs of local populations.

"Faced with the scale of climate displacements in the future, we need to plan ahead for reconfigurations in the world's population, which will involve inter- and intra-state reorganizations."

Indeed, certain states sometimes deliberately choose to restrict access to healthcare, lending credence to the implicit argument that access to healthcare can create an "attraction mechanism" (pull factor) for migrants. But no statistics, no data and no studies actually support this assertion.

On the other hand, some states manage to structure migration flows to make them part of genuine adaptation strategies that deliver benefits not only to the migrants, but to their home and destination regions too. Migration is often considered as a threat to security. A perception which overlooks the fact that migration improves the security of the people who migrate as well as for those who remain, since migrants may send extra funds that will help people in their home country adapt to climate change. It is a very strong dimension which is emerging today in the literature. Migration should not be viewed only as an adaptation *failure*, it is also an adaptation *strategy*. Colombia and Spain, for instance, have a migration labor agreement that allows people living in regions impacted by climate change to work in sectors facing labor shortage, such as horticulture and agriculture. In 2023, Spain alone accounted for close to a third of all new jobs created in the euro zone, with most of them filled by people coming from outside the country. Similarly, New Zealand has labor agreements with most Pacific small island states, enabling people to work in agriculture in New Zealand for a few months, helping out at harvest time and earning money that will then help families to deal with their own poor harvests. These long-term integration strategies can be set up between or within countries to encourage seasonal and pendular migration. Working upstream, anticipating displacement routes remains crucial to protecting people who are or will be at risk of displacement, along the lines of the work carried out by the Platform on Disaster Displacement[8] or the UNHCR's strategic plan for climate action. There are in fact a very large number of programs tackling this issue.

Do you observe significant disparities in terms of preparations for climate migration, particularly regarding healthcare arrangements?

According to the 1951 Convention relating to the Status of Refugees, refugees should not receive different treatment from the host population regarding access to healthcare. Health is a basic human right for everybody, refugees included. However, the practical application of this principle varies considerably from one country to another. These disparities are often a result of the choices and political sensitivities of authorities and governments; for instance, is the ministry of health alert to these issues?

Given the scale of future climate-induced displacements, we need to plan ahead for reconfigurations in the world's population, which will involve inter- and intra-state reorganizations. Partly because some parts of the world will become uninhabitable, but also because internal migration will have to be handled based on environmental factors, and this includes Europe. People forced to move every five years because of flooding will ultimately become very angry. When this happens, what will be the pleasant, safe, and comfortable places to live?

In conclusion, are there aspects of climate-led migration and its impacts on health that remain neglected or insufficiently studied?

The biggest challenge is that climate, migration, and health are dealt with separately. They are often treated in pairs: climate and migration on one side, migration and health on the other, but rarely all together. The challenge lies in connecting them together as a triangle. And there is still too little study of internal displacements within national borders. Currently, governments and the media are only interested in international migration. The two migratory phenomena, internal and international, are treated as if they were distinct movements, whereas the latter is often a continuation of the former.

8 The Platform on Disaster Displacement is a state-led initiative that works with partners toward better protection for people displaced or at risk of displacement due to climate disasters.

Bridging gaps:

Integrating gender into climate-responsive Disaster Risk Management

Virginia Murray
Head of Global Disaster Risk Reduction, UK Health Security Agency

Professor Virginia Murray is a public health doctor committed to improving health emergency and disaster risk management. She was appointed as Head of Global Disaster Risk Reduction for UK Health Security Agency (formerly Public Health England) in April 2014. She is currently the chair of the UNDRR/ISC Hazard Information Profile Steering Group for the 2025 update. She was a member and then vice-chair of the UN International Strategy for Disaster Reduction (UNISDR) Scientific and Technical Advisory Group (STAG), 2008-2017, supporting as required negotiations for the Sendia Framework for Disaster Risk Reduction 2015–2030.

Climate change sets a new challenge for disaster risk management as it increases the frequency and severity of extreme weather events, disproportionately impacting vulnerable and marginalized communities. Women face added risks due to their social roles, biological differences, cultural norms and limited access to resources, that have been historically overlooked and encounter numerous challenges that increase their vulnerability and exposure to disaster-related dangers. Effective anticipation and mitigation of climate-related disasters must consider gender disparities to ensure that interventions effectively address the specific needs and vulnerabilities of women and girls, thereby enhancing overall resilience and promoting more equitable outcomes in the face of climate-related challenges. Besides, it also appears crucial to integrate the active participation and empowerment of women in disaster risk governance to ensure women have a say in the solutions that are designed for them.

INTRODUCTION

As the world faces multiple crises, in part driven by climate change, immense pressure is placed on communities, leading to an even clearer need for achieving gender equality. Women, who are often disproportionately affected by disasters, face unique social, geographical, and physiological vulnerabilities that can exacerbate their risk of harm in the event of crises. These stark realities highlight the critical need to integrate gender considerations into disaster risk management (DRM) strategies. This article starts with a summary of DRM and a brief review of existing international policy frameworks for managing crisis situations that aid evidence-informed decision-making and enhance the effectiveness of crisis management efforts. This is followed by a brief overview of hazards and their risks to human health and where relevant their relationship to climate change, emphases the importance of DRM. It then delves into examining the unique vulnerabilities faced by women and the importance of integrating a gendered perspective into DRM frameworks as a sustainable solution to enhance resilience.

AN INTRODUCTION TO DISASTER RISK MANAGEMENT (DRM)

The United Nations office for Disaster Risk Reduction (UNDRR) defines disaster risk management[1] as '*the application of disaster risk reduction policies and strategies to prevent new disaster risk, reduce existing disaster risk and manage residual risk, contributing to the strengthening of resilience and reduction of disaster losses.*'

"The WHO indicated that over 170 million people will be affected by conflict every year, and another 190 million by disasters. Yet the overall impact on people's health is much more significant."

The World Health Organisation (WHO) documents that health disaster risk management emphasizes the critical importance of prevention, preparedness and readiness, together with response and recovery, to save lives and protect health. The WHO Health Emergency and Disaster Risk Management Framework[2] (Health EDRM) issued in 2019 outlines the need to work together, highlighting how the whole health system can and must be fundamental in all of efforts for DRM.

In this framework, it was reported that emergencies and disasters take a profound toll on people's health. The WHO indicated that over 170 million people will be affected by conflict every year, and another 190 million by disasters. Yet the overall impact on people's health is much more significant. For example, some of these emergencies and disasters will be large national, regional or even global crises, from cyclones and drought to major outbreaks; and others will be more localized, like traffic collisions and fires, but can still result in devastating consequences for human life.

Reducing the health risks and consequences of emergencies is vital to local, national and global health security and to build the resilience of communities, countries and health systems. Such events hinder development for years and jeopardize universal health coverage along with other development agendas. For example, COVID-19 showed us that these crises can overwhelm health systems and decimate the economies that fund them.

All communities are at risk, including from infectious disease outbreaks, conflicts, and natural, technological and other hazards. The health, economic, political and societal consequences of these events are often severe. Climate change, unplanned urbanization, population growth and displacement, antimicrobial resistance and state fragility are increasing the frequency, severity and impacts of many types of hazardous events.

In the health domain, the International Health Regulations[3] (IHR) (2005) have been critical and developed in response to epidemics that once devastated Europe. While disease outbreaks and other acute public health risks are often unpredictable and require a range of responses, the IHR provide an overarching international law that is legally-binding on 196 countries, including the 194 WHO Member States. It defines countries' rights and obligations in handling public health events and emergencies that could spread across borders. These regulations create rights and obligations for countries, including the requirement to report public health events, and outline the criteria to determine whether a particular event, such as COVID-19, constitutes a 'public health emergency of international concern'.

Sound disaster risk management is essential to safeguard development and implementation of the Sendai Framework for Disaster Risk Reduction 2015–2030[4] (Sendai Framework), the Sustainable Development Goals (SDGs), the Paris Agreement on Climate Change (Paris Agreement), the Warsaw International Mechanism for Loss and Damage associated with Climate Change Impacts[5] (WIM), the UNFCCC Santiago Network,[6] and other related global, regional and national frameworks. In line with the recently adopted United Nations Pact for the Future,[7] key statements that are valuable to consider include:

- *"The **achievement of gender equality**, the empowerment of all women and girls and the full enjoyment of their human rights and fundamental freedoms without discrimination" (paragraph 7)*
- *The need to "prioritize urgent action to address critical environmental challenges and implement measures to reduce disaster risk and build resilience, [...] noting the importance for some of the concept of **climate justice**" (paragraph 18)*
- *The importance of promoting "**a disaster risk-informed approach** to sustainable development that integrates disaster risk reduction [...] at all levels" (action 6 paragraph g).*

1 United Nations Office for Disaster Risk Reduction. (n.d.). Disaster risk management. https://www.undrr.org/terminology/disaster-risk-management.

2 Disaster Risk Management and Resilience (DDR). (2019, July 30). Health Emergency and Disaster Risk Management Framework. https://www.who.int/publications/i/item/9789241516181.

3 World Health Organization. (2023). International health regulations. https://www.who.int/health-topics/international-health-regulations#tab=tab_1.

4 The Sendai Framework for Disaster Risk Reduction 2015-2030 is a global agreement providing Member States with guidance and concrete actions to reduce the risk of disaster. It is a milestone in international disaster risk reduction efforts. To read more: https://www.undrr.org/media/16176/download?startDownload=20241030.

5 The Warsaw International Mechanism for Loss and Damage associated with Climate Change Impacts was established during COP19 (in 2013) to address loss and damages associated with the impacts of climate change in developing countries. To read more: https://unfccc.int/topics/adaptation-and-resilience/workstreams/loss-and-damage/warsaw-international-mechanism.

6 The UNFCCC Santiago Network was established during COP25 (in 2019) to facilitate technical assistance in developing countries particularly vulnerable to adverse effects of climate change. It helps implement the functions of the Warsaw International Mechanism described above. To read more: https://unfccc.int/santiago-network/about.

7 The Pact for the Future, adopted in September 2024 by world leaders during the Summit of the Future, is a list of 56 pledges across a broad range of themes (peace and security, climate change, sustainable development, digital cooperation, human rights, gender, youth and future generations...), adapting international cooperation to today's realities. To read more: https://www.un.org/sites/un2.un.org/files/sotf-pact_for_the_future_adopted.pdf.

These frameworks aid evidence-informed decision-making, guide policy development, and enhance the effectiveness of crisis management efforts. While countries have strengthened capacities to reduce the health risks and consequences of emergencies and disasters through the implementation of multi-hazard disaster risk management and health system strengthening, many communities remain highly vulnerable to a wide range of hazardous events.

AN INTRODUCTION TO HAZARDS

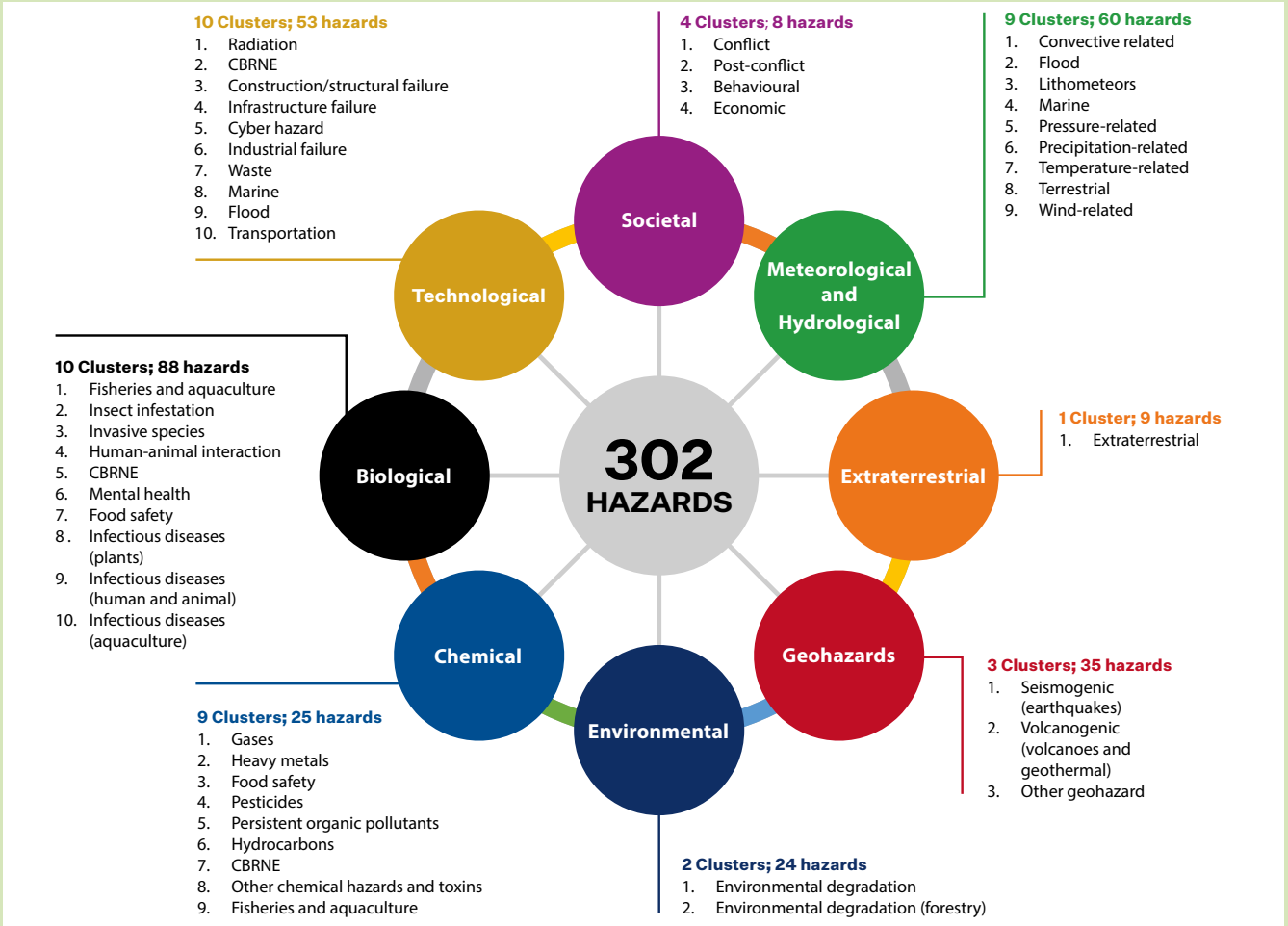
Fragmented approaches to different types of hazards, an over-emphasis on reacting to events rather than preventing them, insufficient preparedness for response, and gaps in coordination within the health system, and across sectors, have hindered the ability of communities and countries to achieve optimal development outcomes, particularly for public health.

Understanding risks and their associated impacts is crucial for effective DRM. By comprehensively identifying and assessing hazards, policymakers and practitioners can better anticipate and mitigate threats, thereby enhancing community resilience to disasters.

The UNDRR, in collaboration with the International Science Council (ISC) has played a pivotal role in this regard by responding to calls for 'a data revolution, rigorous accountability mechanisms and renewed global partnerships'. The UNDRR-ISC Hazard Definition and Classification Review: Technical report[8] and its Supplement provide important resources to support disaster risk reduction, aligned with the Sendai Framework, the Sustainable Development Goals, and the Paris Agreement on Climate Change. They offer a common set of hazard definitions to Governments and stakeholders to inform their strategies and actions on risk reduction and management. Specifically, these documents support the development and updating of national and local disaster risk reduction strategies and loss databases, as well as the integration of disaster risk reduction into national statistics, legal frameworks, and regulatory systems for public and private policy, financing and investment.

8 UNDRR (2020), Hazard Definition and classification review : Technical report, https://www.undrr.org/publication/hazard-definition-and-classification-review-technical-report.

Figure 1: UNDRR/ISC hazard information according to eight hazard types



Source: Reproduced from Fahad S Malik and Anna Schwappach, UK Health Security Agency

The UNDRR/ISC Hazard Information Profiles[9] catalogues 302 hazards worldwide and is now available online.[10] This tool serves as a valuable resource for harmonizing knowledge on hazards and provides crucial insights to inform DRM efforts globally ***(Figure 1)***.

CLIMATE AS A DRIVER OF HAZARDS

Climate change is not a hazard *per se* but is recognised to exacerbate hazards by increasing their frequency, intensity, and complexity. Impacts are interconnected, with the Intergovernmental Panel on Climate Change (IPCC) projecting increasingly complex risks.[11] For example, rising temperatures melt polar ice caps, causing sea-level rise and coastal flooding, which heighten the risk of storm surges.

Climate change-related disasters impact human health both directly and indirectly. Direct risks include the projected tripling of heat-related deaths by 2050, while indirect risks relate to the weakening of social determinants of health, such as access to healthcare, clean water, and sanitation.

Additionally, socio-economic disparities exacerbate the impacts of disasters on marginalised and vulnerable communities. Understanding climate change impacts requires considering social dynamics, which shape how populations experience and respond to these challenges. Social factors include the organization of society (e.g., maturity of healthcare systems and urbanization), as well as vulnerabilities related to social stratification.

9 Ibid.

10 United Nations Office for Disaster Risk Reduction (UNDRR). (2024). Hazard information profiles (HIPs) online reference. https://www.preventionweb.net/drr-glossary/hips.

11 Intergovernmental Panel on Climate Change. (2022). Headline statements from the summary for policymakers. https://www.ipcc.ch/report/ar6/wg2/resources/spm-headline-statements/.

VULNERABILITY AND GENDER IN DRM

The Sendai Framework outlines the inclusive, all-of-society approach that must be taken to reduce disaster risk and considers the specific vulnerabilities and capacities of different groups, including women, children, the elderly, and persons with disabilities. It acknowledges the specific vulnerabilities that women face in disasters, due to pervasive gender inequality across all societies, while recognizing their indispensable role in risk reduction efforts. The Sendai Framework emphasizes that a gender equitable[12] and universally accessible approach is key, and calls for the mobilization of women's leadership in building resilience as they already contribute significantly, but often informally, through participation in disaster management and as agents of social change.[13]

THE GENDERED IMPACTS OF CLIMATE CHANGE

The impact of climate change is not gender-neutral, as women are disproportionately vulnerable to disasters. Gender disparities in access to resources, decision-making power, and cultural norms often amplify women's susceptibility to extreme events, leading to higher mortality rates and reduced access to relief and recovery assistance.

"The impact of climate change is not gender-neutral, as women are disproportionately vulnerable to disasters. Gender disparities in access to resources, decision-making power, and cultural norms often amplify women's susceptibility to extreme events."

From a physiological standpoint:

The increasing frequency of extreme heat events drives a disproportionate heat-related morbidity and mortality among women,[14] due to biological vulnerabilities such as reduced heat dissipation through sweating and decreased radiative cooling. These vulnerabilities interact with socio-economic factors, as women often lack access to healthcare and cooling facilities due to concerns for their own safety or limited personal transportation options.

Among women, certain groups face heightened vulnerabilities during disasters, with pregnant women and young girls of reproductive age being particularly at risk. Pregnancy introduces additional physiological challenges, for example, an increase in temperatures in the week preceding delivery can lead to stillbirth. Rising temperatures favour the spread of vector-borne illnesses like malaria and dengue fever which are linked to worse maternal and neonatal outcomes. Access to essential prenatal care and medical assistance may be limited during disasters, increasing the risk of pregnancy-related complications. Additionally, displacement and loss of infrastructure in the aftermath of such events may disrupt access to maternity services and contraception, placing pregnant women and sexual and reproductive health at further risks.

12 United Nations Office for Disaster Risk Reduction. (2024). Gender inequality. UNDRR. https://www.undrr.org/implementing-sendai-framework/sendai-framework-action/gender.

13 World Health Organization. (2014). Gender, climate change and health. https://www.who.int/publications/i/item/9789241508186.

14 Sorensen, C., Murray, V., Lemery, J., & Balbus, J. (2018). Climate change and women's health: Impacts and policy directions. PLOS Medicine, 15(7).

From a socioeconomic standpoint:

When disasters strike, women are less likely to survive due to long-standing gender inequalities. For example, in the 2004 Southeast Asia tsunami, four times as many women as men died in affected areas. As caregivers, women often stay behind to look for their children and other relatives. Moreover, in these areas, women and girls may not be taught how to swim or climb trees which means that they could not escape when the wave hit the coast.

From a geographical standpoint:

Women living in disaster-prone areas face heightened risks due to their location, which exposes them to recurrent hazards such as floods, fires, and earthquakes. These areas often lack adequate infrastructure and emergency services, limiting women's access to life-saving resources and support during disasters. Additionally, the geographical remoteness of many disaster-prone regions exacerbates challenges related to evacuation, communication, and access to healthcare. The socio-economic disparities further affect women, limiting their ability to prepare for, cope with, and recover from disasters.

From women's heightened exposure to violence in crisis settings:

Reports indicate a growing recognition that affected populations during disasters face various forms of gender-based violence. For example, during 'lock downs' associated with COVID-19, during emergency evacuations and displacements, the risks of sexual and physical violence, intimate partner violence, forced early marriage, trafficking and sexual exploitation or forced/domestic labour are heightened. Prolonged recovery and reconstruction after disasters can leave displaced women and girls in camps and shelters where they are at heightened risk of experiencing violence.[15]

"When disasters strike, women are less likely to survive due to long-standing gender inequalities."

From the various layers of vulnerability:

As stated by UN Women:[16] '*Looking at the way in which various forms of inequality often operate together and exacerbate each other, it is clear that climate change risks are acute for indigenous and Afro-descendent women and girls, older women, LGBTIQ+ people, women and girls with disabilities, migrant women, and those living in rural, remote, conflict and disaster-prone areas*'.

Multiple factors heighten the vulnerability of certain groups of women. An elderly woman belonging to an ethnic minority group and residing in a disaster-prone area faces multiple layers of vulnerability and risks. She may encounter various barriers in accessing essential resources and services and experience discrimination or marginalization amid the challenges posed by disasters. By acknowledging and addressing the intersecting inequalities, inclusive and equitable strategies can be developed to promote social justice in the face of disasters.

THE NECESSITY OF INTEGRATING GENDER CONSIDERATIONS IN DRM

Despite considering many vulnerabilities, disaster risk management still has shortcomings. The lack of consideration for gender is now a significant challenge in DRM that has prompted community and UN organisations to design solutions.

UN Women[17] has led a valuable initiative to build women's resilience to disasters via their Women's Resilience to Disasters (WRD) programme which proposes a comprehensive package to strengthen women's resilience to disasters and threats, including climate change and COVID-19. The objectives for WRD countries are to adopt gender-responsive decision-making and governance systems; and enable targeted action to build the resilience of women and girls. Their aim is to provide a 'one-stop shop' for gender-related disaster and climate resilience knowledge. It brings together practitioners, policymakers, and activists who support women and girls affected by disasters, climate change, and other threats. The programme seeks to bridge the gaps between gender equality, social inclusion, disaster risk reduction, climate change adaptation, and resilience by:

- *Sharing evidence on the gender and intersectional dimensions of disaster and climate risks;*
- *Sharing women's perspectives, experiences, and good practices; and*
- *Providing consolidated access to data, research, resources, tools, and expertise.*

15 Thurston, A. M., Stöckl, H., & Ranganathan, M. (2021). Natural hazards, disasters and violence against women and girls: A global mixed-methods systematic review. BMJ Global Health, 6, e004377. https://pubmed.ncbi.nlm.nih.gov/33958379/.

16 UN Women Headquarters. (2022). Explainer: How gender inequality and climate change are interconnected. UN Women. https://wrd.unwomen.org/index.php/explore/insights/explainer-how-gender-inequality-and-climate-change-are-interconnected.

17 UN Women. (n.d.). Women's resilience to disasters knowledge hub. UN Women. https://wrd.unwomen.org/.

In March 2024, the Sendai Gender Action Plan[18] (Sendai GAP) was launched to support implementation of the Sendai Framework with a renewed focus on accelerating progress toward gender equality and reducing disaster risk. It aims to ensure that disaster risk reduction efforts are gender-responsive and that they actively promote and support women's empowerment and leadership. It emphasizes the mutually reinforcing goals of gender equality and disaster risk reduction, as well as recognizes that gender inequalities exacerbate the impacts of disasters. The Sendai GAP involves analysing how gender norms, roles, and relations shape disaster risks and impacts, integrating this understanding into planning, implementation, monitoring, and evaluation efforts.

Examples of recommendations included in the Sendai Gender Action Plan:

The Sendai GAP includes 33 concrete actions under 8 key objectives aimed at implementing comprehensive, gender-responsive measures that address the vulnerabilities faced by women. The examples below illustrate how the GAP aims to address all areas of women's vulnerabilities:

- *Action 24 promotes **anticipatory actions that overcome social norms and barriers**, such as making emergency drills and risk communications accessible to all women.*
- *Action 27 focuses on **gender-responsive recovery**, to alleviate the negative impacts of domestic work that commonly fall on women and girls. For example, it recommends planning for emergency water supplies to address the additional burdens and security risks women face when collecting water after disasters.*
- *Action 18 promotes **gender mainstreaming into risk-informed development**, emphasising investments in resilient medical facilities to provide continuity of sexual and reproductive health services during disasters.*
- *Action 14 aims at **increasing participation of women and gender stakeholders in DRM**, advocating for quotas to ensure at least of one-third representation of women in national and subnational committees advising the government on disaster risk reduction.*

To further support the integration of a gendered perspective in DRM, it is fundamental to improve disaggregated data collection and analysis, as required by the Sendai Framework, on the distinct impacts of disaster related climate change on men and women, as well as on how emergencies affect differently across physiological, economic, social and psychological dimensions. A deeper understanding of gender differences is required to effectively inform DRM policies.

CONCLUSION

Climate change significantly exacerbates risks, making effective DRM more critical than ever. As the frequency and severity of natural disasters increase, the need for robust DRM strategies that can mitigate these impacts and enhance community resilience becomes paramount. However, while DRM is essential, it has its limitations in addressing specific vulnerabilities, especially those related to gender. Women face unique physiological, socioeconomic, and geographic vulnerabilities during and in the aftermath of disasters, which DRM alone may not fully address.

The international frameworks, *inter alia*, the Sendai Framework, the Sustainable Development Goals, Paris Agreement on Climate Change, the Warsaw International Mechanism for Loss and Damage associated with Climate Change Impacts, the Santiago Network, United Nations Pact for the Future and other related global, regional and national frameworks are essential for DRM. In line with the recently adopted of the Gender Action Plan to support the implementation of the Sendai Framework, this represents a significant milestone in acknowledging and addressing these disparities, emphasizing the importance of moving towards gender-responsive disaster risk reduction efforts.

By embedding gender considerations into all aspects of policy and planning, we can ensure that the unique vulnerabilities faced by women are addressed and also promotes a more equitable and resilient society capable of withstanding the growing challenges posed by climate change.

18 UNDRR. (2024). What is the Sendai Gender Action Plan? United Nations Office for Disaster Risk Reduction. https://www.undrr.org/news/what-sendai-gender-action-plan.

Climate change and occupational health:

Escalating risks and prevention strategies

Cyril Cosme
Director of the French office of the International Labour Organization (ILO)

Cyril Cosme studied at the National School of Administration and the Paris Institute of Political Studies before beginning his career at the French Ministry of Labor in 1997. He headed the Office of Collective Agreements and Workplace Conflicts before joining the General Secretariat for European Affairs in 2000. In 2004 he became advisor for social affairs then head of the employment, social affairs and health department at the Permanent Representation of France to the EU. He was social affairs advisor to the French ambassador in Washington in 2009, then delegate for European and international affairs at the social ministries in 2012. He has headed the French office of the International Labour Organization (ILO) since 2014.

Occupational hazards associated with climate change are increasingly alarming, with the most vulnerable categories of workers particularly at risk. Deaths caused from excessive heat and other climate-related dangers, such as extreme weather events, air pollution and vector-borne diseases are on the rise, with workers in the most at-risk sectors, such as the construction industry and agriculture, hit the hardest. The impacts are greater in countries of the global south where many people work outdoors and standards of protection are inadequate.

In this interview, Cyril Cosme, director of the French office of the International Labour Organization (ILO), discusses the risks related to climate change that workers face and describes the ILO's role in documenting these risks, drawing up standards for protecting workers and helping governments implement them, especially in countries that lack the capacity to manage these challenges alone.

Could you give us a brief description of the main global challenges in terms of occupational safety and health (OSH)?

Worldwide, 1,000 people die every day in a workplace accident, and a further 6,500 as a result of an occupational disease, totaling over 2.3 million victims every year. The data is an estimated average, with the situation varying significantly between regions.

The prevalence of occupational diseases is universal, but morbidity due to workplace accidents is higher in Africa (25%) and Asia (18%) than in Europe and North America (3%). Furthermore, declaration processes and epidemiological monitoring used to identify occupational diseases is far from systematic in many countries, resulting in figures that fail to reflect reality: cancers represent 50% of victims in high-income countries compared to 10% in Africa.

In what way have OSH issues become embedded in international standards as prerequisites for decent work?

Historically, labor law was framed in terms of occupational safety and health. In the event of an accident, employers were only obliged to compensate workers if they were shown to be responsible, which is why the principle of employers' strict liability was adopted. Today, the right to work in a safe and healthy environment is recognized as a fundamental human right, just the same as the prohibition of forced labor.

Several successive phases have led to this, and occupational health has always been central to ILO's concerns. In 1920, it founded the Industrial Hygiene Section and the first international regulations emerged. Today, the ILO is the body that draws up the directives that constitute a form of international OSH code.

International labor standards, in the form of agreements negotiated between governments, employers and workers in member states, have evolved in three ways:

- They initially served to protect workers from specific dangers in certain sectors, such as mining and industry, as well as from exposure to certain physical risks such as toxic substances and dangerous machinery. They also targeted specific groups of people, including women, night workers and children.
- These standards were then used to build social protection systems, with branches dedicated to workplace accidents and occupational diseases, adopting an approach based on compensation in the event of accidents.
- Today's standards are guided by a preventive approach, together with the tenet that views occupational health as a factor in overall wellbeing. This dates back to the 1944 Declaration of Philadelphia, which sought to make work a factor for personal fulfilment and instrument for each individual to contribute to the common welfare by establishing the principle that "labour is not a commodity".

Work and health are inextricably linked and must go hand in hand, which means health has to be a major component of efforts to ensure decent work.

How is work dependent on the environment and the quality of ecosystems?

Work puts people in direct contact with their environment. Humans use their work to transform nature, extracting resources from the natural world to feed themselves and produce goods and services. Climate change and pollution are damaging to ecosystems, with knock-on effects on working conditions and economic performance. It is estimated that close to half of global GDP is compromised as it relies heavily on ecosystemic services. For example, agriculture, fishing and forestry account for 1.2 billion jobs. Current trends make it likely that unsustainable overexploitation of resources will increase, leading to lower productivity and triggering price hikes, water shortages, soil erosion, and a decline in agricultural yields.

"Climate change and pollution are damaging to ecosystems, with konck-on effects on working conditions and economic performance."

This means that degrowth scenarios seemingly equate to an ecological *status quo*, with an economy that consumes huge quantities of fossil fuels and natural resources, resulting in a widespread drop in yields under the twofold effect of long-term extinction of resources and climate change.

These scenarios seriously call into question any hope for full and productive employment. Between 2000 and 2015, 23 million years of working life were lost due to environmental damage[1], and it is estimated that by 2030 we will see a deficit of hundreds of millions of jobs.

The ILO recently published a report highlighting the emergence of new climate change-related risks in the OSH sphere. Could you tell us more about these risks and how they impact workers?

As a general rule, climate change amplifies risks or creates new ones, with the strongest impact on the most vulnerable categories of workers.

The report you mentioned[2] presents six key impacts of climate change on OSH, selected for their severity and the magnitude of their effects on workers: excessive heat, solar ultraviolet (UV) radiation, extreme weather events, workplace air pollution, vector-borne diseases and agrochemicals.

Working in extreme temperatures is a risk that has long been documented. The worst-hit sectors are naturally those involving outdoor work or transport, such as agriculture and tourism. The number of workers exposed is estimated at 2.4 billion, with half of them in agriculture. In addition to heat stress causing a productivity loss equivalent to 80 million full-time jobs, working in very high temperatures also increases the risks of cardio-vascular problems.

Exposure to ultraviolet radiation concerns more or less the same population group. Around 1.6 billion people are exposed to this at work, despite the high risks of cancerous lesions that lead to 19,000 work-related deaths a year.

These two factors have been clearly identified and documented, as the associated risks are easier to observe and have existed for longer. This does not apply to other factors. Extreme weather events affect medical and emergency workers as well as people working in agriculture, fisheries and forestry. The World Meteorological Organization publishes data on the number of deaths worldwide, but does not distinguish work-related deaths. Similarly, it is difficult to gather accurate epidemiological data on vector-borne diseases and work-related exposure to pesticides. Air pollution

1 International Labour Organization. (2018). *World Employment and Social Outlook 2018: Greening with jobs*. International Labour Office. Available from https://www.refworld.org.

2 International Labour Organization. (2024, April 26). *Ensuring safety and health at work in a changing climate*. International Labour Organization. Retrieved from https://www.ilo.org.

represents an increased risk for outdoor workers and people working in transport. There are already up to 860,000 deaths a year linked to exposure to air pollution at the workplace, a figure likely to worsen as a result of climate change impacts.

It is worth noting that the 53% people worldwide without social protection are the most exposed to these risks. Inequality is already glaring and on the rise — with 1% of the world's population earning 7% of global income, while the 50% poorest people on the planet share just 12% of global wealth — and will worsen without corrective preemptive measures between rich and poor countries as well as within countries.

"The vulnerability of the working world to climate change essentially mirrors the current geography of global inequalities."

You mention inequality: which vulnerabilities need to be taken into account to understand the occupational hazards related to climate change and their impact on different groups of people?

The vulnerability of the working world to climate change essentially mirrors the current geography of global inequalities. The poorest countries will have fewer resources to help them adapt, just as their governments will have fewer means to implement the necessary policies. In addition to the increased vulnerability of southern countries, often hit harder by climate change impacts, disadvantaged groups such as the unemployed and workers in the informal and agrarian economies (where women are the majority and migrant workers are numerous) are also particularly exposed to the impacts.

For example, the poorest people are the most impacted by climate change because they are far more sensitive to rising prices for foodstuffs and energy. Food security for 40% of workers could be compromised.

Factors relating to age, state of health and disability are also important. Older people, very young adults, and people suffering from chronic conditions are more vulnerable to occupational hazards related to climate change.

These areas where vulnerabilities need to be taken into account echo the notion of fair transition: in the ILO's view, what does this mean and what does it involve?

It is important not to think of ecological transition independently from other challenges, particularly inequality. The current level of inequality is far from compatible with getting people to embrace the transition, and this is a direct threat. From this perspective, social justice is essential to transitioning toward a decarbonized economy.

I would like to recall the genesis of the notion of fair transition. In the early 2000s, environmental protection and the promotion of renewable energies led to the creation of new jobs, described as green. That was when the ILO launched its first dedicated program.

A few years later it became clear that the climate challenge went far beyond the question of green jobs, and that it required a paradigm shift. The ILO linked the climate crisis to the social crisis and published several studies showing that inequalities and environmental deterioration are two sides of the same crisis, rooted in a growth model driven by fossil fuels.

The Paris Agreement enshrined the concept of fair transition by including it in its preamble and linking it to the creation of decent work for all. That same year the ILO adopted guidelines for "greening the economy to make it as equitable and inclusive as possible for all by creating opportunities for decent work and ensuring no one gets left behind."[3]

In concrete terms, fair transition combines three major changes to the production system: energy transition, transition to a circular economy, and promotion of solutions rooted in nature. These three changes drive job creation in new ways compared to the conventional economic model we are familiar with.

A successful fair transition that gets people onboard needs to correct the factors behind geographical imbalances between the North and South, and redistribution imbalances within countries between different categories of workers, sectors, and income levels.

3 International Labour Organization. (2015). *Guidelines for a just transition towards environmentally sustainable economies and societies for all.* International Labour Organization. Retrieved from https://www.ilo.org.

How are climate change-related occupational hazards incorporated into national and international standards and policies, and what role does the ILO play in this process?

When it comes to OSH, there have always been established principles as well as innovations. Established principles include prevention: primary prevention (preventing the risk from arising), secondary prevention (guarding against the effects with protective measures), and tertiary prevention (reducing impacts in the event of damage). There is also the principle of the liability to workers of employers and order-givers. This legal framework has proven robust when confronted with new challenges, whether linked to the transformation of the production system, outbreaks of violence or harassment, sexism or discrimination.

"Climate change and its impact on OSH have put us in the same situation, where a new phenomenon has to be incorporated into prevention policies for businesses and professional sectors."

Climate change and its impact on OSH have put us in the same situation, where a new phenomenon has to be incorporated into prevention policies for businesses and professional sectors. The capacity to gauge risks and assess the prevention policies put in place is essential, although it involves having more epidemiological data. This is why the ILO plays its role at different levels:

- undertaking research and analysis to document new risk factors and the impact of climate change;
- drawing up standards, particularly recognition of the fundamental right to work in a safe and healthy environment. The application of these standards can lead to defining risk exposure thresholds, requiring the mandatory use of protective equipment, or adapting the list of recognized occupational diseases (as is already the case in a few countries for work-related skin cancer). Several ILO Conventions, listed in the ILO Codes of practice, cover risk factors linked to climate change, such as Convention 148 (1977) on the working environment (air pollution, noise and vibration);
- providing technical assistance for our members to put policies in place, particularly in developing countries.

Which actors must be involved in efforts to manage OSH risks linked to climate change?

Social partners play a central role in preventing climate change-related risks, as highlighted in ILO Convention 187. Only social dialogue allows for listening to those directly affected. For example, in western Europe we began to talk about the effects of extreme heat on work in the construction sector in the wake of the 2003 heatwave and the large number of interruptions to work sites due to heat stroke.

A notable example of the crucial role of social partners is the framework agreement between the Building and Wood Workers' International (BWI) and Belgian construction company BESIX,[4] which protects the safety and health of construction workers in the Middle East facing extreme temperatures. The agreement specifies that work sites must supply essentials such as drinking water in sufficient quantities and shelter from adverse weather conditions. Workers also have to be regularly informed about how to prevent heat stroke and sunburn. In 2023, BWI launched a new campaign called "Heat-up workers' rights, not the planet!" It aimed to raise awareness of the importance of OSH in the event of extreme heat and weather events and demanded better jobs and working conditions in a period marked by the climate emergency. Collective construction conventions in Greece and Spain also include the issue of extreme temperatures.

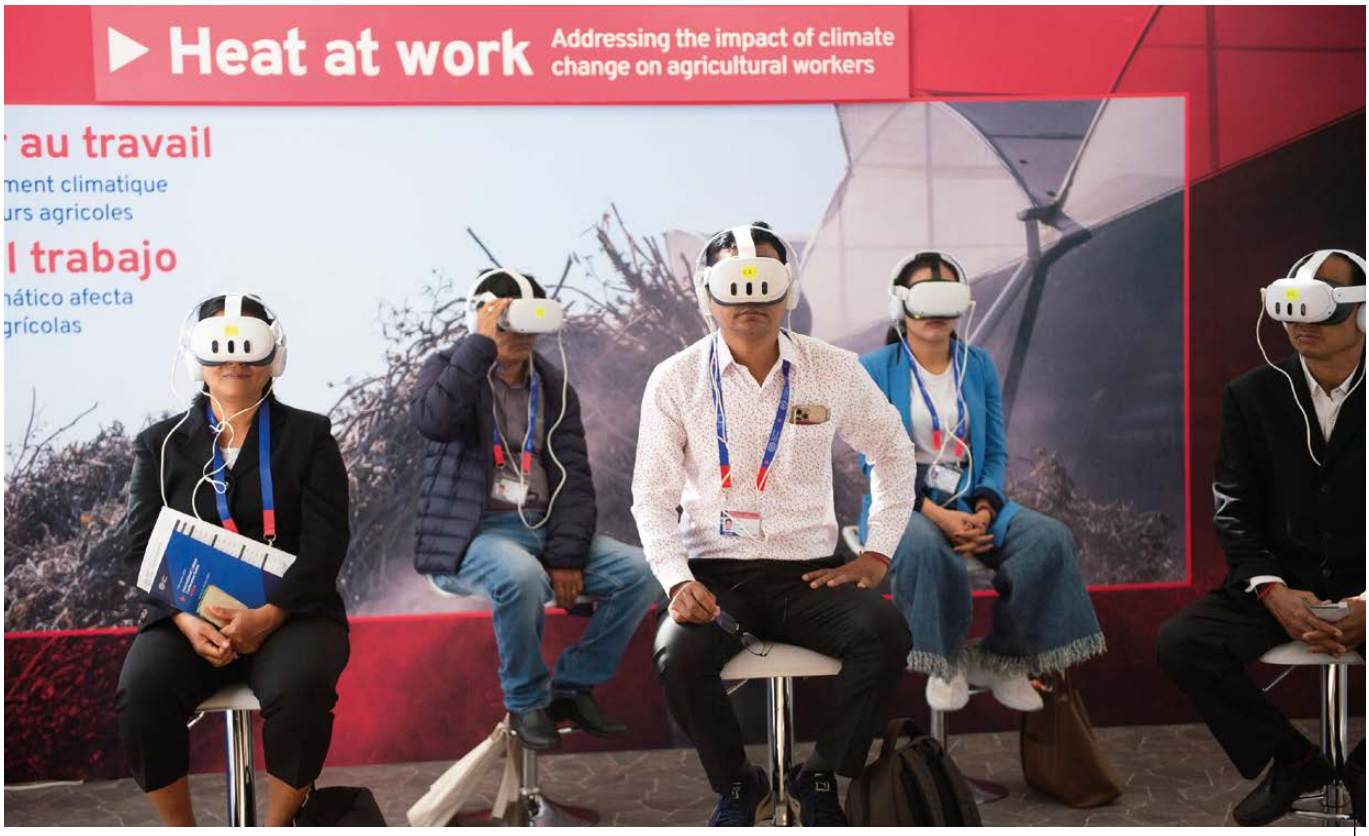
Can you identify any innovative approaches developed to protect workers?

Technology is being increasingly used to reduce OSH-related risks for workers exposed to dangerous situations. For example, drones can be used to assess risks linked to the accessibility of areas after storms or to investigate accidents. They can also be used to monitor and manage forest fires and help to contain them, even in isolated areas. Reducing the scope and duration of fires would cut risks for firefighters and other emergency workers. Smart clothing can also be used to reduce risks caused by extreme weather events. For instance, sensors can be incorporated into workwear to detect extreme body temperature, cameras can record and assess incidents, and GPS can warn workers if they are entering dangerous areas.

How does the ILO use the technological tools you have mentioned to help developing countries manage climate change-related occupational hazards?

We generally get involved at the stage when strategies and policies are being formulated, aiming to support mitigation and adaptation. The ILO has helped several countries with the formulation of their commitments to implement the Paris Agreement by including a social dimension (Nationally Determined Contributions).

4 Building and Wood Workers' International (BWI). (2017). *International Framework Agreement with BESIX Group*. December 14.



Session at the International Labor Conference

In terms of risk prevention, we build the capacity of labor administrations. Training actors is the first area where we provide support to encourage awareness of risks and how to prevent and deal with them. For example, workshops were organized to train work inspectors in Tunisia, Morocco and Egypt about vulnerabilities specific to women. The workshops tackled subjects such as heat stress affecting women working outdoors, air quality, and psycho-social stresses resulting from women's worries about their families and communities.

We also work to promote the exchange of collaborative good practices between actors. In tropical countries, health risks linked to vector-borne diseases impact economic growth. This means it is crucial to reinforce the health system globally and combine the two approaches, public health and occupational health. This involves reinforcing epidemiological monitoring and adapting professional practices.

For instance, a project in Tanzania studied the association of agricultural measures with public health to combat resistance to insecticides, which forms a major obstacle to controlling malaria (often due to inappropriate use of pesticides).[5] The project included workshops and training courses where farmers learnt to differentiate malaria vectors, identify agricultural diseases, use pesticides effectively, and carry out resistance tests. Research underlined the importance of raising farmers' awareness of ecology of mosquitoes and combining public health measures with pesticide management.

"Today, as new risks to workers have arisen and standards have been created to protect them, the workplace has become a central point for broadening social protection."

YOU UNDERLINE THE IMPORTANCE OF LINKING PUBLIC HEALTH AND OCCUPATIONAL HEALTH. AS WE CONCLUDE OUR INTERVIEW, COULD YOU TELL US MORE ABOUT THE RELATIONSHIP BETWEEN THESE TWO SPHERES AND THE OPPORTUNITIES THEIR INTERACTION OFFERS?

Occupational health and public health originally walked separate paths. Today, as new risks to workers have arisen and standards have been created to protect them, the workplace has become a central point for broadening social protection, particularly in southern countries where public health systems are less developed. In these regions, epidemiological monitoring at the workplace and risk prevention measures are being put in place in line with local legal obligations and the requirements of sub-contracting contracts with order-givers in northern countries.

These institutional mechanisms applied to companies were initially designed to prevent occupational hazards but are increasingly used to expand workers' social protection so that it covers all risks, thus offering an opportunity to develop public health.

5 Matowo, N. S., et al. (2022). Participatory approaches for raising awareness among subsistence farmers in Tanzania about the spread of insecticide resistance in malaria vectors and the possible link to improper agricultural pesticide use. *Malaria Journal*, 21(1), Article 277. https://doi.org/10.1186/s12936-022-04289-1.

Drone flying over a forest fire

Environmental crises and climate change:

Eco-anxiety among young people and the urgent need for a transformative response

Annamaria Lammel
Emeritus professor of developmental cognitive psychology at Paris 8 University and Research Director at Paragraphe Laboratory

Source: A. Lammel

Annamaria Lammel is an emeritus professor at Paris 8 University and research director at Paragraphe Laboratory. She has studied anthropology, cognitive psychology and linguistics. Her research, conducted with the Totonac people in Mexico, the Inuit in Canada, and in France, examines the influence of culture and the bio-physical environment on human development. She is interested in children's perceptions of environmental threats and their cognitive and psychological adaptive capacity. She has identified the shift from a "natural" childhood to a "technological" childhood, and the emergence of "cyborg-children". She is a lead author of the two most recent IPCC reports and an advisor to the United Nations on the global environment.

The world faces a threefold environmental crisis: climate change, biodiversity loss, and pollution. Awareness of these crises is growing, as more and more organizations attempt to control harmful human activities. Despite these efforts, the changes made are insufficient. The media delivers alarming news on a daily basis, triggering stress that can turn into eco-anxiety, a chronic fear of environmental catastrophe which in turn can lead to depression and states of anxiety. Climate anxiety, a form of eco-anxiety, is a major threat to mental health in the 21st century. It impacts mental health directly via extreme meteorological events, indirectly via consequences such as famine, and vicariously via the media. Young people are particularly susceptible: 47% of young adults in the US state that it impacts their day-to-day lives. Children are especially vulnerable and may develop eco-anxiety from as young as 8 years old. Tackling this widespread mental health problem, linked to a variety of factors, requires taking action that addresses the root of the problem: education, provision of more green spaces, biophilic design, responsible attitudes, a long-term vision on the part of politicians and businesses, and the transformation of our systems. Governments must protect young people, recognize their fears, and involve them in decision-making. Urgent collective action is essential if we are to protect the mental health of younger generations.

> *"I think there will be lots of storms in France because it has been so hot that the weather will need to catch up and all the water in the sky will fall at once. Perhaps France will become an island. In 30 years from now the planet will be damaged, perhaps there will be no more trees because of all the toxic products, and since they help us breathe we will die without them."*
>
> Julie, age 11, Paris region, 2011

INTRODUCTION

Not a day goes by without alarming new reports in the media about climate change, biodiversity loss, and the ever-growing pollution of water, sea, land, and air. Even if they have no direct personal experience of these phenomena, people are nonetheless affected by them. They feel a sense of cognitive vulnerability in response to the complexity of the problems and an inability to act when faced with their immensity, which triggers powerful negative emotional responses.

Imagine coming home one day to find water damage, a smell of mold, dust everywhere, and an insect invasion. You feel stress – a normal reaction – and use your cognitive capacities to think about how to make your apartment livable again.

But how can we manage stress in the face of a planet that is out-of-balance, threatened, and threatening, and the inertia of human systems in finding effective and lasting solutions? In this case, stress turns into powerful negative emotions, a form of anxiety labelled in 2000 by psychiatrists and psychologists as eco-anxiety.

THE SITUATION TODAY: A THREEFOLD ENVIRONMENTAL CRISIS AND AN INADEQUATE RESPONSE

The world faces a threefold environmental crisis as well as soil degradation:

- climate change: the Sixth Assessment Report of the United Nations Intergovernmental Panel on Climate Change (IPCC) published in March 2021 (working group 1), estimated that global warming will reach 1.5°C above the pre-industrial era by the early 2030s, irrespective of future greenhouse gas emissions scenarios;
- biodiversity loss: according to the 2019 Global Assessment Report from the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES), one million plant and animal species currently face extinction;
- pollution: it is estimated that pollution is responsible for 9 million deaths worldwide every year, with pollution-related deaths having risen by 66% over the last two decades.[1]

In addition to this threefold crisis is the issue of soil degradation. In 2022, the United Nations Convention to Combat Desertification (UNCDD) sounded the alarm in a report stating that 40% of land worldwide was now degraded (up from 25% in 2017), a fact that directly impacts half the world's population and threatens half of global GDP.

Awareness of these global crises has grown significantly in recent years. The multiplication of international and national bodies set up to regulate harmful human activities is a perfect illustration of the scale of the problems. However, despite all the efforts and some progress, the signs point to the fact that the changes needed to rebalance the world's biophysical environment are very far from being achieved.

THE PSYCHOLOGICAL IMPACT OF THE ENVIRONMENTAL CRISIS: ECO-ANXIETY

States of anxiety relating to the dangers of pesticide use or the explosion of the Chernobyl reactor have been recognized since the 1960s: they were therefore already linked to environmental risks. The term eco-anxiety, a specific form of anxiety, only appeared post-2000. Eco-anxiety can be described as a persistent sense of anxiousness relating to the degradation of nature and the natural environment. It is a feeling of loss, a sense that the developmental "niche" we were attached to has been altered. The concept of biophilia[2] is often cited since it refers to our affinity to nature, which is threatened by the technological world based on constant increases in production and consumption. There may also be a sense of losing identity and continuity in the line of living beings, free and protected by balanced ecosystems that evolve gradually over millions of years.[3]

"Eco-anxiety can be described as a persistent sense of anxiousness relating to the degradation of nature and the natural environment. It is a feeling of loss, a sense that the developmental "niche" we were attached to has been altered."

Eco-anxiety is not recognized as a specific pathology by the DSM-5.[4] The American Psychological Association defines it as "chronic fear of environmental doom."[5] This mental state includes excessive worry, anxiety and persistent stress about the devastating potential effects that climate change will have in the future and, naturally, on the young people of today and tomorrow. The scientific literature describes the presence of negative emotions such as fear, pain, sadness, anger, and a sense of guilt as well as frustration. People afflicted with eco-anxiety can feel, for example, that current efforts to cut greenhouse gas emissions are an inadequate response to climate emergency. This form of anxiety can provoke genuine mental health issues: depression, states of anxiety, and stress-related illnesses.

1 UNEP. (2024). How science-policy bodies are driving solutions to planetary crises. https://www.unep.org/news-and-stories/story/how-science-policy-bodies-are-driving-solutions-planetary-crises.

2 Wilson, E. O. (1986). Biophilia. Harvard University Press.

3 Passmore, H. A., Lutz, P. K., & Howell, A. J. (2023). Eco-anxiety: A cascade of fundamental existential anxieties. Journal of Constructivist Psychology, 36(2), 138-153.

4 Fifth and most recent edition of the Diagnostic and Statistical Manual of Mental Disorders published by the American Psychiatric Association.

5 APA and ecoAmerica, 2017.

Source: A. Lammel

A SPECIFIC FORM OF ECO-ANXIETY: CLIMATE ANXIETY

According to an article in The Lancet, "climate change could be the biggest global mental health threat of the 21st century."[6] In this article we will focus on a specific form of eco-anxiety: climate anxiety.

Climate changes can impact mental health in three manners: directly, indirectly and vicariously.[7]

- Directly: the experience of extreme meteorological events can trigger post-traumatic syndromes, depression and anxiety, even thoughts of suicide.
- Indirectly: indirect effects include consequences of climate change such as famine related to droughts, migration, and property loss. These increase cognitive vulnerability and open the door to anxiety and depression.
- Vicariously: even where individuals are not directly or indirectly impacted by climate change, their mental health can still be compromised. In this case we talk of proxy effects: media coverage means people are aware of the changes already happening and often exposed to catastrophic predictions for the future, and they can develop eco-anxiety as a result.

"According to an article in The Lancet, "climate change could be the biggest global mental health threat of the 21st century."

The literature distinguishes between different states of mental health linked to climate crises, but also to the two other crises cited in the introduction (biodiversity loss and pollution). Ecological grief refers to a mental state characterized by sadness and pain triggered by changes to ecosystems. Another similar psychological phenomenon is known as "solastalgia", a form of painful nostalgia caused by the loss of untouched nature. These forms of climate anxiety are linked to humans' innate need to belong to a healthy world. The concept generally evokes a feeling that is omnipresent among indigenous and local peoples, now identified by western scientists as the "One Health" concept, a single health that encompasses all living beings and ecosystems. Human health can no longer be seen as distinct from the health of other life forms and balanced ecosystems.

Psychologists are currently working on tools for identifying climate anxiety. Clayton and Karazsai[8] have, for example, published a method to measure it. A five-point Likert questionnaire[9] offers 13 suggestions, along the lines of "I have nightmares about climate change." This tool has been validated for the American population and is adapted for use in other countries. These sorts of scales of climate anxiety make it possible to identify the extent of the phenomenon.

CLIMATE ANXIETY: A GROWING THREAT TO THE MENTAL HEALTH OF YOUNG PEOPLE AND CHILDREN

A study in the USA shows that 68% of respondents feel at least a little eco-anxiety in relation to climate change. Young adults aged 18 to 34 are particularly concerned, with 47% of them declaring that climate change-related stress impacts their daily lives. Climate anxiety knows no borders when it comes to children and young people. A study in 10 countries involving 10,000 children and young people aged 16 to 25[10] shows how widespread the problem is. A large majority of the young people questioned stated that they are very or extremely worried by the effects of climate change ***(Figure 1)***. Respondents often cited the same negative emotions as adults: sadness, anxiety, anger, powerlessness, and guilt. Over 45% of respondents declared that climate change was a source of chronic stress for them.

Young people are thus very worried about the future and feel a sense of despair and betrayal toward adults and governments. The study suggests that lack of government action in the face of climate change contributes to psychological stress among children and young people, as well as to a sense of moral injustice.

6 Costello, A., Abbas, M., Allen, A., Ball, S., Bell, S., Bellamy, R., ... & Patterson, C. (2009). Managing the health effects of climate change: The Lancet and University College London Institute for Global Health Commission. The Lancet, 373(9676), 1693-1733.

7 Berry, H., Bowen, K., & Kjellstrom, T. (2010). Climate change and mental health: A causal pathways framework. International Journal of Public Health, 55(2), 123–132. https://doi.org/10.1007/s00038-009-0112-0.

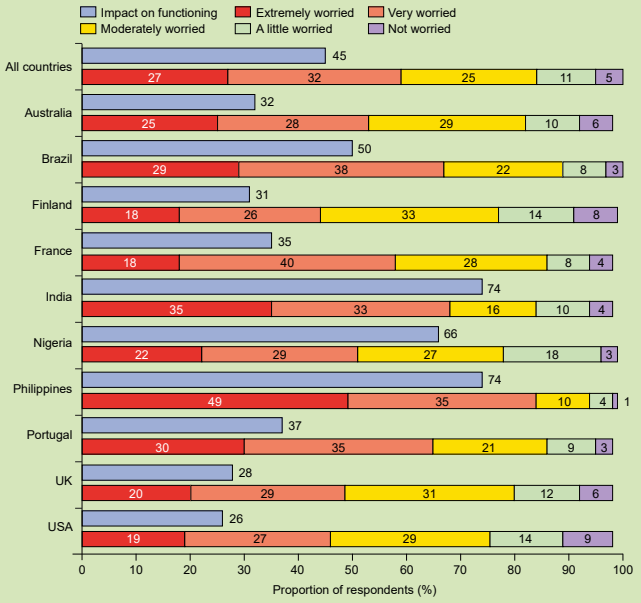
8 Clayton, S., & Karazsia, B. T. (2020). Development and validation of a measure of climate change anxiety. Journal of environmental psychology, 69, 101434.

9 Likert scale questions generally comprise five points (totally disagree, disagree, neutral, agree, totally agree).

10 Hickman, C., Marks, E., Pihkala, P., Clayton, S., Lewandowski, R. E., Mayall, E. E., ... & Van Susteren, L. (2021). Climate anxiety in children and young people and their beliefs about government responses to climate change: a global survey. The Lancet Planetary Health, 5(12), e863-e873.

Figure 1 also shows that the children and young people most exposed to climate risks, such as in the Philippines, India, or Portugal (because of forest fires), are more worried than those who live under more favorable climatic conditions and in countries that offer greater economic protection, such as Finland.

Figure 1: **Proportion sample reporting a negative impact on functioning due to their feelings about climate change and various levels of worry about it. Data for the whole sample (n=10,000) and by country (n=1,000 per country).**



Source: Hickman, C., Marks, E., Pihkala, P., Clayton, S., Lewandowski, R. E., Mayall, E. E., ... & Van Susteren, L. (2021). Climate anxiety in children and young people and their beliefs about government responses to climate change: a global survey. The Lancet Planetary Health, 5(12), e863-e873. Figure 1.

The specific nature of eco-anxiety among younger children has been observed and studied from the age of 8.[11] Children spontaneously develop an environmental moral judgement that is mostly biocentric, meaning they believe the living world, not just humans, enjoys the same rights as people.[12] This concept is close to the notion of biophilia. With growing urban sprawl and the globalization of the virtual world, children have less and less contact with green spaces and water, despite the fact they are acknowledged as necessary for mental health. The absence of such contact can trigger nature-deficit disorders. These vulnerable children are then confronted with the dangers of climate change and the threat of environmental collapse directly, indirectly or vicariously.

A qualitative study was carried out in 2011 as part of the ACOCLI project (Cognitive Adaptation to Climate Change) which I coordinated and was supported by the French National Research Agency (ANR). The study questioned 80 children and teenagers in the Paris region aged from 11 to 14. Analysis of the data showed that already 13 years ago, children from the age of 11 experienced strong negative emotions when facing problems related to climate change (***see Figure 2***). During semi-structured individual interviews, the children expressed signs of anxiety, fear of the future, and a pessimistic outlook. The increasing seriousness of the climate crisis sadly bears out the truth of these predictions: temperatures have risen, flooding and extreme events are more frequent and widespread, species are disappearing, and the world is being unsettled by new diseases. The idea that life on earth will be extinguished emerges in children's imagination, threatening the construction of their identity. However, similar to what we are seeing with narratives of the climate crisis, a glimmer of hope and a desire to act are also emerging. The data corroborates recent studies cited above, clearly indicating that eco-anxiety is prevalent among children and young people, and that this is not a recent phenomenon.

Figure 2: **Topics raised concerning perceptions and predictions about climate change in semi-structured interviews with children aged 11 to 14 (n=80) in the Paris region in 2011 (ACOCLI project, ANR).**

1. **Observation of change:** children notice signs of global warming such as unusual temperatures and extreme meteorological phenomena.
2. **Impact on daily life:** they anticipate there will be changes in their daily life, such as more frequent storms or the transformation/disappearance of their environment.
3. **Fear of species loss:** some children mention melting icebergs and the disappearance of polar bears, indicating fears about the loss of animal species.
4. **Anxiety about the future:** children express concerns about the planet's future and are anxious about how the planet will look in 30 or 100 years' time, fearing extinction.
5. **Concerns about health and the environment:** they are worried about the impacts that climate change will have on human health and the environment, such as water shortages and an increasing number of illnesses.
6. **Frustration and sense of urgency:** they feel frustration and a sense of urgency, they want immediate action to be taken to combat global warming.
7. **Feelings of powerlessness and sadness:** some children express a feeling of powerlessness in the face of the scale of the problem, with little sense of what to do to remedy it.
8. **Mixture of pessimism and optimism:** the children oscillate between pessimism about the current situation and cautious optimism about the possibility of a better future if appropriate measures are put in place.
9. **Impact on behavior:** some children modify their behavior in response to their anxieties, by recycling, walking rather than taking powered transport, or by expressing a desire to work in fields that relate to the environment.
10. **Desire to act:** despite their anxiety, some children show a desire to act and help fight climate change, either through individual actions or by calling for collective actions.

11 Léger-Goodes, T., Malboeuf-Hurtubise, C., Mastine, T., Généreux, M., Paradis, P. O., & Camden, C. (2022). Eco-anxiety in children: A scoping review of the mental health impacts of the awareness of climate change. Frontiers in Psychology, 13, 872544.

12 Lesenecal, A., & Lammel, A. (2023). Comparative study of environmental moral judgment with and without education about sustainable development. In Psychological Applications and trends. inScience Press.

Eco-anxiety can be more pronounced among children than among adults. If we return to the analogy of discovering a house that has been temporarily abandoned, is contaminated and polluted, we recognize that children alone cannot restore it to a good condition. Faced with global environmental threats, they are even more vulnerable than adults since they are still developing and have high levels of cognitive vulnerability,[13] often characterized by naive and mistaken ideas in their understanding of the complex interactions between climate and human systems. This means they need support from adults. But how do they perceive this support?

CHILDREN AND YOUNG PEOPLE FACED WITH THE ADULT WORLD: THE URGENT NEED FOR TRANSFORMATIVE ACTION

Research tells us that there is a very strong correlation between eco-anxiety and the inaction of governments and businesses in response to environmental crises. The ever-widening chasm between "pro-environmental" messaging and concrete action reveals an absence of climate ethics that is a threat to future generations. This disconnect is not limited to the worlds of politics, finance and economics; it also applies to adult lifestyles and behaviors, further exacerbating the crisis of confidence experienced by young people and children.

The scientific literature describes this disconnect as a cognitive bias with deep cultural roots, characterized by the inability to align actions with rational and ethical principles. Climate ethics, which includes inter-species, inter-regional and inter-generational dimensions, is essential to responding to climate emergencies.[14] However, young people perceive this absence of environmental morality as a betrayal, amplifying their feelings of despair and anger and limiting their capacity to imagine solutions and deal with the problems.

Recent research shows that anger can be a key emotional driver for committing to the fight against the climate crisis.[15] However, without truly transformative action on the part of political and economic leaders, this anger risks turning into violence that would compromise any efforts to solve the crisis. A response that is systemic, global and ethical —radically different from the current model—is essential for successfully combating environmental crises and thus eco-anxiety.

While we wait for this necessary transformation to occur, the fast-developing field of environmental education can play a crucial role. It helps young people achieve a better understanding of climate challenges and to channel their energy into positive collective actions. The growing number of non-profits and initiatives encouraging young people to take action collectively is a sign that their voice is increasingly being taken seriously.

Eco-anxiety among young people is a warning signal that needs to be addressed as a matter of urgency. Restoring confidence and giving young people the wherewithal to make an active contribution to fighting environmental crises, particularly climate change, demands immediate, systemic, and profoundly ethical action. We need to take account of their views and fully incorporate them into decision-making processes if we are to build a sustainable future for the generations to come.

CONCLUSION

Eco-anxiety and climate anxiety are a major mental health problem among adults, young people and children worldwide, connected to factors that are psychosocial, environmental, cultural, economic, ethical, legal, and, of course, political.

The scientific literature has demonstrated that climate anxiety is a form of chronic stress that can have long-term negative implications for mental health and the ability to function in day-to-day life. Psychologists and psychiatrists, although always ready to address their patients' difficulties, cannot by themselves deal with this public health problem whose origins lie in multiple factors. Although their work is crucial, their efforts are equivalent to trying to put out a forest fire by tackling it tree by tree.

Action on a wider scale is required, attacking the root cause of the problem: through education, more green spaces, the incorporation of biophilic design, responsible attitudes, and a long-term vision on the part of politicians and businesses. The behavior of adults and human systems must undergo transformation in order to restore environmental health and, thereby, ensure that people enjoy good mental health. Governments have the power to act by acknowledging the fears of children and young people and making them central to policymaking. At this moment in time, urgent collective action is needed to protect the mental health of younger generations.

13 Lammel, A., Dugas, E., & Guillen, G. E. (2012). The contribution of cognitive psychology to studies of adaptation to climate change: the notion of cognitive vulnerability. VertigO, the electronic review for environmental sciences, 12(1).

14 Jones, R.N., A. Patwardhan, S.J. Cohen, S. Dessai, A. Lammel, R.J. Lempert, M.M.Q. Mirza, and H. von Storch, (2014). Foundations for decision making. In Climate Change 2014: Impacts, Adaptation, and Vulnerability. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 195-228.

15 Diffey, J., Wright, S., Uchendu, J. O., Masithi, S., Olude, A., Juma, D. O., ... & Lawrance, E. (2022). "Not about us without us" – the feelings and hopes of climate-concerned young people around the world. International Review of Psychiatry, 34(5), 499-509.


climate emergency
climate crisis
eco-anxiety
extinction

Ecotherapy to rebuild bonds with the living world

Bruno Rousseau
Gestalt therapist, coach, and supervisor

Bruno Rousseau is a Gestalt therapist[1], coach, and supervisor. From the moment he first grasped the importance of ecological issues, and constantly seeing how human health correlates to the health of the planet as a whole, he has dedicated himself to rebuilding bonds between humans and non-humans, working for the health of all using the tools provided by engaged coaching and his ecotherapy practice. He is a member of the Climate Coaching Alliance (CCA) and a coach for the Climate Enterprise Convention (CEC).

As the founder of La Voie du Contact, Bruno Rousseau focuses on bodily and emotional processes to create the conditions needed for the people and teams he supports to move forward. He is also a "Work that Reconnects" workshop facilitator.

I welcome Antoine to my office for our first session. I offer him a coffee and finish my cup of tea. He briefly tells me about his family, professional and social situation. His words are all tinged with his fear of the future. "It began with videos I watched obsessively on YouTube, showing all the damage we're doing to our planet. And now I see that future as bleak." "I'm worried for my children." "I'm worried about losing all my energy if that's all I think about."

This fear of the future finds its way into my sessions. Is it linked to Antoine, to my own eco-anxiety, to the situation? In the here-and-now of my encounter with Antoine, I allow myself to be touched by visions of a bleak future. Since I am particularly eco-anxious (or eco-lucid!) myself, this is a stance that requires me to look for support outside the sessions (such as a network of colleagues working on themes relating to the climate, biodiversity collapse and social emergencies) and during sessions (such as my breathing and bodily sensations when talking to Antoine), helping me to endure the discomfort of an intense and prolonged emotional experience that includes waves of fear, sadness, anger and helplessness.

After several months of therapy, I ask Antoine if he would join me for a walking session in a park near my practice. I get the impression that taking a short walk together in the fresh air opens up a whole new world to us: the pace of our steps, the physical proximity between our walking selves, the way he/I/we stop at the red light before entering the woods, the way he/I/we are moved by the bend of a tree, the color of the pond, the sound of parakeets crisscrossing the sky above our heads allow me to engage with what is emerging in the most intimate way possible. And to support Antoine through his fears of an emotional tsunami while being accompanied by the living world all around us.

In parallel with the sessions, Antoine gradually begins to share his vision of the world with his family, friends and colleagues, allowing the associated feelings to well up. He meets people who share his worries, gets involved in environmental projects and tells me that his eco-anxiety weighs less heavily on him. "I'm getting much better at living with it, and it helps me stay aware of what's going on..."

ACCEPTING EXISTENTIAL ANGST AND ECO-ANXIETY

Gestalt therapists[1] see the emotions and existential angst associated with certain situations as phenomena they contribute to. Anxiety associated with existential givens (freedom and responsibility, loneliness, the search for meaning) is a source of transformation when accepted and harnessed. Otherwise, it risks being concealed and is likely to trigger compensation mechanisms such as addiction, overconsumption, and hyperactivity.

For existentialists, the mere fact of being in the world and confronted with the freedom inherent in every moment gives rise to anxiety. And because this anxiety is linked to existence, we should not try to eliminate it. Existential angst is a source of engagement and creativity and drives our actions in the world.

1 Gestalt is a therapy first developed in the 1950s in the USA. It focuses on the process of contact between human beings and their environment and gives a central place to bodily and emotional dimensions.

Alongside this, eco-anxiety phenomena are developing, particularly in light of growing awareness of global warming, the collapse of biodiversity and increasingly violent social tensions.

Eco-anxiety is a fear of the future, an anticipatory fear that reflects a high degree of emotional intelligence. It is rooted in a lucid analysis of the state of the world and caused by a certain malfunctioning of society. Ultimately, eco-anxious people are rational and perceptive beings in a world that is neither.

The Gestalt paradigm, whereby a person and their environment are indivisible, precludes perceiving anxiety as "belonging" to the person suffering from it. Gestalt invites us to consider our anxiety as primarily belonging to the situation, here and now.

As therapists, we need to let ourselves be touched by the situation to help us move closer to our clients, who increasingly suffer from the violence engendered by being cut off from the living world. Once I allowed myself to physically experience a form of eco-anxiety in my own body, many of my clients began to share their questions and concerns about these subjects.

HOW ECOPSYCHOLOGY CAN HELP

The term ecopsychology was coined in 1992 by American writer and historian Theodore Roszak.[2] A transdisciplinary field born of the ecological crisis, ecopsychology explores deep-rooted interrelations between nature and the human psyche.

The approach is heavily influenced by Norwegian philosopher Arne Naess, who founded the deep ecology movement. This movement challenges the fundamental assumptions of the industrial growth society, one of whose principles is that the world is not a resource humankind can exploit at will.

Ecopsychology "explores the way in which our cultural separation from nature causes not only neglectful and destructive behavior toward our environment but also a great many widespread problems such as depression and addiction."[3] This observation led Joanna Macy to draw up a set of practices she named "work that reconnects" to foster an emotional reconnection with the community of the living world as a whole and overcome despair and the temptation to embrace denial in response to ecological and social situations. For example, as part of the Convention des Entreprises pour le Climat, we invite managers to write a "letter to someone in the future", a family member or friend who will read it in twenty years' time.

As part of the ecopsychology approach, the ecotherapy practiced by professional therapists, particularly in relation to problems with inner transition, eco-anxiety and distress caused by the increasingly visible signs of the collapse of our ecosystems, seeks to move beyond the dualisms of humans and nature, body and mind.

CONTACT WITH OUR INNER NATURE, CONTACT WITH NATURE... SO WE CAN TAKE ROOT AGAIN

Contact includes all movements between a sentient being and their environment. "Tact" refers to the tactile nature of touch and the delicacy of that touch, while "con" (meaning "with") refers to otherness. I cannot touch without being touched, which opens the door to something new.

But we are gradually losing this contact, spending hours and hours on cellphones and in front of computers. David Abram invites us to "reacquaint ourselves with the sensuous world in which our practices and technologies are rooted." We need to re-root ourselves by getting back to our bodies.

The notion of the ***body as contact*** brings us closer to experiencing the body, in the sense of a living organism constantly in motion. Whereas the body in our daily life tends to be a *body as machine*, which does not connect us to the world. Too often it has become a resource to be managed, optimized, and maintained like a productive tool exploited to achieve results.

I am still often amazed when I see the insights of the people I help, working with them to create experiments during sessions, including with the bodily dimension. For instance, by expressing the feeling associated with a difficult situation through a movement of "push against" by pressing our hands against each other.

CONCLUSION :

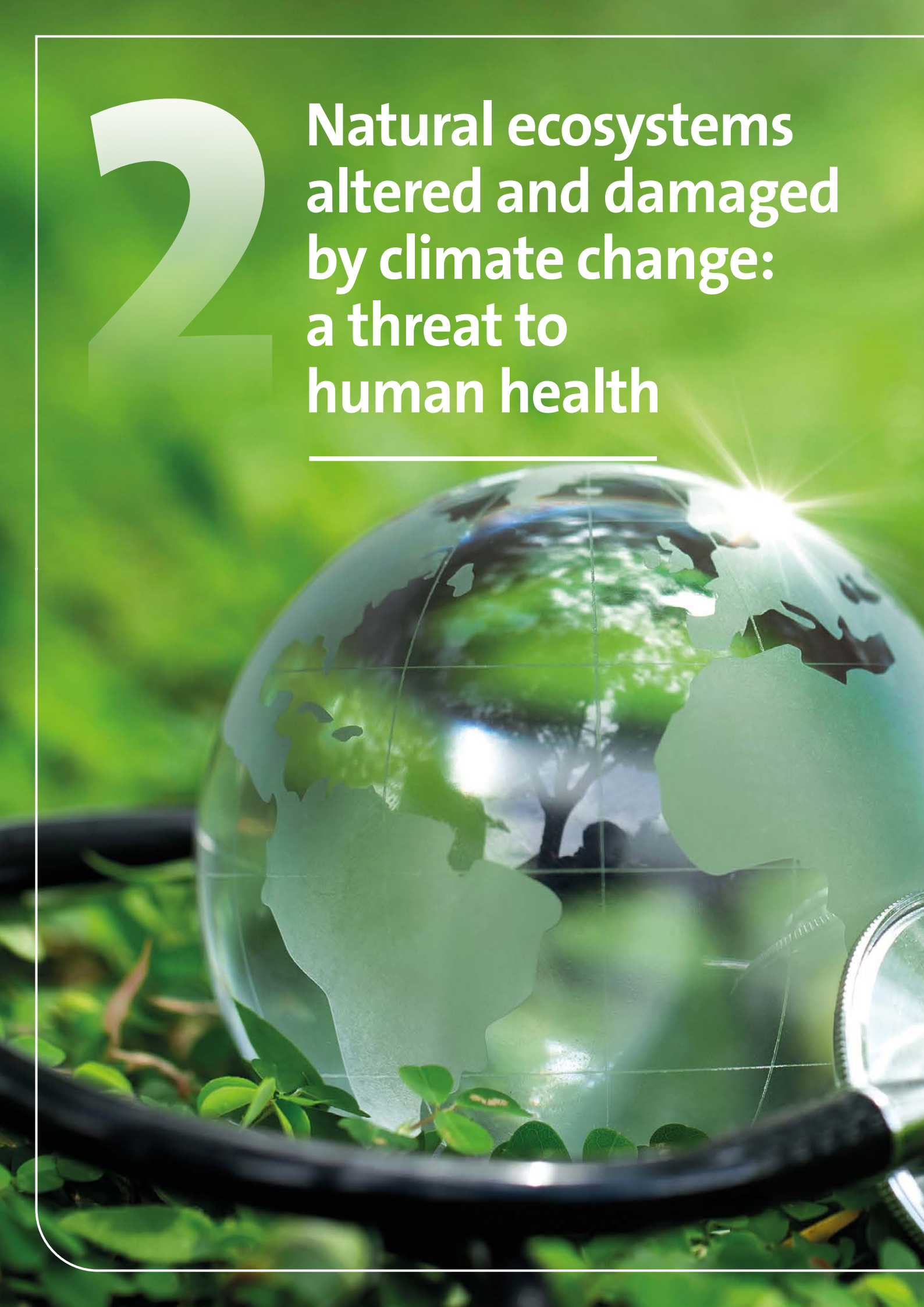
"Our experience of pain for the world springs from our interdependency with all living things, which is also where our power to act in their name derives from. When we stifle our pain for the world, or when we treat it as a personal pathology, the power to be part of its healing is diminished." (Joanna Macy)

The health of people, organizations and the Earth is one and this very indivisible health needs to be invented!

2 Roszak, T. (1992). The voice of the earth: An exploration of ecopsychology. University of California Press.

3 Macy, J., & Young Brown, M. (1998). Coming back to life: Practices to reconnect our lives, our world. New Society Publishers.

2 Natural ecosystems altered and damaged by climate change: a threat to human health



Humans, animals and ecosystems all share "one health". One Health is an integrated, unified approach that invites us to think about health in a new way, recognizing the close interactions between the health of humans, animals and ecosystems. At a time when nearly a quarter of deaths and illnesses worldwide are a consequence of poor environmental conditions,[1] it is clearly vital to acknowledge that human health can only flourish if the other two pillars are preserved. We need to protect them so we can safeguard our life on earth.

"When we harm[1] our environment, we harm ourselves," warned WHO Director-General Tedros Adhanom Ghebreyesus in an op-ed piece appealing for climate change and pollution to be included in our approach to health.[2] This reality is increasingly embedded in our collective conscience as the consequences of the damage to ecosystems continue to be assessed and analyzed. The intergovernmental science-policy platform on biodiversity and ecosystem services (IPBES) says that humanity has never exploited so many natural resources nor generated as much waste as it has in the past 50 years. Climate change is partly responsible because, together with human activities, it is one of the main causes of long-term changes in biodiversity.

The second part of FACTS uses the One Health approach to explore the indirect effects of climate change on human health, via the alterations it causes to natural ecosystems. This begins with the impacts it has on the planet's oceans. Our oceans cover almost two thirds of the globe and play an essential role in the health of the planet's ecosystems. They regulate the climate, are home to almost 80% of the planet's lifeforms, keep us fed and are key to global trade. In summary, says **Françoise Gaill**, there would be no life on earth without them. But we are moving dangerously close to the oceans' limits. Acidification, eutrophication, and variations in temperature and pH may trigger cascading consequences on a scale we still struggle to comprehend.

Beyond the oceans, aquatic ecosystems as a whole are under threat. **Frank Galland** highlights the critical situation facing water courses and water tables as a result of disruption caused by extreme weather events that alter the quantity and quality of water resources. Rivers run dry, leading to water shortages, while floods damage habitats and promote the spread of disease. For **Jessica Fanzo** and **Alison Rose**, climate change and its consequences amplify the vulnerability of our food systems. With farmland impoverished and degraded by climate events and the nutritional qualities of food reduced, how will it be possible to feed a global population estimated to reach 10 billion people by 2050, when three billion people already suffer from malnutrition today?[3]

It should also be remembered that ecosystem disruption has a direct influence on the propagation of infectious diseases. According to a recent scientific study,[4] over half of all human diseases could be aggravated by climate change. **Mary E. Wilson** emphasizes the fact that factors such as rising temperatures, destruction of habitats, and forced migration all contribute to the proliferation of vector-borne diseases. The rise in zoonotic diseases – transmitted from wild animals to humans – illustrates the increasing fragility of natural health barriers. This escalating propagation of infectious diseases is particularly evident in certain regions of the world: **Sandy Moore** and **Rita Colwell** highlight a growing vulnerability to water-borne diseases in sub-Saharan Africa, for instance. Limited access to infrastructure for water, sanitation and health (WASH) is a major factor underpinning the advance of these diseases, a situation exacerbated by extreme weather events.

Finally, climate change also accentuates other forms of environmental pollution. In particular, it amplifies air pollution by encouraging the concentration of certain pollutants such as ozone and fine particles created by fires and sand haze, posing yet another risk to public health around the world. **Emmanouil Proestakis** recounts the effects that fine particles have on human health, with their presence in the air responsible for cardiovascular and respiratory diseases that afflict millions of people every year.

1 Prüss-Üstün, Annette, Wolf, J., Corvalán, Carlos F., Bos, R. & Neira, Maria Purificación (2016). Preventing Disease Through Healthy Environments: a global assessment of the burden of disease from environmental risks. World Health Organization. https://iris.who.int/bitstream/handle/10665/204585/9789241565196_eng.pdf.

2 Ghebreyesus, T. A. (2024, March 28). "Human health is the number one reason that should push us to take climate action." Le Monde.fr. https://www.lemonde.fr/idees/article/2024/03/28/la-sante-humaine-est-la-premiere-raison-qui-doit-nous-pousser-a-agir-sur-le-plan-climatique_6224595_3232.html.

3 World Health Organization (March 1, 2024), Malnutrition. https://www.who.int/news-room/fact-sheets/detail/malnutrition.

4 Mora, C. *et al.* (2022). Over half of known human pathogenic diseases can be aggravated by climate change. Nature Climate Change, 12(9), 869 875. https://doi.org/10.1038/s41558-022-01426-1.

Climate change and food systems interactions:

Ensuring resilient and healthy diets

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Food and the systems in which food is produced, processed, packaged, transported, sold, and consumed are becoming increasingly fragile with the changing climate. At the same time, how we grow food, what food we grow, and the trading and selling of these foods have profound consequences on the climate and environment. The world has benefited from technological advances in food systems, but we now stand at our breaking point. Malnutrition is worsening – both hunger and obesity are rising. Much of that malnutrition has to do with the types of diets we consume, which have contributed to adverse health outcomes. We must change the way we govern, manage, and engage with food systems if we want them to produce healthy diets that benefit everyone's health and nutrition. We need various solutions to do this, and food and climate communities must come together around common goals and actions.

INTRODUCTION

Over the last century, human consumption of energy, food, transport, and infrastructure, land use change, and changing lifestyle patterns have been the primary sources of increased greenhouse gas emissions worldwide. These emissions have increased global surface temperatures and led to massive and expedited changes in earth systems, including ocean and biosphere alterations. Due to these planetary boundary shifts, human-induced climate change alters weather and climate extremes, causing widespread adverse impacts, losses, and damages to both human society and nature.[1]

Food systems comprise all the activities, actors, and policies related to food production, storage, processing, packaging, transportation, and sale in the global economy. The attributes of food systems can be wide-ranging, from global to hyperlocal. Food systems and climate change are in an intimate dance – one that could be beneficial or detrimental for life on this planet, depending on how we act. These systems are fragile and vulnerable to climate change and are not managed sustainably, resulting in devastating impacts on human health. However, there are solutions. It is up to the collective global citizenry to spur transformation and ensure that food systems are resilient and contribute positively to the planet.[2]

1 IPCC (2023) Summary for Policymakers. In: Climate Change 2023: Synthesis Report. Contribution of Working Groups I, II and III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, H. Lee and J. Romero (eds.)]. IPCC, Geneva, Switzerland, pp. 1-34, doi: 10.59327/IPCC/AR6-9789291691647.001.

2 Willett, W., Rockström, J., Loken, B., Springmann, M., Lang, T., Vermeulen, S., ... & Murray, C. J. (2019). Food in the Anthropocene: the EAT–Lancet Commission on healthy diets from sustainable food systems. The Lancet, 393(10170), 447-492.

FOOD SYSTEMS ARE VICTIMS

The impacts of near- and long-term climate variability and change will have widespread implications for food systems, including agriculture productivity and supply chains. Global warming is projected to alter what type and where crops are grown and their ability to generate enough yields to feed a population of 10 billion by 2050. Climate projection models have shown that more atmospheric carbon dioxide concentrations could challenge some crops, particularly maize grown in the tropics, to maintain current-day yields.[3] Various modeling studies also suggest that with elevated atmospheric carbon dioxide concentrations, crops such as wheat, rice, potatoes, and barley could lose their nutritional quality – with declines in the protein and micronutrient content – of highly consumed plant-based foods. These nutritional declines could exacerbate what is already an alarming global health crisis – over half of children under five years old are micronutrient deficient in either iron, zinc, or vitamin A, and two-thirds of women of reproductive age are micronutrient deficient in either or at least iron, zinc, and folate.

Other harmful effects of climate change are mediated through sea-level rise. Small Island Developing States and coastal areas of South Asia, Southeast Asia, and West Africa – where rice – and aquaculture-based production systems dominate – are at increasing risk from both encroachment by coastal waters as sea level rises and increased groundwater salinity. Salinization of soil and groundwater further limits the physical extent of land suitable for agricultural production, potentially exacerbating food insecurity and poor nutrition outcomes such as undernutrition and micronutrient deficiencies.

While longer-term climate change projections paint a grim future, climate variability and extreme weather events, such as droughts, heat, and heavy precipitation, require more immediate attention because they impact food availability and access, diets, and nutrition outcomes.

"Global warming is projected to alter what type and where crops are grown, as well as our ability to generate enough yields to feed a population projected to reach 10 billion by 2050."

The damage of extreme events such as droughts, heat waves, or floods on productive assets, infrastructure, and essential services can persist long after the shock has passed. Extreme events can decimate local and regional food systems by impacting production, transportation, storage, market and food environment access, and by causing the loss and waste of food. Until fairly recently, East Africa was experiencing an unprecedented drought, with multiple failed rainy seasons.

The region has a history of droughts, so the compounding effects of repeated years exacerbated vulnerabilities. In Ethiopia, for example, this led to millions of people experiencing food insecurity over the years due to impacts on vegetation and livestock as well as rangeland degradation and water shortages.[4] Extreme weather events can also impact urban settings. In 2006, after Hurricane Katrina struck New Orleans, access to food was impacted through the closure of a significant proportion of supermarkets in the city. Two years later, the number of supermarkets still had not returned to pre-storm levels.[5] Extreme events hamper food supply chains and disrupt global food trade and distribution channels, making it harder for foods to be available in markets. Less predictable supplies create market speculation, significantly affecting physical and economic access to healthy diets.

These events also put people at significant risk for severe food insecurity and undernutrition, and failing food systems can impact the availability and physical and economic access to safe, diverse, and healthy diets. For example, across 19 studied countries, higher long-term temperatures were associated with lower dietary diversity.[6] Another related study found that periods of minor to severe drought and severe wetness were correlated with more stunting (a measure of chronic undernutrition) among children across 53 low – and middle-income countries.[7] Lastly, a study in 5 countries in West Africa found that lifetime exposure to temperatures above 35°C increases the prevalence in young children of stunting by 18% and wasting (defined as low weight-for-height) by 16%. A permanent 2.0°C rise in average global temperatures above preindustrial levels is estimated to increase stunting by 7%.[8]

Climate change affects diets and nutrition outcomes through various food and health pathways, as shown in **Figure 1.** Direct climate effects will impact not only food quantity and quality but also water quality. This, in turn, will affect food and water security and the ability to access quality, diverse diets. Climate change and extreme weather events impact the quantity and quality of food available, exacerbate food inflation and prices, and reduce the affordability of a healthy diet, particularly for low-income and vulnerable populations. This reduction in food affordability is compounded by increased economic losses (for example, lost livelihoods).

3 Jägermeyr, J., Müller, C., Ruane, A. C., Elliott, J., Balkovic, J., Castillo, O., ... & Rosenzweig, C. (2021). Climate impacts on global agriculture emerge earlier in new generation of climate and crop models. Nature Food, 2(11), 873-885.

4 World Health Organization. (2024, May 7). Snapshot: Greater Horn of Africa food insecurity and health - grade 3 emergency: 31 March 2024. World Health Organization. https://www.who.int/emergencies/greater-horn-of-africa-food-insecurity-health-snapshot.

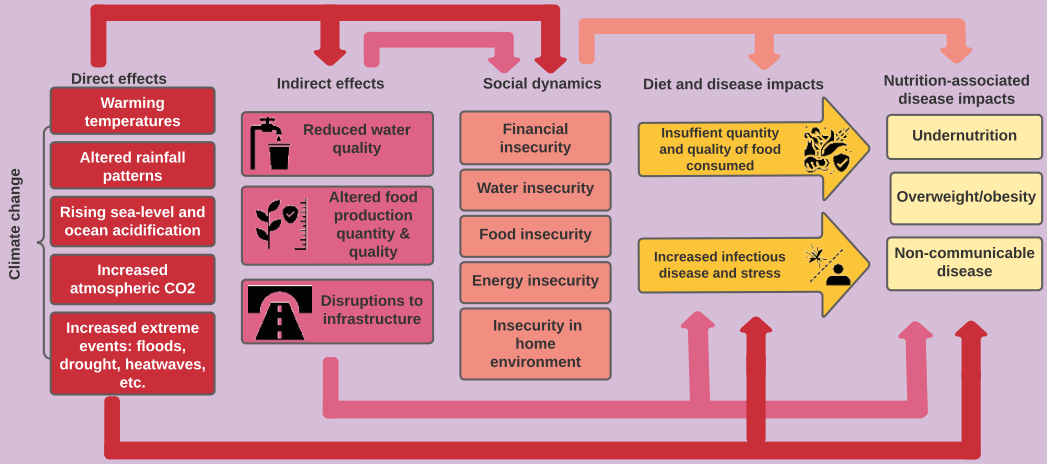
5 Foster, A. M. (2024, July 24). Food Access five years after the storm. Center for American Progress. https://www.americanprogress.org/article/food-access-five-years-after-the-storm/.

6 Brown, M. E., Grace, K., Shively, G., Johnson, K. B., & Carroll, M. (2014). Using satellite remote sensing and household survey data to assess human health and nutrition response to environmental change. Population and environment, 36(1), 48-72.

7 Brown, M. E., Backer, D., Billing, T., White, P., Grace, K., Doocy, S., & Huth, P. (2020). Empirical studies of factors associated with child malnutrition: highlighting the evidence about climate and conflict shocks. Food Security, 12, 1241-1252.

8 Blom, S., Ortiz-Bobea, A., & Hoddinott, J. (2022). Heat exposure and child nutrition: Evidence from West Africa. Journal of Environmental Economics and Management, 115, 102698.

Figure 1: Climate change has impacts on diets and nutrition-associated diseases



Source: Fanzo, J.C. and Downs, S.M., 2021. Climate change and nutrition-associated diseases. *Nature Reviews Disease Primers, 7*(1), p.90.

Already, 3 billion people cannot afford what is considered a healthy diet – one that meets nutrient needs and is health protective – and diets are now a top risk factor of disease and death globally. Even in high-income countries, modeling shows that climate change-associated reduction in fruit and vegetable consumption is the leading risk factor for diet-related non-communicable diseases (such as cardiovascular disease, diabetes, and some cancers).

To paint a stark picture, the quality of the world's diets and nutrition are declining. Diets are now one of the top risk factors for disease and death in the world. Hunger has been rising over the last five years, primarily due to climate change, conflict, and the economic downturn of the COVID-19 pandemic. Stunting has been declining, but still, over 20% of the world's children under the age of five suffer from it. Overweight and obesity, significant risk factors for non-communicable diseases, are rising everywhere. The global prevalence of obesity more than doubled between 1990 and 2022.[9] In North America, for example, 34% of the adult population is overweight and another 32% is obese. Not one country has been able to halt the upward trends of obesity across all ages.

"To paint a stark picture, the quality of the world's diets and nutrition are declining. Diets are now one of the top risk factors for disease and death in the world."

FOOD SYSTEMS ARE INSTIGATORS

While food systems are vulnerable to climate change, they also contribute to climate change and environmental degradation. Food systems are estimated to generate approximately 30% of the total greenhouse gas emissions globally, contributing to all three major gases – carbon dioxide, methane, and nitrous oxide. Most carbon dioxide emissions come from land use change, largely deforestation due to livestock and oil seed crops (such as soy and palm) and on-farm agriculture production. Livestock (mainly cattle for beef, dairy, and sheep) and rice paddy production are major methane emitters, and food systems generate the most methane, a toxic, short-lived greenhouse gas. Nitrous oxide mainly comes from fertilizer use on crops.

Food systems are also significant contributors to environmental and natural resource declines. Agriculture uses 70% of all freshwater resources globally, and the use of chemicals, pesticides, and herbicides also pollutes waterways. In addition, agriculture production is one of the main contributors to biodiversity loss, particularly from forestscapes. According to the Science Panel for the Amazon,[10] 17% of the Amazon has been deforested, with nearly all of that (14%) converted into agricultural land. Such deforestation is one of the primary threats to biodiversity in the region, with projections that climate change and deforestation combined could lead tree richness to decline by 58% by 2050.

Diets overall have impacts on both human health outcomes and environmental sustainability. Dietary quality and other factors contribute to the growing burden of all forms of malnutrition: undernutrition (stunting, wasting, and underweight), micronutrient deficiencies, overweight and obesity, and non-communicable diseases. While food supplies have been able to adapt to rapid global dynamics and changes, food systems are showing some strain. For example, food supplies have, in general, been able to provide enough calories and diversity to meet the rising demand for animal-source foods, fruits, vegetables, legumes, and the range of processed food products that dominate grocery store shelves. These processed foods, called ultra-processed foods, are however devoid of nutrients but with excess sugar, salt, saturated fats, and additives. These foods, along with shifts from whole grains rich in fiber to refined carbohydrates, are of great concern for nutrition and health outcomes.

9 World Health Organization. (2024, March 1). Obesity and overweight. World Health Organization. https://www.who.int/news-room/fact-sheets/detail/obesity-and-overweight.

10 Science Panel for the Amazon. (2021). Impacts of deforestation and climate change on biodiversity, ecological processes, and environmental adaptation. In Amazon Assessment Report 2021 (pp. 1–3). United Nations Sustainable Development Solutions Network. https://doi.org/10.55161/VKMN1905.

In addition, the demand for animal-source foods has risen. Between 1990 and 2015, the global supply of animal-source foods increased by more than 60%, keeping up with global demand. Animal-source foods have become a scientific and political impasse, with divergent interpretations of the scientific literature and intractable value judgments concerning their consumption for human and planetary health. Producing animal-source foods can tax land, biodiversity, and water resources and drive rising greenhouse gas emissions. To lessen the impact of these foods on the environment and climate, some experts within the nutrition and climate science community suggest that we can meet global nutrient requirements from a highly plant-based diet containing just 14% of calories from animal-source foods, much less than the amount of animal-source foods consumed in a typical North American diet (~30%). Moreover, excess consumption of saturated fat, red meat, and processed meat can increase the risk for non-communicable diseases such as cardiovascular disease, diabetes, and some forms of cancer.[11] Limiting the consumption of these foods, particularly those associated with disease risk, has potential benefits for both human and planetary health.

There is increasing evidence that while these animal-source foods contain high amounts of protein and critical micronutrients needed for human growth, development, and overall health, excessive intake of red meat and processed meats specifically has detrimental impacts on health outcomes.

However, others underline that limiting animal-source foods may not provide all the necessary nutrients for human health, particularly calcium, iron, vitamin B12, and zinc. They indicate that minimizing the consumption of these nutrient-dense foods among key populations could be detrimental to growth, development, and health, particularly in poverty-stricken environments in which the milieu of infectious disease burden on individuals is taxing on physiological systems.

Nevertheless, we must recognize how difficult it will be to fulfill the nutritional needs of 10 billion people living on the planet. Massive injustices and inequities exist in people's ability to access healthy diets. Land-use conflicts, many of which are driven by deforestation and agricultural development, also contribute to such inequities and injustices. Land-use conflict contributes to the food insecurity seen in Nigeria through the impacts of violence, forced migration, and agricultural investment decisions, among others.[12] With the current business-as-usual response to climate mitigation and continued environmental and natural resource constraints and degradation, raising animals and growing foods to feed them will become even more complex, exacerbating inequities in who gets access to what types of foods, when, and through what means.

11 Willett, W., Rockström, J., Loken, B., Springmann, M., Lang, T., Vermeulen, S., ... & Murray, C. J. (2019). Food in the Anthropocene: the EAT–Lancet Commission on healthy diets from sustainable food systems. The Lancet, 393(10170), 447-492.

12 Olanrewaju, O., & Balana, B. B. (2023). Conflict-induced shocks and household food security in Nigeria. Sustainability, 15(6), 5057. https://doi.org/10.3390/su15065057.

FOOD SYSTEMS ARE SOLUTIONS

While food systems are both instigators and victims of climate change, they are also part of the solution for mitigation and adaptation. A range of supply-side macro- to micro-level policies and interventions can be adopted, adapted, and scaled across agriculture landscapes and food supply chains. There are a host of demand-driven solutions that policymakers and the private sector can implement to assist consumers in making healthy and sustainable dietary choices.

Nutrition resilience can be achieved by improving food productivity and minimizing food loss, reducing GHG emissions from agriculture, and implementing adaptation strategies for those who are nutritionally vulnerable. As shown in **Figure 2**, these measures span agriculture inputs, as well as the availability of, access to, and utilization of food. Specific actions that can increase the resilience of food systems and households to climate change include research and development of stress-tolerant and resilient crop varieties and animal breeds, more efficient food markets, agricultural information services, improved social protection measures, and early-warning systems.

Figure 2: Climate-resilient strategies across food systems

Theme	Action
1. Food supply-chain inputs	Increase access to seed varieties and livestock breeds that are diverse and resilient to variable weather conditions (heat and drought), pests, and diseases.
	Use agricultural extension programs to improve access to information and training about these varieties and breeds.
	Improve soil quality through the use of cover crops, crop rotation, balanced use of fertilizers, and manure.
	Increase irrigation systems to protect crops and livestock from loss due to changes in seasonal precipitation and extreme weather events.
2. Agriculture production	Invest in and provide education on integrated land-use policies and mixed crop and livestock systems.
	Expand access to services and financing to support farmers, including farmer risk-management tools, insurance, and loans.
3. Post-harvest storage and processing	Improve infrastructure, especially in rural areas, including roads, warehouses, and processing plants.
	Provide training on safe storage and processing techniques, such as drying.
4. Distribution, marketing, and retail	Improve retailer access to water, electricity, and cold storage.
	Create networks of food producers to increase market access and help limit food waste.
	Improve transportation infrastructure in areas where the effects of climate change will limit people's ability to access markets.
5. Food consumption and utilization	Expand access to social protection services, including unconditional cash transfers and supplementary food allowances.
	Increase consumption of animal-source foods in low- and middle-income countries while educating the public about the health risks associated with the overconsumption of these foods.
	Improve access to safe and energy-efficient cookstoves.
6. Undernutrition	Increase access to healthcare for vulnerable populations, especially the rural poor, by increasing healthcare facilities and staff.
	Provide access to animal-source and fortified foods for nutritionally vulnerable populations.
7. Early warning systems	Improve early warning systems and increase farmers' access to them.
	Provide training to producers on how to protect crops, store food, and otherwise prepare for extreme weather events.
8. Evidence for and inclusion of nutrition in climate research	Conduct research and collect and analyze data on how climate change affects the food system and how to maximize nutrition amid these effects.

Source : Fanzo, J., Davis, C., McLaren, R., & Choufani, J. (2018). The effect of climate change across food systems: Implications for nutrition outcomes. Global Food Security, 18, 12-19.

Agriculture production practices can be a source of mitigation potential. Depending on the system – be it crops, livestock, or aquaculture – there are a range of solutions such as precision agriculture (using GPS or drones to optimize the use of fertilizers and pesticides, etc.), crop rotation and diversification, conservation tillage to reduce soil disturbance and erosion, agroforestry, and cover cropping. Solutions also include sustainable livestock management such as improved feeds, rotational grazing, and vaccines to reduce methane emissions. Uruguay, which is a significant livestock producer and where agriculture is a major contributor to the country's total GHG emissions, has introduced measures to support improved management of livestock in grasslands.[13] While all these solutions have their strengths and weaknesses, there needs to be robust policies and an enabling political environment to make these changes and facilitate and assist farmers through them so they can adapt without significant risk.

To ensure supply chains are resilient, there is a need to invest in improved technologies and practices for storing food and reducing post-harvest loss. There must also be more innovation and technology in cold-chain storage to ensure food is not spoiled, lost, or wasted in transport and storage. Establishing early-warning systems and climate information services is critical to enable farmers and others working in food systems to incorporate climate and weather information and analyses into their decision-making.

13 Food and Agriculture Organization of the United Nations. Reducing emissions intensity and improving natural resources management through livestock in natural grasslands in Uruguay. 2020.

Various policies and strategies are also available to incentivize consumers to shift their diets towards healthier and more environmentally sustainable ones. However, with the high cost of nutrient-rich foods and overall diets, climate change, and food inflation worldwide, safety nets and other social protection measures are needed for resource-constrained households and vulnerable and marginalized individuals. The affordability of low-cost healthy items is essential, but more is required to ensure access to and consumption of healthy diets.

"However, with the high cost of nutrient-rich foods and overall diets, climate change, and food inflation worldwide, safety nets and other social protection measures are needed for resource-constrained households and vulnerable and marginalized individuals."

For those who have more choice, there are ways to help guide populations towards healthier and more sustainable food choices, including providing health and environmental information and declarations on food product packaging and instituting national food-based dietary guidelines to guide public procurement, such as school meal programs.

CONCLUSION

It is increasingly recognized that food is central to the climate agenda and that moving towards more sustainable food systems that produce healthy diets is a pathway to climate mitigation and adaptation. However, the opportunity to mitigate climate change is closing, and food systems' action and investment must be scaled rapidly.

To ensure food systems are climate resilient and able to produce healthy diets for everyone in equitable ways, a range of actors working at different scales – from local to global – need to participate in the transformation. However, the latter will have its fair share of trade-offs. Policymakers are often in the dark about how these will materialize and how food systems perform under duress, leaving them uncertain of where to intervene and invest.

To deal with these trade-offs and better guide policymakers, the research community needs to provide rigorous data and evidence to unpack some of the most complex food issues in real-time and translate those findings to decision-makers across food systems. The challenges and opportunities for food systems data and science that lay ahead are significant, requiring that high-quality science be translated into policy faster than ever before.

Yet, data is not enough. We need more political will and commitment to food systems actions to tackle the climate crisis. Integrating food commitments and investments into the Conference of Parties climate meetings and committing to food systems transformation will be of the utmost importance in the next few years if we want to achieve both human and planetary health.


REDFLAM
WONDER

Spillover:

From climate change to pandemics

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Climate change will increase human infections and the risk of pandemics by affecting pathogenic microbes, their environmental reservoirs and animal hosts, and the mosquitoes and other vectors that transmit them. Climate-induced movement of arthropod vectors and range shifts of wildlife will place larger populations at higher risk for infectious spillover events. Recent epidemics and pandemics (e.g., HIV/AIDS, Covid, SARS, mpox, Ebola) have all originated from wildlife viruses carried by bats, rodents and other animals. While some areas in Africa are projected to become too hot for malaria transmission, changing climate will allow expansion of *Aedes*-transmitted viral infections, such as dengue, chikungunya, and Zika, into areas with large urban populations. Animals and plants are themselves susceptible to die-offs and even extinction from infections, jeopardizing food security and health.

Another unknown is whether the vast permafrost, now melting, could become a source of novel microbes that are pathogenic for humans.

Travel, trade, and migration contribute to the global movement of human and animal pathogens and vectors. These forces will be amplified by climate change, and climate-related loss of biodiversity will make ecosystems less resilient to invasive species.

A One Health approach - considering together humans, animals, plants, and the shared environment – can inform surveillance, monitoring, research, and response, and help preserve human well-being while protecting the planet.

INTRODUCTION

Infections are multiplying. Pathogens causing many of these infections are viruses typically found in wildlife. Since 2020, massive die-offs of birds related to H5N1 influenza virus have been observed, and more than 50 species of mammals have been infected. Several well-known mosquito-borne viral infections, such as dengue, chikungunya, and West Nile infections, are similarly expanding.

The Covid pandemic has killed millions, disrupted daily life, and exposed vulnerabilities in global systems for public health, health care, food security, governance, political discourse, and equitable sharing of resources.

This article explores how climate change can be expected to affect the appearance and progression of outbreaks and epidemics, even the resurgence of old diseases. Discussion will focus on spillover events—transfer and establishment of infection from one species to another—and vector-borne infections, and give the tools to aid understanding and mitigation of microbial threats to health. A One Health approach, that embraces humans, animals, plants, climate, and ecosystems, offers insights to build the necessary global, integrated surveillance and response systems.

SPILLOVER EVENTS

A network of biological interactions underpins the development of infections in humans and animals; these biological systems are responsive to temperature, rainfall, humidity, and environmental conditions. Many infections, such as salmonella or campylobacter routinely spread from animals to humans. These are known as zoonoses, and most have been occurring for centuries.

Many recent pandemics have been caused by animal viruses that have more recently spilled over into humans (e.g. SARS, MERS, Covid, HIV/AIDS). A spillover event refers to the transfer of a microbe from one species to another and establishment of infection.[1] After such an event, some pathogens use a vector, like a mosquito, to spread to other humans and/or animals. Most spillover events leading to epidemics have been caused by viruses, but they can involve bacteria and other types of pathogens.

Occasionally spillover events with novel microbes for which humans have no immunity can spark epidemics and pandemics. It is thus important to understand the drivers of spillover, including such factors as climate change and human behavior, and to identify ways to mitigate them.

1 Plowright, R.K., et al. (2017) Pathways to zoonotic spillover. Nature Rev Microbiol 15(August):502-510. www.nature.com/nrmicro.

Viruses and other microbes that live harmlessly in one animal species may cause deadly diseases in others. Bats carry a number of viruses that can cause severe disease in humans. They can be transmitted directly by bite, or after they have infected another animal, as occurred with SARS-CoV-1 (cause of SARS pandemic in 2003), which infected palm civets, and MERS-CoV, which infected camels and then spread to humans. The Nipah virus, which can cause fatal encephalitis in humans, can infect pigs, in which the virus amplifies and can then spread to farmers or can contaminate date palm sap when bats feed on the sap being collected for human consumption. The virus also occasionally spreads from person-to-person under conditions of extremely close contact.

Bats

Bats, the only mammal that flies, are the source of several viruses that have caused severe epidemics in humans. Scientists are eager to understand how they can carry these viruses without showing obvious signs of tissue damage. Bats are old evolutionarily, widely distributed (all continents except Antarctica), abundant (>1400 species and constitute about 20% of all mammals), varied, ranging from the 2-gram bumblebee bat to flying foxes with wing spans of 6 feet. They live in colonies that may have tens of thousands or even millions of bats. They migrate to seek food. Some hibernate during harsh conditions, often in caves. They are active at night and navigate using echolocation. They live longer than other mammals of similar size, often 7-8 years or even longer.

Many consider bats as shadowy, dark figures but they serve critically important roles, pollinating plants, spreading seeds, and consuming insect pests that destroy crops. Their diet includes insects, small mammals, fruit and nectar. Consumption of partially eaten fruit contaminated with bat urine and feces by pigs in Malaysia may have been the route that infected pigs with Nipah virus, who passed infection to pig farmers. In many areas of the world clearing of land for agriculture or development has displaced bats from habitats where they live or feed. This has increased the contact of bats with human and domestic animal populations.

Household pets often share microbes with their human companions. Microbes from food animals, like salmonella and campylobacter, regularly reach humans via meat, milk or eggs, following long-established pathways that typically do not introduce novel pathogens into the human population. The growing global demand for animal protein has led to industrial farming where animals, especially swine and chickens, are raised by the thousands in concentrated areas. Globally the biomass of food animals now exceeds that of all humans. In many regions, wild animals are intensively farmed for fur, food, and other products. Wild animals introduce multiple possible pathways of spread of novel pathogens to humans: animal bite (e.g., rabies), inhalation of microbes in the air (possibly influenza, coronaviruses), eating or drinking contaminated animal products, etc. Live animal markets

selling wild animals, such as the palm civets infected with the bat-origin-SARS coronavirus in 2003, may provide the intermediate hosts through which pathogens in other wildlife reach humans. Bats are also hunted and eaten in some cultures. Novel connections pose new risks.

Some economic development practices have expanded opportunities for spillover events at the human-wildlife interface by bringing species into contact that would not normally interact. These practices include land use change (often for agricultural expansion to support livestock production), encroachment on habitats and displacement of species (such as bats), wildlife farming and trade, live animal markets where multiple different species of wild animals may share crowded stalls, and global travel and trade.

Spillover of a virus into a mammalian host provides opportunities for viral evolution and potential spread. While most spillover events do not lead to epidemics or pandemics, notable ones, like HIV-1 spilling over from chimpanzees in Central Africa in the 1900s, have had devastating global consequences. The virus did not disperse globally until later in the century when many factors, including travel, trade, injection drug use, broad dissemination of blood products, and change in sexual mores, fueled a pandemic that killed millions.

"While most spillover events do not lead to epidemics or pandemics, notable ones, like HIV-1 spilling over from chimpanzees in Central Africa in the 1900s; have had devastating global consequences."

SPECIES RANGE SHIFTS

Many species live in specific geographic areas, defined by ecoclimatic conditions that allow optimal survival. Climate change is shifting the geographic range and distributions of species, including insects, and changing pathways for migratory animals, all creating more opportunities for novel interactions across species.[2]

Crossing the species barrier can be difficult. Many cultural, behavioral, biological, environmental, and immunological barriers inhibit the successful passage and establishment of a microbe from one species to another - and then its global spread. Physical proximity and contact are necessary but not sufficient. The common methods of entry into a human are through the air, from food/drink, or through the skin or mucous membranes. Entry via the skin may be accomplished by an arthropod vector, such as mosquito or tick, or by breaking of skin by trauma. Many microbes carried by animals cannot establish infection in a human host. Viruses must be able to attach to and enter a cell and take over cellular processes to survive and replicate, but human tissues may not have cells with receptors that allow attachment of the virus. Whether infection will follow direct contact with a microbe depends on microbial and host factors (such as abundance of microbe, site of contact, virulence of the microbe, susceptibility of the host, and immune response). The outcome of infection also depends on both host and microbe factors.

Only rare pathogens have the capacity to cause severe disease in humans and to spread globally sparking an epidemic or pandemic. For infection to be propagated to other humans or animals, the infecting microbe must have a way to exit the body, to survive, and to reach susceptible hosts. Among the most successful in leading to pandemics are those organisms that spread by the respiratory route (SARS, influenza, Covid) and those that are sexually transmitted (HIV, mpox – formerly called monkeypox). If a virus can be transmitted before it causes symptoms (or if it never causes symptoms), it can spread much more successfully.

2 Carlson, C. J., Albery, G. F., Merow, C., et al. (2022). Climate change increases cross-species viral transmission risk. *Nature, 607*(7919), 555–562. https://doi.org/10.1038/s41586-022-04788-w.

VECTORBORNE DISEASES

West Nile virus

In the United States in 1999, an unusual number of dead crows were observed in New York during the same month when an unusual number of cases of encephalitis and deaths were being seen in hospitalized patients in the same area. After a few weeks, a flavivirus, West Nile virus, never previously known to be present in the US was identified. It was spread by locally abundant mosquitoes from bird to bird; mosquitoes could also infect humans. Already present in the US were mosquitoes competent to transmit the virus and susceptible birds and humans. The virus spread westward across the US, reaching California by 2002. By 2004 every state in the contiguous US had reported West Nile virus infections in humans or animals.

While climate change will have diverse impacts through direct and indirect mechanisms on multiple infectious diseases in humans, the impact on vectorborne diseases (VBD) is expected to be widespread and serious.[3][4] VBD are infections spread to humans by bites of bloodsucking (hematophagous) arthropods, including mosquitoes, ticks, sandflies, midges, blackflies, and triatomine bugs. These arthropods can transmit infections caused by viruses, bacteria and parasites, like malaria. More than 6 billion humans live in areas at risk for vectorborne infections. Globally an estimated 700,000 people die annually from vectorborne infections, with malaria accounting for the largest number. Other prominent and deadly VBD include yellow fever, dengue fever, African sleeping sickness, West Nile fever, and Japanese encephalitis. Animals are also affected by VBD.

Arthropod vectors, like mosquitoes, can carry a pathogen from an animal to a human (e.g., West Nile virus) or from one human to another (e.g., malaria). Mosquitoes are not simply flying syringes or passive transporters of infected blood. Vector transmission requires a complex biological interaction involving the pathogen and at least two hosts, the arthropod and the human. For an infection to be transmitted by a vector, the pathogen must be able to infect and to multiply in both the arthropod and in humans, and sometimes also in an intermediate or reservoir host, like a bird or nonhuman primate.

For example, after a mosquito takes a blood meal from a bird infected with West Nile virus, the virus must infect the mosquito tissues, replicate (multiply), and then disseminate to its salivary glands so that when the mosquito takes another blood meal, virus can be passed to a new host.

The process takes time (days to more than a week, depending on the pathogen and the temperature), and compatibility between pathogen and arthropod is necessary. More than 3500 species of mosquitoes have been identified. Most do not feed on humans and many that can bite cannot transmit infection. Only a limited number of species are competent to transmit a given virus, parasite, or other pathogen. Plus, a mosquito may not live long enough to take another blood meal or may not find another human to bite.

VBD are climate-sensitive infections. Arthropods are ectothermic, meaning they assume the temperature of the ambient environment. Every part of the life cycle of the mosquito (or other arthropod) is affected by the environment. Temperature, rainfall, and humidity affect rates of development, survival, biting rate, abundance, and, critically important, the extrinsic incubation period. The latter is the time it takes for the pathogen (virus, parasite) to infect and replicate within the mosquito and reach the salivary glands, so that it can be transmitted to another host. Up to a point, warmer temperatures lead to shorter extrinsic incubation periods, meaning more mosquitoes survive long enough to transmit infection. However, in a cooler environment, a mosquito may die before the pathogen replicates and disseminates. Extreme weather events also affect mosquito survival, distribution, and abundance. Flooding can provide water that is essential for breeding, but it can also destroy breeding sites. Winds can carry mosquitoes to new areas. Some mosquitoes have evolved mechanisms to survive prolonged dry periods.

Thermal performance curves can be used to describe the thermal tolerance range and the optimal performance range for arthropods.[5] Each mosquito species has optimal ranges for survival, reproduction, and biting activity. Each vector-pathogen pair has its optimal thermal ranges ***(Figure 1)***.[6]

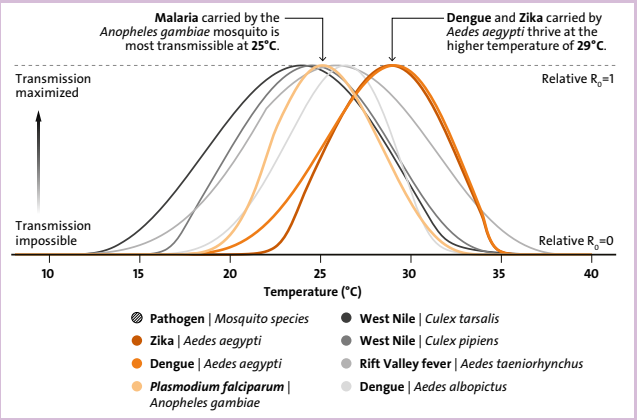
3 Mora, C., McKenzie, T., Gaw, I.M., et al. (2022) Over half of known pathogenic diseases can be aggravated by climate change. *Nature Climate Change, 12*(9), 869–875. https://doi.org/10.1038/s41558-022-01426-1.

4 de Souza, W.M. &, Weaver, S.C. (2024) Effects of climate change and human activities on vector-borne diseases. *Nature Reviews Microbiology, 22*(8), 476–491. https://doi.org/10.1038/s41579-024-01026-0.

5 Mordecai, E.A. et al. (2019) Thermal biology of mosquito-borne disease. Ecol Lett 22:1690-1708. Doi:10.1111/ele.13335.

6 Kuperschmidt, K. (2023) Feeling the heat. Science 2023;381(issue 6665):1388-92, p.1390.

Figure 1: Optimal temperature ranges for mosquito-borne diseases by disease-vector combination



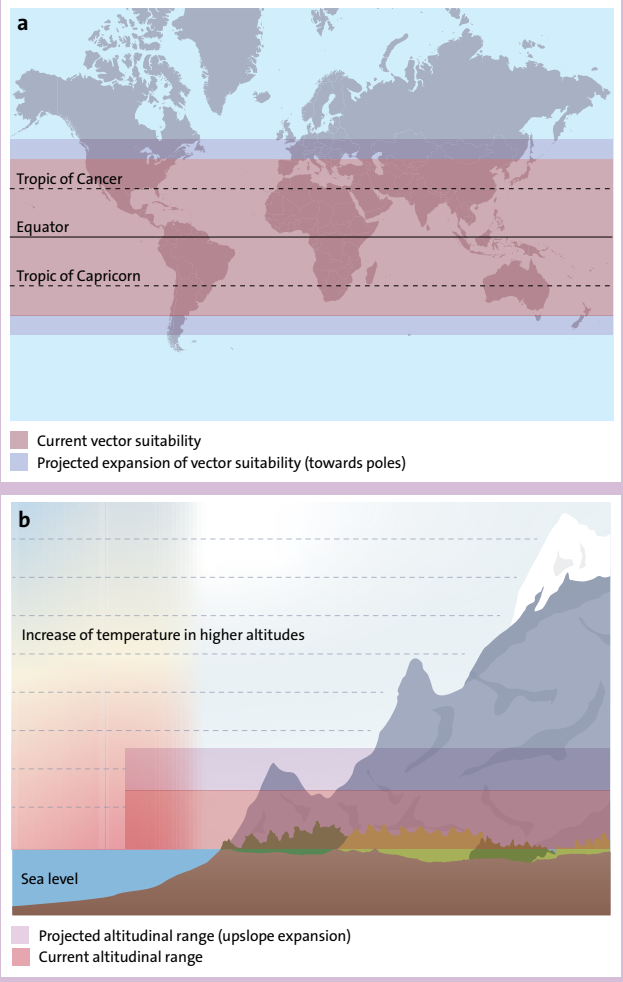
Source: Kuperschmidt, K., 2023

Ticks have a longer development cycle and live longer than mosquitoes but are also affected by temperature, rainfall, and humidity. Upper and lower lethal temperatures and thermal preferences vary by tick species.

Climate change is expected to shift the geographic distribution of many important vectors of human infections and alter the intensity of transmission. The general trend for changes in distribution will be a shift of transmission to higher latitudes and to areas of higher elevation. The projected, expanded distribution will include many densely populated areas ***(Figure 2)***.[7]

"Climate change is expected to shift the geographic distribution of many important vectors of human infections and alter the intensity of transmission."

Figure 2: Potential impacts of climate change on the geographical distribution of vectors



Source: de Souza et al., 2024

Transmission of many vectorborne infections is seasonal in temperate areas, occurring during the warmer summer months, while in tropical areas it may peak during the rainy season. With climate change, periods favorable for transmission will lengthen and, in some areas, may allow year-round transmission. Arthropod populations that usually decline in cold winter conditions, may survive during milder winters. Climate change will also influence reservoir and intermediate hosts such as rodents, birds, and bats involved in VBD.

Each mosquito species has specific habitats and behaviors, such as feeding time, that influence its capacity to transmit infections. *Aedes aegypti*, which now infests tropical and subtropical areas, is exceptionally well suited to transmit infections to humans. It thrives in urban environments, breeding in flower pots, discarded plastic cups, used tires, and other sites found widely in cities. It prefers human blood and will feed on more than one person if its feeding is interrupted. It bites during the daytime, so bednets offer no protection. In areas where piped water service is unreliable and residents store water in their homes, these water receptacles provide an ideal, in-house breeding site for mosquitoes. Control has been difficult, and this mosquito is a competent vector for multiple major human pathogens, including dengue, yellow fever, Zika virus, and chikungunya virus.

Humans facilitated the spread of mosquito vectors globally through travel and trade and have provided habitats that support their continued survival. The confluence of urbanization, massive uncontrolled growth of cities in tropical and subtropical areas, travel and migration that allow the movement of the virus in human hosts and reintroductions, have contributed to worsening epidemics of dengue infections in tropical and subtropical areas globally.

Up to a point, warmer temperatures can favor increased transmission of vectorborne infections. Performance of a key malaria-transmitting mosquito, *Anopheles gambia*e, peaks at 25°C, whereas transmission of dengue virus by *Aedes aegypti* peaks at 29°C. With global warming, parts of west and central Africa are projected to become too warm for efficient malaria transmission. This may make malaria control and eradication easier to achieve. Other infections, such as dengue, may replace malaria as major threats to local populations.[8]

Other factors can limit or worsen the burden of transmission of vectorborne infections. These include type of housing, presence of screened windows and air conditioning, source of water in households, availability of treated bednets in areas with malaria transmission, and local mosquito control activities. The mosquitoes that commonly transmit malaria in Africa bite at night, and sleeping under a bednet can provide considerable protection.

7 de Souza, W.M. &, Weaver, S.C. (2024) Effects of climate change and human activities on vector-borne diseases. *Nature Reviews Microbiology, 22*(8), 476–491. https://doi.org/10.1038/s41579-024-01026-0.

8 Mordecai, E.A., et al. Ryan, S.J., Caldwell, J.M. Shah, M.M., LeBeaud, A.D. (2020) Climate change could shift disease burden from malaria to arboviruses in Africa. Lancet Planet Health 4:e416-23. www.thelancet.com/planetary-health.

Dengue

Reported dengue cases have increased more than ten-fold in the past two decades. The world is currently experiencing widespread epidemics, the largest ever reported, with more than 10 million cases in WHO regions as of July 2024. One can expect to see more introductions (human carriers) into nonendemic areas that are infested with competent mosquitoes, like France and parts of southern US, that will spark local outbreaks. Housing with screens and air conditioning can reduce risk of infection for local residents.

Four different serotypes of dengue virus infect humans. An unusual feature of dengue is that infection with one serotype can predispose to more severe disease if followed by infection by a different serotype. This means that instead of being protected, populations that have already experienced dengue infections can experience more severe disease and increase in deaths if a different dengue serotype is introduced into the population.

PERMAFROST

One quarter of the northern Hemisphere is underlain by permafrost, a permanently frozen ground mostly present in Alaska, Canada, Greenland and Siberia, and in high mountain regions such as the Himalayas and the Alps. Above the permafrost lies an active layer (15 cm to 250 cm thick) that undergoes seasonal freeze-thaw cycles, while permafrost itself can reach depths of up to 1,500 meters deep.

Permafrost contains a wide range of microbial communities which remain stable due to the constant freeze. For example, as of today, up to 1,000 different microorganisms and hundreds of viruses were found in the Alpine permafrost and glacier ice. Yet, it is still unclear how these organisms survived, metabolized and even reproduced in such extreme conditions.[9]

The rapid thawing of permafrost due to climate change poses unknown health risks, potentially releasing bacteria and unknown viruses. The temperature in the Arctic is warming twice as fast as in other areas, and projections suggest that up to two-thirds of the near-surface permafrost could disappear by 2100.[10]

We live in a sea of microbes – in air, soil, water, in and on plants and animals. Most are not pathogenic for humans; many are essential for life as we know it. But microbes embedded in the permafrost or other inaccessible locations may have never been in contact with humans and might have novel virulence factors or toxins for which humans have no immunological experience.

Samples of Siberian soil, that had been frozen for 30,000 years, harbored two large DNA viruses that could infect amoebae.[11] Other amoebae-infecting megaviruses dating back 48,500 years have also been unearthed.[12] Additionally, over 100 microorganisms were found to be antibiotic resistant in Siberian permafrost.

While the low population density of these areas lowers the likelihood of exposure and spread (less than 5 million people live on permafrost), communities living close to thawing sites may face increased risks, as animal carcasses or human remains are discovered. In Siberia for instance, in a particularly hot summer of 2016, 2,649 reindeers were killed and 36 people sickened by the *Bacillus anthracis*, the cause of anthrax.[13] Scientists fear that it may have been released from the frozen ground. Although many uncertainties remain about the future impacts of thawing permafrost, the potential risks to human health warrant close monitoring and investment in scientific study of this unique ecosystem.

"The rapid thawing of permafrost due to climate change poses unknown health risks, potentially releasing bacteria and unknown viruses."

INTERVENTIONS

The one health concept refers to the interconnectedness of humans, animals, plants, climate, and environment.[14] Surveillance systems to detect microbial threats in humans and animals, including wildlife, should be systematic, global, and integrated. Surveillance for zoonotic viruses at animal-human interfaces should be strengthened, including in agricultural systems raising domestic animals. This means sampling birds and other wildlife, farm animals, agricultural workers, vectors, such as mosquitoes and ticks, and integrating it with data about human disease and outbreaks and with meteorological and other data.[15]

9 Swiss Federal Institute for Forest, Snow and Landscape Research WSL. (2024). Understanding the impacts of climate change on Arctic, Antarctic, and Alpine permafrost microbiomes. https://www.wsl.ch/en/projects/einfluss-des-klimawandels-auf-das-permafrostmikrobiom-cryolink/.

10 European Space Agency. (2021, October 26). Permafrost that could release bacteria and viruses. European Space Agency. https://eo4society.esa.int/news/permafrost-thaw-could-release-bacteria-and-viruses/:contentReference[oaicite:0]{index=0}:contentReference[oaicite:1]{index=1}.

11 Often called an amoeboid, an amoebae is a type of cell or unicellular organism found in fungi, algae and animals.

12 Wu, R., Trubi, G., Tas, N., & Jansson, J. K. (2022). Permafrost as a potential pathogen reservoir. One Earth, 5(4), 351–360. https://doi.org/10.1016/j.oneear.2022.03.010.

13 Cohen, J. (2023). Permafrost can imprison dangerous microbes for centuries. Will the Arctic thaw release them? Science.org. https://www.science.org/content/article/permafrost-can-imprison-dangerous-microbescenturies-will-arctic-thaw-release-them#.

14 National Academies of Sciences, Engineering, and Medicine. (2022). Systematizing the One Health approach in preparedness and response efforts for infectious disease outbreaks: Proceedings of a workshop. The National Academies Press. https://doi.org/10.17226/26301.

15 Hill, R., et al. (2024). Realizing a global One Health disease surveillance approach: insights from wastewater and beyond. Nature Comm 15:5324. https//doi.org/10.1038/s41467-024-49417-4.

Wastewater provides vital health data as many pathogens or traces of them and chemicals enter the wastewater stream through saliva, urine and feces of people and animals. Wastewater monitoring has been used for decades to detect presence of polio virus in communities and guide vaccine use. Now, as part of a one-health surveillance system, it can serve as a valuable tool for detecting residues of antibiotics, presence of antibiotic resistance genes and fungal pathogens, and circulation of viruses in the community, such as SARS Co-V2 and mpox. Investigators are exploring its use in identifying new threats and mapping their spread, as rising levels of virus in wastewater often precede increased transmission in a community.[16]

Social policies should aim to reduce spillover risks from wildlife to humans, such as by closing or strictly regulating commercial wildlife trade and markets.

New tools, like field diagnostics and smart phones that can readily share data, have expanded the geographic reach and speed of communication. There are many examples of country, regional, and global systems that can contribute relevant data in realtime, including the Versatile Emerging Infections Observatory (VEO Forecasting) coordinated by Marion Koopmans (Netherlands); the CLIMADE, a consortium of scientists to develop tools to predict, track and control infections and develop ways to prevent epidemics; and the Global Virus Network. The GeoSentinel Global Surveillance Network systematically collects data on travelers worldwide (primarily after travel) as another way to identify infections linked to specific geographic exposures.

The WHO Hub for Epidemic and Pandemic Intelligence, started in September 2021, focuses on Collaborative Surveillance, now a core element in WHO's framework for global health emergency preparedness and response. Another key network is the Epidemic Intelligence from Open Sources. The platform now supports 94 Member States to enhance early detection capacity by connecting global experts. Despite these laudable efforts, many gaps remain in surveillance and response systems.

CONCLUSION

Humans have created a world with more opportunities for connections – for contact across species and for rapid dispersal of microbes.

Climate change will shift distribution of some vectorborne infections to expose even larger human populations. Climate change will lead to range shift of species allowing novel interactions and increasing the likelihood of spillover events. Shifts in migratory patterns of birds and other animals to achieve synchrony with food sources that shift with climate change, may also allow novel interactions among species. Waterborne- and food-associated infections, discussed later in this review, will likely increase with a warming climate.

Climate change occurs in concert with multiple other profound, global changes that may exacerbate spillover events. These include changes in land use (cleared for agriculture or other development), travel, trade and migration, and loss of biodiversity making ecosystems more vulnerable to invasive species. Local events can now quickly become global.

Most pandemics originate in animals. Global surveillance systems must include domestic animals and wildlife; vectors, such as mosquitoes; environmental reservoirs; and human populations. Better education and policies to regulate animal markets and wildlife trade can help reduce one area of risk. Although the one-health approach and new tools and communication networks show promise, much more needs to be done to limit the health consequences of climate change.

16 National Academies of Sciences, Engineering, and Medicine. (2024). Increasing the utility of wastewater-based disease surveillance for public health action: A Phase 2 report. The National Academies Press. https://doi.org/10.17226/27516.

Climate change and the resurgence of waterborne diseases:

Focus on Sub-Saharan Africa

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Rita Colwell, Environmental microbiologist, Distinguished University Professor at University of Maryland

Sandy Moore and Rita Colwell co-authored this article. Dr Moore is recognized for her work integrating epidemiological and phylogenic studies to establish a comprehensive understanding of cholera dynamics in Sub-Saharan Africa. Dr Colwell, a distinguished microbiologist, has pioneered research on global infectious diseases, marine bacteria and ecology. Their efforts have significantly advanced global health initiatives as well as disease prevention and control strategies.

Climate change, driven primarily by human activities, leads to persistent shifts in global temperatures and weather patterns. These changes trigger more frequent and intense weather events, which impact populations through both direct and indirect consequences. In particular, populations in Sub-Saharan Africa face heightened risks from climate change due in part to inadequate infrastructure and limited climate resilience. Climate change has significant implications for waterborne diseases, such as cholera, typhoid fever, schistosomiasis and hepatitis A, which affect populations throughout Sub-Saharan Africa. Limited access to clean water, sanitation, and hygiene infrastructure constitute significant risk factors for such diseases. Extreme climate-related events exacerbate these risks. For example, flooding can lead to contaminated water sources, while droughts compromise water quantity and quality. Additionally, extreme weather events can cause malnutrition, population displacement and disrupt livelihoods, further increasing vulnerability to diseases. Mitigating climate change involves reducing greenhouse gas emissions and transitioning to cleaner energy sources. However, short- to medium-term prevention and preparedness can minimize the impacts of waterborne diseases. To prevent waterborne diseases in Sub-Saharan Africa, it is crucial to improve access to safe drinking water, sanitation and hygiene infrastructure.

INTRODUCTION

Climate change refers to the persistent shifts in global temperatures and weather patterns. Although some of these changes are due to natural processes, human activities have become the predominant drivers. Climate change triggers extreme weather events, which are projected to become more frequent and intense, affecting certain regions of the globe more than others.

Beyond the significant environmental concerns posed by climate change, the impacts of these extreme weather events have far-reaching consequences on human health, especially for vulnerable populations. In many countries across Sub-Saharan Africa, extreme weather can adversely affect populations via both direct effects (e.g., infectious diseases, injury and fatalities) and indirect effects (e.g., chronic diseases, poor mental health, malnutrition, population displacement and reduced healthcare access). Moreover, the economic impacts of these natural disasters exacerbate population vulnerabilities, while constraining public health capacity to prevent and respond to health threats.

THE LINK BETWEEN CLIMATE CHANGE AND WATERBORNE DISEASES

Climate change has significant implications for waterborne diseases in Sub-Saharan Africa. These diseases are caused by pathogens such as viruses, parasites and bacteria, which can contaminate drinking water, food and water bodies. Major waterborne diseases that affect populations include cholera, typhoid fever, schistosomiasis, hepatitis A and poliomyelitis. Depending on the pathogen, disease transmission occurs through direct contact with infested water (e.g., bathing, washing, swimming) or via the fecal-oral route (ingesting water or food contaminated by the feces of infected individuals). Limited access to safe and clean water, sanitation and hygiene (WASH) infrastructure, along with open defecation, constitute significant risk factors. Climate change further heightens the risk of waterborne diseases by impacting WASH factors through increased precipitation, flooding, rising temperatures and drought.[1]

"Increased temperatures have shown significant positive association with waterborne diseases, caused by bacterial and protozoan pathogens. Warmer temperatures promote pathogen growth and reproduction."

Bacteria seen under the microscope

Flooding events can augment the risk of waterborne disease outbreaks by contaminating drinking water sources and increasing human exposure to pathogens, especially in areas with inadequate WASH infrastructure. During extreme rainfall, sewer systems and latrines can overflow, discharging wastewater into the environment. In areas where open defecation is common, feces can contaminate surface water, which then infiltrates unprotected drinking water sources, damaged water distribution pipes, and water bodies used for recreational and domestic purposes. The concentration of waterborne pathogens in runoff tends to be higher in crowded urban settings or if a flooding event is preceded by a protracted dry period. Flooding can also hinder efforts to respond to infectious disease outbreaks.[2]

Increased temperatures have shown significant positive association with waterborne diseases caused by bacterial and protozoan pathogens. Warmer temperatures promote pathogen growth and reproduction. Rising ocean temperatures accelerate marine bacteria replication, resulting in bacterial blooms in coastal waters. Elevated environmental temperatures can also trigger expression of bacterial virulence genes in human pathogens, such as *Shigella* species.

Drought-induced water scarcity compromises both water quantity and quality. During prolonged droughts, people are forced to modify their behavior to secure access to drinking water, potentially jeopardizing their health. They may rely on contaminated water sources and store domestic water under inadequate conditions or use the same water source for multiple purposes (watering livestock, washing, cooking and drinking), risking additional contamination. People may also practice unsafe hygiene behaviors, such as reduced handwashing. The lack of clean water for consumption and hand hygiene increases the risk of contracting waterborne diseases. Indeed, in low- and middle-income countries, drought was found to be associated with a 5% to 8% increase in the risk of diarrhea among children under five. The association was stronger for households that had no access to water or soap for handwashing.[3]

Extreme weather events can also have serious indirect effects, such as malnutrition, population displacement and disrupted livelihoods. Loss of crops and livestock deaths due to flooding or drought contribute to famine and malnutrition, which in turn, weakens immune function. Severe, frequent or long-term natural disasters can also cause forced population displacement, a driving factor in spreading infectious diseases to new areas. Disruption of rural livelihoods can also accelerate the expansion of informal urban settlements, where access to safe water sources is often limited.

1 Semenza, J. C., & Ko, A. I. (2023). Waterborne diseases that are sensitive to climate variability and climate change. The New England Journal of Medicine, 389(23), 2175–2187. https://doi.org/10.1056/NEJMra2303681.

2 Semenza, J. C. (2020). Cascading risks of waterborne diseases from climate change. Nature Immunology, 21(5), 484–487. https://doi.org/10.1038/s41590-020-0648-9.

3 Wang, P., Asare, E., Pitzer, V. E., Dubrow, R., & Chen, K. (2022). Associations between long-term drought and diarrhea among children under five in low- and middle-income countries. Nature Communications, 13(1), 3661. https://doi.org/10.1038/s41467-022-31230-7.

CASE STUDY: CHOLERA

Cholera is an acute diarrheal disease caused by the bacterium *Vibrio cholerae*, which provokes severe diarrhea and dehydration and can lead to death within hours if untreated. The disease is generally contracted by ingesting water or food contaminated with toxigenic forms of *Vibrio cholerae* O1 and O139. Major factors of cholera transmission include limited access to safe drinking water and sanitation facilities. From 2017 to 2020, approximately 645,000 suspected cholera cases were reported in Africa.[4] Although the majority of African countries reported cholera cases during this time, the disease burden exhibited spatial heterogeneity, with certain regions regularly bearing the brunt of cholera epidemics.

"Poor access to WASH infrastructure and low sanitation access significantly contribute to cholera outbreaks."

CHOLERA EPIDEMICS DRIVEN BY DROUGHT IN THE HORN OF AFRICA

One of the major cholera hotspots on the continent is the Horn of Africa, most notably Somalia and Ethiopia. Poor access to WASH infrastructure (less than 60% of Somalians and Ethiopians have access to at least basic drinking water sources) and low sanitation access significantly contribute to cholera outbreaks. The Horn of Africa is also extremely vulnerable to climate-related risks, with frequent severe weather events including floods, rising temperatures and droughts.

Climate refugee migration - Somali families leave their homes due to deadly droughts and settle in refugee camps

A severe drought in late 2016 to 2017 increased water scarcity in this desert and semi-arid climate region. Against the backdrop of the drought, Somalia and Ethiopia experienced large-scale cholera epidemics. In 2017, Somalia reported a total of 75,414 suspected cases, a near five-fold increase in cholera cases compared with the previous year. At the time, WHO epidemiologists linked this surge to the drought which created widespread shortages of safe drinking water and food.

That same year, neighboring Ethiopia reported a total of 47,542 suspected cholera cases. Approximately 75% of all reported cases in Ethiopia were concentrated in Somali Region, which shares a border with the country of Somalia.[5] Pastoralist[6] communities in this desert region were forced to travel longer distances in search of water and gathered at unprotected water sources. As cholera affected pastoralists living in remote camps, access to healthcare was limited and a rapid response to control the outbreak was a significant challenge. Although direct evidence of cross-border transmission between Ethiopia and Somalia is limited, these two epidemics likely represent a single regional epidemic, with transborder transmission driven by population movement.

Climate change models have predicted further extreme dryness and drought not only in the Horn of Africa, but also in other areas such as the Sahel and southern Africa. These climate pattern projections indicate serious implications for the health of populations in drought-prone areas.

Cholera outbreaks triggered by cyclones in Mozambique

Mozambique represents another major cholera hotspot in Sub-Saharan Africa. From 2017 to 2022, Mozambique experienced cholera epidemics every year, with a total of 27,049 suspected cholera cases reported.[7] The country also has low WASH indicators and is susceptible to extreme climate events such as drought, storms and flooding.

In March of 2019, Cyclone Idai struck Mozambique. The storm made landfall twice, first as a tropical depression in Zambezia Province and second as a tropical cyclone near Beira City, Sofala Province. The cyclone caused torrential rains and winds. Crossing over land, the storm caused severe flooding that affected approximately 3 million people in Mozambique and neighboring countries.[8] In Mozambique alone, an estimated 1.85 million people were affected, with 603 deaths.[9] Thousands of houses were destroyed, which caused displacement of 400,000 people, primarily in shelters with poor access to basic water and sanitation services. Critical infrastructure such as roads, water supply, the electric grid, communication services, and healthcare centers suffered significant destruction, which hindered healthcare and response efforts.

4 World Health Organization. (2023). Cholera data 2000-2022 [Internet]. World Health Organization.

5 Moore, S., Worku Demlie, Y., Muluneh, D., Dunoyer, J., Hussen, M., Wossen, M., Edosa, M., & Sudre, B. (2024). Spatiotemporal dynamics of cholera epidemics in Ethiopia: 2015-2021. Scientific Reports, 14(1), 7170. https://doi.org/10.1038/s41598-024-51324-z:contentReference[oaicite:0]{index=0}.

6 Pastoralists are semi-nomadic or nomadic groups of people whose livelihood primarily depends on herding livestock.

7 World Health Organization. (2023). Cholera data 2000-2022 [Internet]. World Health Organization.

8 OCHA. (2019, March). Southern Africa: Cyclone Idai snapshot (as of 26 March 2019) [Data set]. https://www.medbox.org.

9 Government of Mozambique & World Health Organization. (2019, May 10). Tropical cyclones Idai and Kenneth, Mozambique National Situation Report 1. ReliefWeb. Retrieved from https://reliefweb.int/report/mozambique/tropical-cyclones-idai-and-kenneth-mozambique-national-situation-report-1-10-may.

In the areas severely affected by the cyclone, overcrowding, limited access to sanitation, as well as flooding that led to latrine overflow and contamination of the drinking water supply created ideal conditions for a waterborne disease outbreak. Only two weeks after Cyclone Idai made landfall near Beira—the region of Mozambique hardest hit by the cyclone – five cases of cholera were confirmed in Beira City. Thereafter, the cholera outbreak rapidly amplified, with 1,428 suspected cholera cases reported during the first week. Between March 27 and April 18, 2019, a total of 6,382 suspected cholera cases were reported.[10]

CASE STUDY: SCHISTOSOMIASIS

Schistosomiasis is an acute and chronic parasitic disease caused by trematode flatworms of the genus *Schistosoma*. Humans contract the disease in infested water, when larval forms of the parasite are released by freshwater snails and burrow into the host's skin. The parasite's lifecycle continues when people suffering from schistosomiasis contaminate freshwater sources with feces or urine containing parasite eggs. Schistosomiasis manifests in two major forms: intestinal and urogenital. Depending on the form, symptoms can include rash and fever, followed by abdominal pain, diarrhea, blood in the stool or urine, enlargement of the liver or spleen, and kidney or bladder damage. Schistosomiasis can cause anemia and stunting in children, thereby affecting development. The disease is prevalent among poor communities with limited WASH access located in tropical and subtropical regions and has been identified as one of the most widespread neglected tropical diseases in Sub-Saharan Africa. An estimated 112 million individuals are infected with *Schistosoma haematobium*, one of the most prevalent species of *Schistosoma* in Sub-Saharan Africa.[11]

"Climate change further compounds the level of vulnerability of these communities, as they lack the resources to adapt to extreme weather events."

Climate change significantly influences schistosomiasis transmission in Africa by affecting the ecosystem and the lifecycle of freshwater snails and schistosomes. Extreme climate events can also alter human behaviors that contribute to the likelihood of exposure to infected snails.

Schistosomiasis transmission is temperature-dependent, affecting both parasite development and snail populations. A study has shown that between 15°C and 31°C, snail populations were stable and parasite production within snails was enhanced, thereby increasing metabolic activity and vitality. However, beyond these temperatures snail numbers sharply declined.[12] Infection risk may rise with small temperature increases in regions characterized by this ideal temperature range, while it may decrease in hotter regions, depending on the local species of host snail. For example, a study in Zimbabwe showed a downward trend in schistosomiasis prevalence from 1981 to 2010, in parallel with a transition towards a warmer and drier climate.[13]

Increased rainfall plays a significant role in schistosomiasis transmission throughout Sub-Saharan Africa. In Ghana, increased precipitation levels have been positively correlated with schistosomiasis prevalence, while years with reduced rainfall have shown a negative correlation.[14] Increased rainfall creates additional suitable habitats for snails, allowing populations to expand. When the levels of waterbodies rise, people may come into contact with infested water more frequently. However, during severe storms, rainfall may have a negative impact on transmission when snail habitats become disrupted by fast flowing waters.

Drought impacts schistosomiasis transmission. In Ethiopia, prolonged drought resulted in reduced prevalence of schistosomiasis due to a decrease in both transmission sites and the reproductive and survival rates of the intermediate host snails.[15] However, in Senegal, shorter drought periods were associated with an increased risk of schistosomiasis transmission.[16] These variations likely also depend on location, climate and intermediate host species.

Overall, as the impact of climate change on snail populations and parasites is complex and can either increase or decrease the risk of schistosomiasis depending on the context, the future trajectory of the disease is challenging to forecast.

VULNERABLE POPULATIONS

In Africa, waterborne diseases disproportionately affect low-income areas with inadequate access to WASH services and healthcare. Climate change further compounds the level of vulnerability of these communities, as they lack the resources to adapt to extreme weather events. In Sub-Saharan Africa, 65% of the population has access to at least basic drinking water services, while 37% of the population has access to at least basic sanitation infrastructure. However, there are significant variations across the continent. Countries with low average drinking water coverage rates between 35% and 60% include the Democratic Republic of Congo (DRC), Central African Republic, South Sudan, Niger, Ethiopia and Somalia.[17]

10 Lequechane, J. D., et al. (2020). Mozambique's response to cyclone Idai: How collaboration and surveillance with water, sanitation and hygiene (WASH) interventions were used to control a cholera epidemic. Infectious Diseases of Poverty, 9(68). https://doi.org/10.1186/s40249-020-00673-7.

11 World Health Organization. (2020). Current estimated total number of individuals with morbidity and mortality due to Schistosomiasis haematobium and S. mansoni infection in Sub-Saharan Africa. World Health Organization. Retrieved from https://www.who.int/schistosomiasis/epidemiology/en/.

12 McCreesh, N., & Booth, M. (2014). The effect of simulating different intermediate host snail species on the link between water temperature and schistosomiasis risk. PLoS ONE, 9(7), e87892. https://doi.org/10.1371/journal.pone.0087892.

13 Pedersen, U. B., et al. (2017). Comparison of the spatial patterns of schistosomiasis in Zimbabwe at two points in time, spaced twenty-nine years apart: Is climate variability of importance? Geospatial Health, 12(1), 505. https://doi.org/10.4081/gh.2017.505.

14 Codjoe, S. N. A., & Larbi, R. T. (2016). Climate change/variability and schistosomiasis transmission in Ga district, Ghana. Climate and Development, 8(1), 58–71. https://doi.org/10.1080/17565529.2015.1008771.

15 Zein, Z. A. (1989). Spontaneous reduction in Schistosoma mansoni infection in endemic communities of the Lake Tana basin, north-western Ethiopia. Transactions of the Royal Society of Tropical Medicine and Hygiene, 83(5), 656–658. https://doi.org/10.1016/0035-9203(89)90209-0&#8203.

16 Senghor, B., Diaw, O. T., Doucoure, S., Sylla, S. N., Seye, M., & Talla, I. (2015). Study of the snail intermediate hosts of urogenital schistosomiasis in Niakhar, region of Fatick, West central Senegal. Parasites & Vectors, 8, 410. https://doi.org/10.1186/s13071-015-1050-6.

17 WHO, & UNICEF. (2023). Progress on drinking water, sanitation and hygiene: 2023 update and SDG baselines. Joint Monitoring Programme (JMP). https://data.unicef.org/resources/jmp-report-2023/.

These figures are concretely reflected in the expansion of waterborne diseases, highlighting the importance of having not only access to drinking water but also to WASH services. Indeed, four of these countries (DRC, Somalia, Ethiopia and Niger) reported nearly 40% of all suspected cholera cases in Africa from 2019 to 2022.

Many populated urban areas with informal urban settlements are often characterized by inadequate sewage, unsafe piped water networks, and dysfunctional rainwater drainage systems, subjecting residents to a high risk of contracting waterborne diseases, especially during the rainy season. Indeed, cholera outbreaks have been shown to amplify exponentially in urban settings, as observed in Accra, Conakry, Nairobi, Port-au-Prince, and many other cities. Other populations that are particularly at risk include refugees, internally displaced persons, nomadic populations and other marginalized groups with limited access to WASH services and healthcare. Remote and hard-to-reach populations are also vulnerable to waterborne diseases, as healthcare access is limited for these communities and outbreak response measures are often delayed.

PUBLIC HEALTH RESPONSE

Mitigating climate change involves reducing greenhouse gas emissions by transitioning away from fossil fuels towards cleaner energy sources, reforestation, and sustainable practices. However, short- to medium-term prevention, preparedness and response interventions can significantly minimize the impacts of waterborne diseases due to climate change.

Boosting climate resilience to **prevent waterborne diseases** involves a multi-faceted approach (e.g., community engagement, policy, research and innovation). A key strategy focuses on reducing the underlying vulnerabilities by improving access to safe drinking water and effective sanitation. For example, the Veolia Foundation supports cholera elimination efforts in the DRC by implementing sustainable and resilient WASH services, such as water network rehabilitation in cholera hotspots. Such preventative measures should be focused on areas where populations are at a high risk of waterborne diseases and prioritizing regions at risk of natural disasters. Epidemiological studies and risk assessments are critical to identify disease hotspots, highly exposed populations, and areas of converging risk factors.

Preparedness and response measures should be strengthened to control outbreaks when they occur, through strong coordination, multisectoral engagement, robust disease surveillance, early warning systems,[18] [19] effective risk communication, community engagement, and proper case management. Vaccination against waterborne diseases such as cholera, hepatitis A and typhoid fever can be effective when appropriate and feasible. As soon as cases of waterborne diseases are detected, a rapid response guided by real-time surveillance data is critical to stop transmission and prevent avoidable deaths, especially for diseases with a short incubation period such as cholera. Recognizing interconnectedness between human health and the environment, One Health approaches that integrate weather and climate monitoring into early warning systems can help to quickly identify those areas at risk, triggering prompt preventive and response interventions.

CONCLUSION

Extreme weather events due to human-driven climate change have considerable implications for population health. In particular, many waterborne diseases pose a significant public health threat, especially in Sub-Saharan Africa. Limited access to safe drinking water and sanitation facilities are key risk factors for waterborne diseases. Severe weather phenomena play a significant role in the transmission dynamics of waterborne diseases by impacting access to safe water sources. Climate change can also compound health disparities, by hindering healthcare opportunities, causing malnutrition and restricting public health capacity. Thus, in areas with poor WASH indicators, extreme weather can rapidly escalate into a catastrophic public health emergency. Severe droughts, floods and storms have affected many regions across sub-Saharan Africa, and the intensity and frequency of these natural disasters will increase due to climate change, albeit in a heterogenous manner. As a result, many vulnerable populations will face heightened risk. To prevent waterborne diseases in Sub-Saharan Africa, it is critical to improve safe and equitable access to drinking water and sanitation, ideally by applying a holistic approach to building community resilience that can cope with the multifaceted effects of climate change.

18 Usmani, M., et al. (2024). Building environmental and sociological predictive intelligence to understand the seasonal threat of SARS-CoV-2 in human populations. American Journal of Tropical Medicine and Hygiene, 110(3), 518–528. https://doi.org/10.4269/ajtmh.23-0077.

19 Usmani, M., et al. (2023). Combating cholera by building predictive capabilities for pathogenic Vibrio cholerae in Yemen. Scientific Reports, 13, 2255. https://doi.org/10.1038/s41598-022-22946-y.

Ocean in danger:

Climate challenges and sustainable solutions

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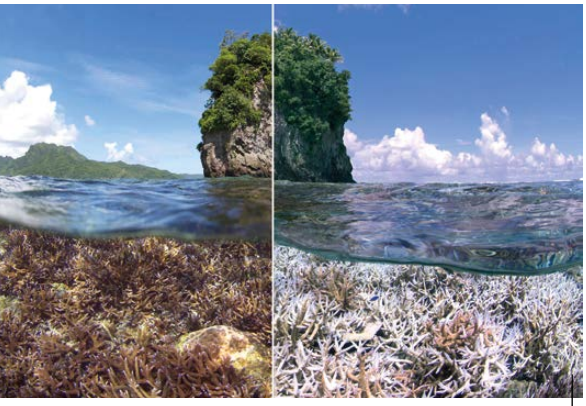


Coral Bleaching in American Samoa, Before (Dec 2014) & After (Feb 2015). Credit: The Ocean Agency

Françoise Gaill is a French marine biologist who specializes in deep-sea ecosystems. A former director of the CNRS Institute of Ecology and the Environment, she has contributed to the development of research programs studying the ocean and adaptation to climate change. She is Vice-President of the Ocean & Climate Platform and heads the CNRS-hosted Ocean Sustainability Foundation, working to protect marine ecosystems and sustainability of the oceans.

Protecting the ocean, the planet's number one climate regulator, is the *sine qua non* for maintaining life on earth. The ocean's resources are vast, diverse and essential, particularly in ensuring our supply of food. Our trade and communication both depend on the ocean. It is indispensable to our physical and social lives. It ensures that the planet remains habitable for all life, including humankind.

But human activities pose threats to the health of the ocean and its resources. If we fail to take appropriate, concerted and ambitious action, this tendency may quickly trigger famines, major population movements, and socio-economic inequalities, hampering our societies' aspirations for fair and sustainable development. How will the ocean behave tomorrow in the face of the pressures placed on it by humans and the uses we make of it? If we fail to remember this key element of our life on earth, we will alter how it functions and its health. This will inevitably affect our well-being, as our habitat depends on the ocean's vitality. How can we ensure the long-term future of this natural capital on an international scale? The ocean is a complex, dynamic and interconnected system, making it difficult to turn warnings from the scientific community into firm, actionable policy decisions. The Intergovernmental Panel for Ocean Sustainability (IPOS) is a project initiated by scientists that proposes the creation of an international body under the *aegis* of the United Nations to facilitate concerted reflections on the future of a sustainable ocean, and to take the necessary action.

INTRODUCTION

The ocean is essential to life on earth. It is the primary climate regulator, the largest carbon sink, and the number one generator of oxygen: since the oceans first formed, they have produced over 50% of the available oxygen that we breathe. Home to a considerable diversity of resources, the ocean feeds close to three billion people. It also plays an irreplaceable economic role as the vector for trade and communication between human societies. The ocean carries 90% of global freight and 99% of digital communications and data streams. This immense, much-coveted potential, particularly in terms of exploitable resources, makes the ocean a potential arena for future confrontation. Lying at the heart of vital environmental, social and economic challenges, the ocean must be protected to guarantee our health as well as that of the planet.

HUMAN ACTIVITIES, CLIMATE CHANGE, AND THE OCEAN

The Intergovernmental Panel on Climate Change (IPCC)[1] has been warning us for decades about the impacts of climate change. Although not often mentioned, the very first consequence of our greenhouse gas emissions is disruption to the role the ocean plays in regulating the climate. Since 1950, the ocean has absorbed over 90% of excess heat and 23% of the CO_2 generated by human activities, which has led to its acidification; a rise in water temperature, particularly at the surface, of 0.11°C per decade between 1971 and 2010; and a probable 3.5% fall in the amount of oxygen in the ocean by 2100.

The ocean today is experiencing record temperature rises, leading to widespread marine heatwaves that threaten emblematic ecosystems such as coral reefs. According to the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES), close to a third of coral reefs have already disappeared. Another concern is increasing pollution of the oceans, which has also had a major environmental and economic impact. Every year, it is estimated that between five and twelve million metric tons of plastic find their way into the ocean, costing around €13 billion in annual clean-up costs and financial losses for a range of sectors, fisheries in particular. And approximately 90% of all plastic waste found in the ocean comprises single-use items, such as plastic bags, that take a very long time to break down.

These changes are already having unwelcome consequences on marine ecosystems and human societies in the form of rising sea levels, an increase in extreme climate events, and intensification of coastal erosion. Regarding biodiversity, the IPBES[2] identified five primary drivers of its decline in 2019, ranked in descending order: direct exploitation of vagile species[3] through overfishing; changing uses of land and sea; climate change; pollution, and invasive exotic species. In addition, ocean-related tourism, which generates an estimated annual $134 billion and employs over a third of the labor force in certain countries, needs to be managed very carefully. If not, this form of tourism can be a major threat to the natural resources it relies on, as well as to local culture and industries. Our activities are thus a danger to the health of the ocean and the resources it is home to.

1 IPCC: https://www.ipcc.ch/.

2 IPBES: https://www.ipbes.net/.

3 Aquatic animals living and moving in the overall aquatic habitat (fish, mollusks, etc.).

CLIMATE CHANGE AND SPECIES DISTRIBUTION

Variations in temperature, pH and oxygenation in the ocean also influence species distribution by modifying their habitat.[4] Additionally, these disruptions can alter the physiological functions of organisms or engender phenological[5] changes that impact the seasonality of individual lifecycles. These pressures lead to a potential alteration in the geographical distribution of species that will, because of rising temperatures, migrate to cooler regions. This results in a gradual shift by certain species toward zones where organisms will find more favorable habitats. Modelling changes in species ranges makes it possible to predict the probability that a species will be present in 2100. We are already often seeing changes in the distribution ranges of fish species that bring them closer to the poles. Every year it is estimated that marine species move six kilometers nearer to the poles to find cooler water. But although the available models make it possible to predict movements of certain vagile species such as fish, the phenomena are sometimes more complex for benthic species that live on the seabed without moving location, such as corals, algae and oysters. Scallops, for example, are forecasted to disappear from the English Channel but this has yet to happen. The origin of these differences remain unclear, but it may, but it may lie in a failure either of the models used or of the appropriate management measures.

"Acidification of the ocean as a consequence of climate change leads to a fall in the availability of carbonate ions, significant repercussions for the marine biosphere. [...] These consequences may have a snowball effect on climate change by limiting CO_2 absorption by the biological carbon pump, whose absorption capacity correlates to the abundance of certain plankton species."

Acidification of the ocean as a consequence of climate change leads to a fall in the availability of carbonate ions,[6] with significant repercussions for the marine biosphere. This reduction affects the growth of organisms with calcareous structures such as phytoplankton, zooplankton, mollusks, and corals. Once over a certain threshold of acidification, we note a weakening of coral structures, greater fragility of mollusk shells, and a trend for large phytoplankton[7] to be replaced by smaller species. These consequences may have a snowball effect on climate change by limiting CO_2 absorption by the biological carbon pump,[8] whose absorption capacity correlates to the abundance of certain plankton species.

4 Euzen, A., Gaill, F., Lacroix, D., & Cury, P. (2019). *L'océan à découvert* [*The Ocean Revealed*], CNRS éditions.

5 Phenology is the study of natural cyclical and seasonal events in biological lifecycles. Phenological changes are changes in the calendar of species' biological cycles.

6 Carbonate ions enable numerous marine species to form their skeletons and shells. They also help maintain pH balance in the ocean.

7 Microscopic algae present in water.

8 Two mechanisms make the ocean the planet's primary carbon sink: the physical pump that carries surface water rich in CO_2 to greater depths, and the biological pump that absorbs CO_2 thanks to the presence of phytoplankton.

Copepod (zooplankton) under microscope

THE WATER COLUMN AND PLANKTONIC ECOSYSTEM

The ocean is often considered in geographical terms: exclusive economic zone, territorial waters, and ocean coastlines, all refer to a horizontal division of this common good. However, the ocean is characterized above all in terms of its verticality, or its immense depth, extending from the surface water all the way down to the seabed. This depth, essential to understanding oceanic dynamics, is known as the water column. The processes for capturing CO_2 from the atmosphere and storing it in the depths of the ocean occur in the water column. The water column is at the heart of the ocean's physical and biological processes, yet, along with the deep ocean, it remains one of the least-known zones. The water column is also where we find plankton, a term used to designate an infinite number of species that sit at the bottom of food chains. Despite being mostly microscopic, plankton represent incredible genetic wealth, as demonstrated during recent Tara Ocean expeditions.[9] The planktonic ecosystem is the cornerstone of oceanic biodiversity, supplying half of the oxygen that we breathe via photosynthesis during the world's evolution. Lastly, the majority of species that provide food and ensure the survival of human societies live in the water column. However, the riches and benefits it provides to humanity are inexorably shrinking.

"The planktonic ecosystem is the cornerstone of oceanic biodiversity, supplying half of the oxygen that we breathe via photosynthesis during the world's evolution."

Water color provides a very good indicator of the local populations of microscopic algae (phytoplankton) it contains. Phytoplankton species proliferate very rapidly and can alter the ocean's characteristics in a short number of days. Dark green water is, for example, home to diatoms surrounded by their silica cell walls while white and foamy water is caused by the presence of choanoflagellates. Dinoflagellates turn the water a pronounced green-yellow, and the red waters of Brazil are the result of a predator dinoflagellate species.

Eutrophication is a problem created by the accumulation of algae biomass in far greater quantity than the local ecosystem can manage. It disrupts the food chain by depleting oxygen in the water, suffocating organisms. Inflows of elements such as nitrogen, phosphorous and nutrient pollution from farming can have damaging consequences. The accumulation of organic material leads to bacterial decomposition on the seabed, beginning with an aerobic situation (bacteria multiply and decompose excess organic material by consuming oxygen in the water) which then becomes an anoxic[10] situation owing to depletion of the oxygen. Under these conditions, the population of anaerobic bacteria will increase thanks to sulfates in the seawater, releasing sulfides that are toxic to humans and animals. This very situation occured in Brittany with the green algae tides. This phenomenon is at the origin of the dead zones we have seen growing in size and number over the past two decades.

THE CHANGING OCEAN CLIMATE AND HUMAN HEALTH: THE OCEAN AS MOLECULAR RESERVOIR

In addition to issues relating to disturbance to the food chain, these environmental variations have other consequences that will have a direct impact on human populations.[11] An increase in marine temperature will lead to major repercussions on the pathology of certain species of marine bacteria, and there are critical temperature thresholds above which these bacteria can become toxic. This toxicity may also affect other marine species, such as the *Vibrio harveyi* bacteria which at temperatures above 17°C will infect abalones, crustaceans and marine mammals. Toxins from microalgae are secondary metabolites[12] whose varied modes of action can lead to diarrheal, amnesic and neurotoxic illnesses.[13]

The ocean is also a well of potentiel new resources, both for health and for other fields ranging from energy to food and materials. Close to twenty thousand new secondary metabolites have been observed in marine organisms over the past 40 years.

Pathogens also progress far faster than on land, and it is impossible to isolate the contaminated areas. Almost 15 million food infections in the USA are caused by eating contaminated seafood. The toxic effects of certain unicellular algae are all the more severe when they are displaced because of climate change and human activities. For example *Ostreopsis ovata*, which is usually found in warm

9 Tara Ocean Foundation (2024b, August 5th). *Defend Life. Protect the ocean.* https://fondationtaraocean.org/en/home/.

10 An anoxic environment no longer contains oxygen.

11 Zhivkoplias, E., Jouffray, J. P., Dunshirn, P. A., Pradndinti, A., & Blaziac, R. (2024). Growing prominence of deep-sea life in marine bioprospecting. Nature Sustainability, 7(11), 1027–1037.

12 Compounds produced by organisms and that play crucial roles in defense against predators, competition with other organisms, and attracting pollinators. They include substances that are often responsible for the medicinal and toxic properties of plants.

13 Landrigan, P. J., Stegeman, J. J., Fleming, L. E., Allemand, D., Anderson, D. M., Backer, L. C., ... & Rampal, P. (2020). Human health and ocean pollution. Annals of Global Health, 86(1), 151.

tropical waters, is now present in the Mediterranean where it provokes respiratory illnesses via aerosol inhalation without direct contact with the sea.

But the ocean can also provide solutions. At the present time, almost twenty medicines of marine origin are available on pharmaceutical markets in the EU and USA as well as Australia and China. Most of them are anti-cancer agents, although other molecules are used for pain relief or to treat viral infections. Moreover, new antibiotics should appear during the decade ahead. For instance, one of the emblematic organisms found in hydrothermal vents in the Pacific, *Alvinella pompejana*, is a thermophile animal that exhibits remarkable behavioral, cellular and molecular adaptations.[14] A new antimicrobial peptide, *Alvinellicin*, has been patented, and exploring the therapeutic potential of this type of antibiotic in lung environments infected by Gram-negative pathogenic bacteria is expected to lead to beneficial applications.[15]

Florida beach covered with toxic Atlantic sargassum algae known as red tide

PROTECTING HUMAN HEALTH AND THE HEALTH OF THE OCEAN: WHAT ACTION CAN WE TAKE?

While the IPCC and IPBES play a major role in influencing policy decisions relating to the climate and the erosion of biodiversity and natural resources, neither body is primarily focused on the sustainability of the ocean, and no equivalent body exists to plan on how to keep the ocean healthy. Although the World Ocean Assessment regularly issues summaries of the current state of the ocean, and despite a plethora of international organizations and initiatives that seek to inform ocean policymaking, most initiatives in this domain concentrate primarily on specific topics. Several UN agencies have special-interest mandates relating to the oceans: the International Maritime Organization for maritime transport, the Food and Agriculture Organization for food issues that concern the ocean, the International Seabed Authority for deep-water mining, and the UN Environment Programme for the treaty on plastics. Other efforts concentrate on specific themes, such as the High Level Panel for a Sustainable Ocean Economy or the High Ambition Coalition for Nature and People, which targets ocean conservation and Agenda 30x30.[16]

Acting to ensure that the ocean is recognized as a "common good of humanity"[17] so that it can be kept healthy and managed sustainably is the aim of the International Panel for Ocean Sustainability (IPOS) that we have set up with scientists, experts, representatives from civil society and all the oceans' stakeholders.[18] The IPOS seeks to act as a cross-disciplinary interface to promote knowledge-sharing between science, society and policymakers to help map a path toward solutions for the future of the oceans. It aims to bring together all available knowledge that will be of use in determining future ocean behavior and provide tools to support decision-making. The range of challenges affecting ocean territories create a diversity of problems that we have to get to grips with, whether they are social, economic, health-related, or environmental in a more general sense. Thanks to Towards IPOS,[19] a program financed by private partners and the European Commission, the characteristics, operation, cost and mechanism for incorporating IPOS into the constellation of UN bodies will be presented at the third UN Ocean Conference (UNOC3) in Nice, France, in June 2025.

CONCLUSION

Faced with growing threats posed by climate change, it is more important than ever to adopt a coordinated cross-cutting approach to protecting the ocean, the planet's largest lung. This vital ecosystem absorbs a large part of the impacts of climate warming and plays a crucial role in regulating the climate. However, its ability to absorb is not unlimited, and the consequences for marine ecosystems and human societies are already visible: rising sea levels, increase in marine heatwaves, acidification, and species migration to cooler regions. Deterioration of the ocean also impacts human health, including with the emergence of diseases of marine origin, increasing toxic emanations, and disruption to food chains. Nevertheless, the ocean is also a well of resources with lasting positive impacts on our health, where we can find molecules that can heal us. The urgency of the current situation requires the creation of a global governance process for ocean health. This is why the IPOS seeks to act as an interface for dialogue between science and knowledge, society and policymakers, aiming to promote sustainable management of the ocean and guarantee that it is protected for future generations. We cannot wait before taking action to preserve the ocean because the ocean's timescales far exceed human lifespans, stretching from centuries to millennia.

14 Gaill, F. (2017). The Pompeii worm or how to adapt to extreme conditions [Le ver de Pompéi ou comment s'adapter à des conditions extrêmes]. In A. Euzen, B. Laville, & S. Thiebault (Eds.), Adapting to climate change: A question for our societies (pp. 175–182). ediSens.

15 Tasiemski, A. et al., (2014). Characterization and Function of the First Antibiotic Isolated from a Vent Organism: The Extremophile Metazoan Alvinella pompejana. *PLoS ONE*, *9*(4),

16 Agenda 30x30 is a global initiative that seeks to protect 30% of the planet by 2030.

17 Gaill, F., Riblier, E., Chabaud, C., et al. (2021). L'océan bien commun de l'humanité: Séminaires de la task force océan du CNRS [The Ocean as a Common Good of Humanity: CNRS Taskforce Seminars]. La Revue Maritime, 5, 37.

18 Gaill, F. et al., (2022). An evolution towards scientific consensus for a sustainable ocean future. *Npj Ocean Sustainability*, *1*(1). https://doi.org/10.1038/s44183-022-00007-1.

19 *Towards an Intergovernmental Panel for Ocean Sustainability (IPOS)* (August 2023). European Climate, Infrastructure and Environment Executive Agency. https://cinea.ec.europa.eu/funding-opportunities/calls-tenders/towards-intergovernmental-panel-ocean-sustainability-ipos.

Tackling the effects of atmospheric dust hazard on human health

Emmanouil Proestakis
Postdoctoral researcher at the Remote sensing of Aerosols, Clouds and Trace gases (ReACT) research unit of the National Observatory of Athens (NOA) and AXA Research Fund fellow

April 2023, Greece: an impressive cloud of sand from the Sahara invades the skies over Athens

Emmanouil Proestakis is a postdoctoral researcher at the Remote sensing of Aerosols, Clouds and Trace gases (ReACT) research unit of the National Observatory of Athens (NOA) and an AXA Research Fund fellow. His expertise lies in the field of amphoteric aerosols, with focus on the dust component and its related impacts through advanced remote sensing observations, sophisticated techniques, and theoretical models. His recent work led to the establishment of a global and multiyear climate data record of the inhalable component of atmospheric dust, enabling data-driven insight on dust-induced health disorders, with the objective to enhance adaptation, mitigation, and risk management to preserve human health.

What is the contribution of the inhalable component of atmospheric dust to the total aerosol load? How much of it resides close to the Earth's surface, where most human activity takes place? To what extent has it changed over the highly-industrialized and densely-populated areas/Megacities over the last two decades and over which areas is the atmospheric concentration foreseen to exceed the World Health Organization Air Quality Guidelines in the near-future? To what extent have dust emissions changed since the pre-industrial times and what can the national and international initiatives say about the amount of dust that will reside in the atmosphere by the end of the century? The article discusses the current status of pressing societal questions related to the health risk posed by the inhalable component of atmospheric dust, which are made even more pressing by the ongoing climate change. Insights are delivered under the prism of ongoing international initiatives, recent advancements, and the challenging limitations of our capabilities.

INTRODUCTION

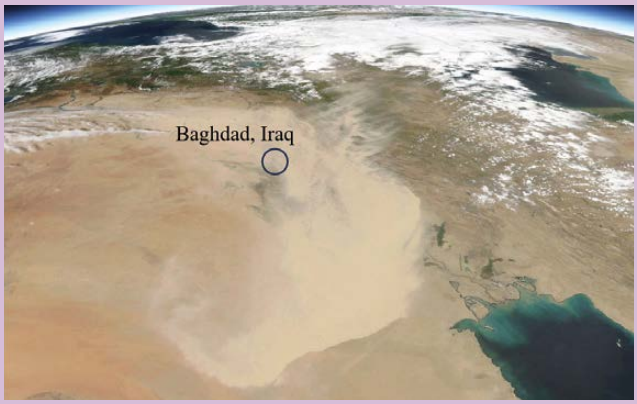
According to the World Health Organization (WHO) and the Intergovernmental Panel on Climate Change (IPCC) Sixth Assessment Report (IPCC 6thAR), the intensifying climate change represents a major threat to human welfare and health, with adverse socioeconomic impacts. Among the aerosol[1] species, mineral dust plays a key role in the Earth's climate system, affecting anthropogenic activities as well as human health. Recent epidemiological studies report on the strong association between dust and disorders induced on human health, ranging from mild skin irritation to allergic responses, cardiovascular and respiratory diseases, cancer, and even to epidemic outbreaks. Despite the evidence that atmospheric dust constitutes an important environmental risk factor and the international collaborative efforts that have facilitated unprecedented scientific advances, current knowledge is still characterized by large uncertainties, hampering the potential to enhance tailored and high-quality products and services for assessing the dust-related negative impacts on human health. Ongoing international and scientific initiatives need to be strengthened to address better the challenges posed by atmospheric dust, especially under the ongoing climate change.

1 A mixture of particles (= extremely small pieces of matter) and the liquid or gas that they are contained in, that can spread through the air, Cambridge dictionary.

EXPLORING THE DUST-RELATED THREATS TO HUMAN HEALTH

According to Copernicus – the European Union's Earth observation programme – and the World Health Organization (WHO), a remarkable massive dust storm ravaged Iraq in May 2022, resulting in 5000 people hospitalized for respiratory problems due to poor air quality, just in the province of Baghdad ***(Figure 1)***. And while dust hazards of this magnitude are unusual, high concentrations of dust aerosol load are frequently a norm not only over regions in close proximity to the dust sources of the Earth, but also over areas located hundreds – or even thousands – of kilometers downwind, posing a significant threat to human health.

Figure 1: **Iraq engulfed by a sand and dust storm, as observed by the NASA Aqua and Terra MODIS satellite systems between the 15th and 17th of May, 2022**



Source: NASA Worldview

Just in the past year, according to the World Meteorological Organization (WMO) and the released annual Airborne Dust Bulletin report,[2] several intense sand and dust storm (SDS) events affected extensive regions of the globe, such as the Maghreb, the Sahel and the Gulf of Guinea in December 2023, and the broader eastern Caribbean and northern-south America between December 2023 and April 2024. During the same period, in April 2024, southern Europe (particularly Italy and Greece) was completely swallowed by waves of Saharan dust, with dust surface Particulate Matter (PM_{10}) concentrations reaching as high as 200 μgm^{-3} for extensive periods of time, as reported by AtmoHub,[3] the Copernicus Atmospheric Monitoring System (CAMS) National Collaboration Programme in Greece. The reported levels of dust concentrations, though high, were totally dwarfed by the respective extreme mass concentration levels of the severe dust storms that engulfed Mongolia and northern China in March 2023, causing a dramatic decline in air quality for several consecutive days, with PM_{10} concentrations exceeding 9000 μgm^{-3}. It should be noted, as comparative metric, that the adopted WHO Air Quality Guidelines,[4] established in order to provide a worldwide roadmap towards reducing the negative impacts of air pollution on human health, propose ***(Table 1)***:

"A remarkable massive dust storm ravaged Iraq in May 2022, resulting in 5000 people hospitalized for respiratory problems due to poor air quality, just in the province of Baghdad."

***Figure 2*: WHO - Air quality guidelines**

$PM_{2.5}$:	10 $\mu g/m^3$ annual mean
	25 $\mu g/m^3$ 24-hour mean
PM_{10} :	20 $\mu g/m^3$ annual mean
	50 $\mu g/m^3$ 24-hour mean

i. for 24-hour mean particulate matter exposure the upper safety thresholds of 25 μgm^{-3} and 50 μgm^{-3} for $PM_{2.5}$ and PM10, respectively (see definition below).
ii. for annual-mean exposure the upper safety thresholds of 10 μgm^{-3} and 20 μgm^{-3} for $PM_{2.5}$ and PM_{10}, respectively.

It appears that dust events characterized by such exceptionally high concentrations of particulate matter may lead to extremely hazardous conditions, posing considerable challenges to both public life and human health, as reported by several epidemiological studies.[5] However, not all particles composing the aeolian transported dust layers pose the same environmental risk factor. A key aspect governing the association between aerosols, air quality, and the dust-related negative disorders induced on human health is the amount of airborne Particulate Matter (PM) ***(Figure 3)***. In general, PM is divided into three distinct classes, (i) PM_{10} (coarse), (ii) $PM_{2.5}$ (fine), and (iii) UFP (ultra-fine), referring to categories of airborne particles with aerodynamic diameter ≤10 μm, ≤2.5 μm, and ≤0.1 μm, respectively. With respect to mineral dust, large scale intensive experimental campaigns employing airborne in-situ instrumentation (e.g., AER-D/ICE-D campaign in 2015) reported on the size of dust particles residing in atmospheric aeolian transported layers – spanning over more than three orders of magnitude, from less than 0.1 μm (~of the order of SARS-CoV-2 virus) to more than 100 μm (~of the order of a human hair) in diameter.[6] In general, the health risk attributed to coarse-size mineral dust particles is considered low, referring mainly to mild skin irritation or allergic responses, even under conditions of high dust concentrations and long-term exposure. However, dust $PM_{2.5}$ particles – due to their small size – can penetrate deep into the lungs and alveoli, leading to allergic responses, cardiovascular and respiratory diseases, and even cancer. To dive even deeper into the fine-mode dust hazard, the relation between the inhalable component of atmospheric dust and epidemic outbreaks remains an open scientific question, for the role of aeolian mineral dust particles as bacterial carriers, such as in the case of meningitis outbreaks in the Sahel during the Harmattan Seasons, is still elusive.

2 World Meteorological Organization. (2024, July). WMO Airborne Dust Bulletin No. 8. https://library.wmo.int/records/item/68953-no-8-july-2024.

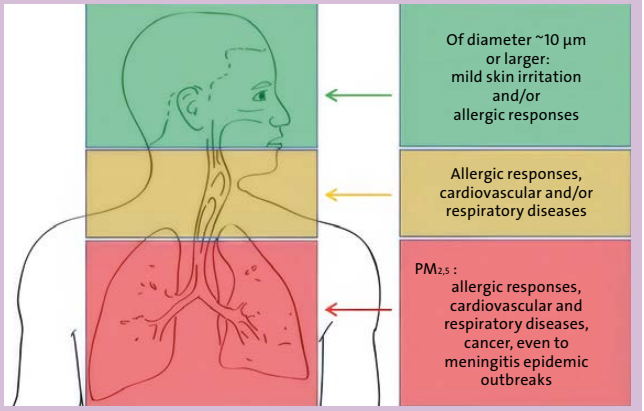
3 *AtmoHUB* - https://atmohub.gr/.

4 World Health Organization. (n.d.). Health impacts of climate change in the WHO European Region (WHO-SDE-PHE-OEH-06-02). World Health Organization. https://www.who.int/publications/i/item/WHO-SDE-PHE-OEH-06-02.

5 Goudie, A. S. (2014). Desert dust and human health disorders. Environment International, 63, 101–113. https://doi.org/10.1016/j.envint.2013.10.011.

6 Ryder, C. L., Marenco, F., Brooke, J. K., Estelles, V., Cotton, R., Formenti, P., McQuaid, J. B., Price, H. C., Liu, D., Ausset, P., et al. (2018). Coarse-mode mineral dust size distributions, composition and optical properties from AER-D aircraft measurements over the tropical eastern Atlantic. Atmospheric Chemistry and Physics, 18, 17225–17257. https://doi.org/10.5194/acp-18-17225-2018.

Figure 3: Size of dust particles and reported disorders induced on human heal



Source: Emmanouil Proestakis

To better assess the dust-related negative impacts on human health, it is mandatory to enhance our fundamental understanding on the inhalable fine-mode component of dust ($PM_{2.5}$). Towards this objective, it is of high significance to begin with expanding further our basic understanding of the complex life cycle and journey of dust into the atmosphere. This is even more important considering that, in terms of total mass, dust is one of the most predominant types of aerosols encountered in the atmosphere, second only to marine sea salt emissions. More specifically, a recent review quantified and reported the total amount of dust emitted by natural sources (i.e. arid and semi-arid areas) into the atmosphere ~4680 Tg/yr,[7] an amount that would translate to more than 463,000 times the weight of the Eiffel Tower. However, it should be noted that this amount of dust is only a fraction of the total atmospheric dust. At a global scale natural dust sources account for ~75% of dust emissions, with the additional ~25% attributed to anthropogenic activities,[8] such as transportation, infrastructure, building and road construction, deterioration of extended soil surfaces, change in land use, deforestation, grazing, urbanization, and agriculture. Once these thousands of teragrams of dust are released into the atmosphere they are subject to long-range aeolian transport, prior to their removal through wet or dry deposition. Consequently, the frequently dramatic decline in air quality due to increased levels of dust concentration over extensive areas located sometimes even thousands of kilometers downwind from the dust emission sources is a pivotal characteristic of atmospheric dust, elevating the dust hazard from local to regional or even to global scale.

"A recent review quantified and reported the total amount of dust emitted by natural sources (i.e. arid and semi-arid areas) into the atmosphere ~4680 Tg/yr , an amount that would translate to more than 463,000 times the weight of the Eiffel Tower."

REGIONAL AND INTERNATIONAL SCIENTIFIC COORDINATION TO FACE CHALLENGES POSED BY ATMOSPHERIC DUST

Nowadays several national and international initiatives have been established with the objective of tackling dust-related problems, since atmospheric dust represents a serious hazard not only for life and health, but also for property, the environment, and the economy and plays a significant role in determining weather and climate systems. For example, the WMO Sand and Dust Storm-Warning Advisory and Assessment System (SDS-WAS), in partnership with the Global Atmosphere Watch (GAW), is a worldwide collaborative cooperation to improve and enhance the capabilities of more reliable operational SDS forecasts. The United Nations Environment Programme (UNEP) Global Environment Outlook (GEO) reports the state and direction of the global environment, including assessments in atmospheric dust sources, trends, and impacts. The Dust Alliance for North America (DANA) consists of an initiative aiming to accelerate the transition of dust-related research into societal solutions. The European Space Agency (ESA), through the Climate Change Initiative (CCI), provides long-term, high-quality climate data records (CDR) derived from satellite observations to support climate research and policy-making, such as the LIVAS CDR.[9] Meanwhile, the European Aerosol Research Lidar Network (EARLINET) operates state-of-the-art stations in Europe -and beyond- to observe and analyze the three-dimensional distribution of aerosols in the atmosphere, including dust.

These indicative initiatives highlight the coordinated actions taken across international organizations, regional groups, and research centers to address the multifaceted challenges posed by atmospheric dust. The collaborative efforts have facilitated unprecedented advances in observational and modelling capabilities of aerosol, which in our times have reached a level of maturity to be ready to translate into user-oriented products and services, helping to shape policies and mitigation strategies. However, more advances still have to be achieved in order to reduce the current scientific uncertainties when it comes to the inhalable fine-mode component of dust, to eventually achieve tailored and high-quality products and services for assessing the dust-related negative impacts on human health. For example, the vast majority of satellite-based Earth Observation (EO) systems today lack the capacity to retrieve and provide the elevation and extension of aerosol layers in the atmosphere, hampering the potential to resolve the aerosol load within the Planetary Boundary Layer, where the main anthropogenic activity takes place. Moreover, most dust-related health disorders depend primarily on the size of dust particles and secondarily on the total mass of dust. However, satellite-based Earth Observations, without extensively applying assumptions and parameterizations, lack the capacity to decouple the dust aerosol component from the total aerosol load, making the retrieval of the inhalable fine-mode component of dust an even more formidable challenge. Finally, today's state-of-the-art atmospheric aerosol models are broadly utilized

7 Kok, J. F., Storelvmo, T., Karydis, V. A., Adebiyi, A. A., Mahowald, N. M., Evan, A. T., He, C., & Leung, D. M. (2023). Mineral dust aerosol impacts on global climate and climate change. Nature Reviews Earth & Environment, 4, 71–86. https://doi.org/10.1038/s43017-022-00379-5.

8 Ginoux, P., Prospero, J. M., Gill, T. E., Hsu, N. C., & Zhao, M. (2012). Global-scale attribution of anthropogenic and natural dust sources and their emission rates based on MODIS Deep Blue aerosol products. Reviews of Geophysics, 50, RG3005. https://doi.org/10.1029/2012RG000388.

9 Amiridis, V., Marinou, E., Tsekeri, A., et al. (2015). LIVAS: A 3-D multi-wavelength aerosol/cloud database based on CALIPSO and EARLINET. Atmospheric Chemistry and Physics, 15, 7127–7153. https://doi.org/10.5194/acp-15-7127-2015.

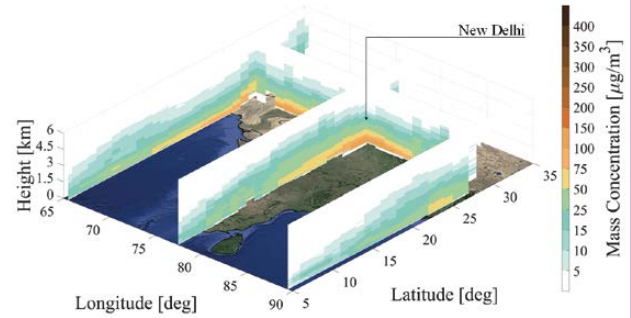
to provide spatiotemporal information on dust emission, transport, deposition and vertical structure. These models typically use static land cover types to classify arid and semi-arid regions as dust emission sources. However, the reliance on empirical emission inventories that do not change over time leads to large uncertainties, especially in regard to unaccounted anthropogenic dust emissions in highly-industrialized and densely-populated regions of the Earth or as feedback from anthropogenic activities (e.g. deforestation of the Amazon Rainforest). This results in considerable underestimations of the amount of dust released into the atmosphere, and thus in assessing the environmental health risks associated with dust.

FUTURE DUST EMISSIONS PROJECTIONS IN THE LIGHT OF CLIMATE CHANGE AND THEIR LIMITATIONS

At this point, it is crucial to highlight that scientific advancements would still be insufficient to achieve ideal adaptation and mitigation strategies on the risks of high concentrations of airborne dust to human health, if they do not take into account one of the most pressing challenges of our era: climate change. More specifically, it is estimated that the global atmospheric dust mass load in modern climate (1981–2000) has increased by approximately 55 ± 30%[10] since pre-industrial times (1841–1860), with observational findings suggesting that anthropogenic land-use change was the key driver for this significant change. This is especially the case for extensive Asian areas, hosting some of the most densely populated and heavily industrialized areas and megacities of the planet, sometimes within or in close proximity to the dust-belt of the Earth. For example, a recent scientific study supported by the AXA Research Fund quantified on the basis of more than a decade-and-a-half of satellite Earth Observations the inhalable fine-mode component of dust (PM_1) over the New Delhi megacity area and close to the surface to be more than 75 μgm^{-3}, translating to concentration levels more than seven times higher than the annual-mean safety threshold for $PM_{2.5}$, as proposed by the WHO in the framework of the Air Quality Guidelines (***Figure 4***).[11] With respect to future dust emissions, projections are highly variable among the climate models, with some of them showing increasing tendencies whilst others show opposing tendencies. Numerous factors of different significance contribute to the apparent discrepancies of climate models' projections, having as a key driver the Shared Socioeconomic Pathways (SSPs) scenarios.[12] More specifically, according to the climate model parametrizations under different socioeconomic trajectories of different possible futures that humanity will face, as established by the Integrated Assessment Modeling (IAM) community in the framework of the Intergovernmental Panel on Climate Change (IPCC) and during the Fifth Assessment Report (5thAR-2013), atmospheric dust load may vary significantly from nowadays.

Despite facing substantial challenges, the global scientific community keeps pushing the boundaries of the current state of knowledge beyond its limitations, translating observational and modelling advances into knowledge, and accordingly into information, tailored products, and end-users' services. A final but highly significant aspect to be enhanced is the coordination between the scientific community, society, and policy makers. An improved flow will amplify information and knowledge exchange between the involved communities, across multidisciplinary and fractured socioeconomic and political sectors, and across cultural boundaries. This improved flow will further assist policy-makers, stakeholders, and end-users with advanced systems and services, towards their endeavor to support effective adaptation and mitigation strategies to preserve human health in the face of climate change.

Figure 4: Atmospheric dust - PM_1 (annual mean: 2006-2022)



Atmospheric dust PM1 over the Indian Subcontinent, with focus over the New Delhi megacity urban area.
Source: Proestakis et al., 2024[13]

CONCLUSION

Atmospheric dust layers, composed of mineral particles of size ranging from less than 0.1 µm to more than 100 µm in diameter, play a key role in Earth's weather and climate systems. These layers come with adverse socioeconomic and environmental impacts, while significantly affecting anthropogenic activities and human welfare, health, and life. Towards addressing the multifaceted challenges posed by atmospheric dust, several national and international initiatives are established, with the collaborative efforts facilitating unprecedented advances in observational and modelling capabilities of dust aerosol. However, despite the evidence that the inhalable fine-mode component of dust is an important environmental risk factor for human health, current knowledge is still characterized by large uncertainties, hampering the potential to reach a significantly higher level of user-oriented products and services that would help shape policies and mitigation strategies. While international initiatives strive to tackle the issues posed by dust emissions, individuals can also take proactive steps to safeguard their health. For those with pre-existing conditions, such as heart or lung disease, monitoring air quality indexes allows them to adjust their daily activities, reducing outdoor exposure or avoiding strenuous exertion when particle levels are high. By combining scientific advances, large-scale mitigation efforts, and individual actions, we can build more resilient communities better prepared to face the challenges of climate change.

10 Indicates the uncertainty range around the estimated increase of 55%. It means that the actual increase in global atmospheric dust mass load could be as much as 85% (55% + 30%) or as little as 25% (55% - 30%).

11 Proestakis, E., Gkikas, A., Georgiou, T., Kampouri, A., Drakaki, E., Ryder, C. L., Marenco, F., Marinou, E., & Amiridis, V. (2024). A near-global multiyear climate data record of the fine-mode and coarse-mode components of atmospheric pure dust. Atmospheric Measurement Techniques, 17, 3625–3667. https://doi.org/10.5194/amt-17-3625-2024.

12 Climate change scenarios of projected socioeconomic global changes up to 2100 as defined in the IPCC Sixth Assessment Report on climate change in 2021.

13 Proestakis, E., Gkikas, A., Georgiou, T., Kampouri, A., Drakaki, E., Ryder, C. L., Marenco, F., Marinou, E., & Amiridis, V. (2024). A near-global multiyear climate data record of the fine-mode and coarse-mode components of atmospheric pure dust. Atmospheric Measurement Techniques, 17, 3625–3667. https://doi.org/10.5194/amt-17-3625-2024.

Climate change and water resources:

Excess, shortage, and pollution

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A series of extreme climate events in 2022 had a profound impact on water resources in France and western Europe. Droughts led to water shortages in several areas and were followed by winter storms that caused record flooding.

Long-term projections point to significant reductions in the amount of water in rivers and groundwater reserves. Some French departments, such as the Pyrénées-Orientales, are already confronted with conditions of semi-aridity while others, such as Pas-de-Calais, are experiencing water surplus. The changing climate has serious, unsettling effects on homes and infrastructure, particularly for the production and distribution of drinking water as well as on sectors such as agriculture and industry that are heavily reliant on water. This article explores these issues and presents individual and collective solutions to address these challenges and prepare critical infrastructure for the impacts of extreme climate events.

INTRODUCTION

"Gouverner, c'est pleuvoir" [*to govern is to rain*]. Whether attributed to Marshal Hubert Lyautey, the first French Resident-General in Morocco, or to Théodore Steeg, his successor in Rabat from 1925 to 1929, this saying refers to the impact of drought on the colony's economy. It shows how forward planning in Morocco inevitably involved making allowances for water resources and setting strategies for the construction of water infrastructure designed to respond to the vagaries of the climate.

Although pronounced in Morocco 100 years ago, the phrase perfectly describes the water situation in present-day France and its nearby European neighbors as a consequence of climate change. In some regions, this change takes the shape of structural water shortages caused by persistent drought and heatwaves. Conversely, other regions sometimes have too much water, with tropical downpours resulting in the equivalent of three months' rainfall in just three hours.

2022: A MARKER OF CLIMATE CHANGE

2022 is perceived as a turning point in terms of resource scarcity. According to the interministerial mission on drought,[1] 1,260 French waterways were dry on August 1, 2022, causing disruption to water supplies in a little over a thousand municipalities. Another thousand, under stress, were on the point of tipping into a water shortage.

This pattern of resource depletion is likely to occur on a regular basis between spring and late fall, without any region in western Europe being entirely spared. According to a range of forecasts, France will experience an average 20% fall in river flows and a 20 to 30% decrease in groundwater levels by 2040.

1 Ministère de l'Agriculture et de la Souveraineté Alimentaire. (2023, April 12). Retour d'expérience sur la gestion de l'eau lors de la sécheresse 2022 [Overview of water management during the 2022 drought]. https://agriculture.gouv.fr/retour-dexperience-sur-la-gestion-de-leau-lors-de-lasecheresse-2022.

However, these reductions will not be spread evenly across the country, with regions such as the Pyrénées-Orientales moving toward lasting semi-aridity, similar to the situation in neighboring Spain. Month after month, it is the only area marked in red – showing levels of groundwater classed as low to extremely low – on maps compiled by the French Geological Survey (BRGM).[2] In 2023, the station in Perpignan recorded just 245 millimeters of rain compared to an annual average of 578 millimeters.

Conversely, on the other side of France, Pas-de-Calais recorded extremely high groundwater levels on May 1, 2024, the result of winter rains that had battered the region earlier in the year. Storms Ciaran and Domingos brought as much rain to the Hauts-de-France region in the space of a few days as usually falls over three or four weeks. Throughout November 2023, the Boulogne-sur-Mer station recorded cumulative rainfall of almost 317 millimeters, surpassing the previous record of 304 millimeters in 2000.[3]

"According to a range of forecasts, France will experience an average 20% fall in river flows and a 20 to 30% decrease in groundwater levels by 2040."

The duration and volume of these heavy rains, falling on ground that was already saturated, led to widespread storm flooding. The devastation caused by the floods was exacerbated by the harmful effects of widespread soil sealing over the past 50 years. Flooding from rivers bursting their banks is generally aggravated by the impact of rising groundwater and overloaded sewage networks.

This threefold flooding (heavy rain, rising groundwater, uncontained discharges from wastewater networks) has devastating and long-lasting impacts on infrastructure that is vital to local communities, such as electricity and telecommunication networks, and causes damage to countless houses and apartment blocks.

CONSEQUENCES FOR DRINKING WATER

Water use is disrupted by these extreme phenomena caused by climate change. Accounting for 18.7% of water withdrawals in France, the production and distribution of water by operators (whether public or private under delegated management) ensure the supply of drinking water to the population and to high-risk customers for health (e.g., hospitals) and security reasons (e.g., critical industrial sites).

2 BRGM. (2024, July 12). Groundwater reserves on July 1, 2024. BRGM. https://www.brgm.fr/fr/actualite/communique-presse/nappes-eau-souterraine-au-1er-juillet-2024.

3 Infoclimat. (2023). Climatologie de l'année 2023 à Boulogne [Climate data for 2023 in Boulogne]. https://www.infoclimat.fr/climatologie/annee/2023/boulogne/valeurs/07002.html.

33% of the water withdrawn is abstracted from the surface, with the remainder coming from underground sources.[4] In 2022 the sight of parts of the River Loire looking like a sea of sand was justifiably alarming for operators of the water treatment plants found widely along the river's course. In the Loire region as elsewhere, water treatment plants need access to raw water that must not exceed a temperature of 25°C, be overloaded with pollutants caused by low flow rates, or suffer from eutrophication.[5] Unfortunately, precisely the opposite occurs in low-water[6] rivers during extended heatwaves and droughts.

Still in 2022, wildfires in the Gironde department highlighted the vulnerability of water and sewage infrastructure threatened by advancing flames. That summer, 70,000 hectares burned, ten times more than usual. The fires that ravaged the municipality of Teste-de-Buch are a perfect illustration. Water infrastructure such as well fields[7] in forest areas were at risk, along with the availability of water for firefighting.

A new problem arises with the fact that affected areas are no longer located exclusively in the southern half of France, where farmers are used to clearing scrub and brush from around their facilities in the winter and adopting fire-prevention strategies in the summer. On July 18, 2022 95 wildfires were reported in 37 different departments, including in places like Finistère, Maine-et-Loire and Eure with no history of forest fires, not even during exceptionally hot years such as 2003.

4 Bureau d'informations et de prévisions économiques. (2019). Les services publics d'eau et d'assainissement en France [Public water and watsewater services in France]. https://economiev2.eaufrance.fr/sites/default/files/2020-10/doc408-fp2e-bipe-2019-eau-assainissement-.pdf.

5 State caused by an overabundance of organic matter in a waterway, lake or coastal area.

6 Lowest average level/minimum waterway flow rate.

7 Series of bores and wells used to extract water from underground. These installations are often used to supply drinking water or for agricultural and industrial uses.

Flooding also causes serious disruption to drinking water production and distribution capacity. It leads to issues that include: turbidity, pollution of raw water caused by uncontained discharges from wastewater plants with insufficient capacity to deal with the volumes of storm water, and pollutants arising directly from the flooding, such as from home heating oil tanks and waste oil from garages being washed into the floodwater.

As with every other essential activity, the water industry must improve its robustness and needs to be better prepared to manage the consequences of climate change. This is an issue covered by the December 14, 2022 EU directive on the resilience of critical entities.[8] When it enters into law in France on October 17, 2024, the directive will require water and wastewater operators, as designated critical operators, to draft resilience plans that include details of their efforts to anticipate and respond to extreme climate risks.

CONSEQUENCES FOR OTHER USES

Climate change also has a significant impact on the water-energy nexus. While energy is needed to extract groundwater, treat raw water to make it drinkable, and carry it all the way to users' taps (in France this takes 0.5 Kw/h per cubic meter of water distributed), generating energy also requires large amounts of water.

"While energy is needed to extract groundwater, treat raw water to make it drinkable, and carry it all the way to users' taps (in France this takes 0.5 Kw/h per cubic meter of water distributed), generating energy also requires large amount of water."

The energy industry is a major water user, accounting for 44.7% of all water abstraction in France.[9] Water is used mainly for hydro-electric generation and cooling nuclear reactors. Although a major abstractor, the energy industry is a relatively small consumer, as EDF's nuclear plants, operating in a closed loop, discharge the vast majority of the water they abstract.[10]

The biggest challenge facing EDF lies elsewhere, in its capacity to dilute the cooling water discharge from its power plants when rivers are at their lowest.[11] This is why nuclear power plants need to increase their effluent storage capacity in tanks holding 300 to 500 cubic meters, making it possible to reach the minimum flow rate above which cooling water can be discharged into the environment.

Water scarcity also impacts the manufacturing industry, which accounts for an average of 7.6% of water abstracted in France, with significant variations across the country. South of the Loire estuary for example, industrial water use can account for up to 50% of total withdrawals due to water-intensive activities. The Donges refinery, which supplies 11 million metric tons of refined petroleum products annually (17% of French fuel), uses 3 to 4 million cubic meters of water annually, taken mainly from the Campbon aquifer. Nearby Saint-Nazaire, Cargill processes sunflower seeds into vegetable oil and livestock feed, using the equivalent of half an Olympic-size swimming pool every day.

Like the petrochemicals and the agri-food industry, the new technology sector is also a major consumer. The ST Microelectronics site in Grenoble, whose output is strategically important for the production of chips in the European Union, used 4.5 million cubic meters of water in 2022. This amount is equivalent to 20% of the drinking water distributed by city authorities, and is necessary for ensuring ultrapure water required for its manufacturing process.

In a context of resource scarcity due to changes in precipitation patterns, one of the major challenges for the coming decades will be to boost the resilience of power plants and industrial sites, including those located in zones that have not yet experienced any meaningful signs of water shortage.

Let us take the Rhône as an example. Between 1960 and 2020, the Rhône basin saw temperatures rise by 1.8°C as well as changes in river flow, which is 7% lower when exiting Lake Geneva in Switzerland and as much as 13% lower at Beaucaire in the Gard department of France. These figures, when taken in combination with lower volumes of water in shrinking

8 Directive 2022/2557 of the European Parliament and the Council.

9 Ministère de la Transition Écologique et de la Cohésion des Territoires. (2023). Les prélèvements d'eau douce : principaux usages en 2020 et évolution depuis 25 ans en France [Freshwater abstraction: main uses in 2020 and changes in France over 25 years]. https://www.statistiques.developpement-durable.gouv.fr/les-prelevements-deau-douce-principaux-usages-en-2020-et-evolution-depuis-25-ans-en-france.

10 Water abstracted is not the same as water used. Water abstracted is "freshwater taken from underground or surface sources to meet the needs of human activities." Water used is "water abstracted and not returned to the aquatic environment: this is mainly water that has evaporated or been incorporated into the soil, plants and products."

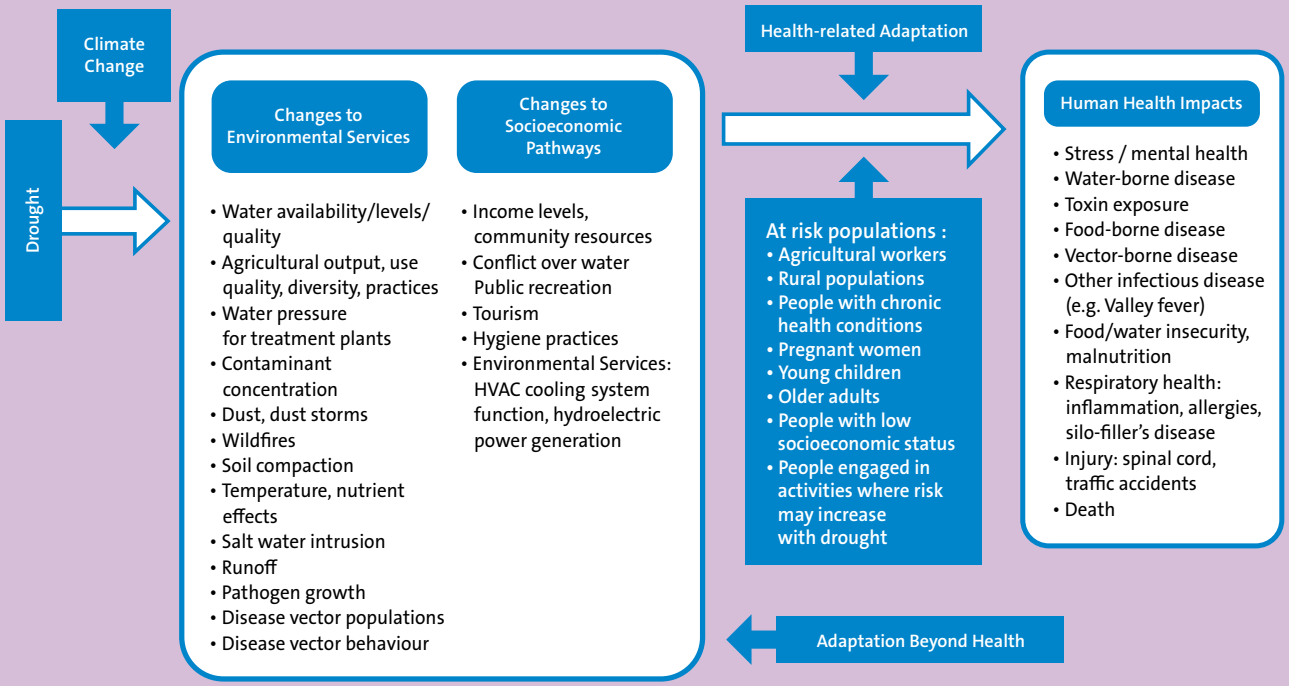
11 As defined above, lowest average level/minimum waterway flow rate.

Drought is a threat to health

Water is vital to human health. Maslow's pyramid depicting the hierarchy of needs places water as one of the pillars of human health: it includes physiological needs, such as drinking and eating, among the fundamental prerequisites for survival and wellbeing. Our social and economic structures mean that health is also indirectly dependent on water: water conditions the production of electricity, agriculture, housing, and sometimes even employment.

The phenomena described above underline the likelihood of an increased incidence of droughts, with consequences that could have profound impacts on health and wellbeing. For example, changes in flow rate or water temperature can increase the presence of pathogens, as bacteria thrive in water with temperatures between 25°C and 50°C. Additionally, interruptions to water supply can undermine healthcare providers such as hospitals, dialysis units, and care homes.

The diagram below offers a non-exhaustive illustration of the direct and indirect impacts drought has on health. It also highlights how closely human health is linked to the environment and socio-economic context.



Pathways through which drought impacts human health in the context of climate change

Source: Yusa, A., Berry, P., J Cheng, J., Ogden, N., Bonsal, B., Stewart, R., & Waldick, R. (2015).

Alpine glaciers, are cause for alarm, especially considering that 25% of France's electricity production, as well as a quarter of all the residents and employment opportunities in the Rhône-Mediterranean-Corsica basin, are concentrated along the banks of the Rhône.

Downstream from Beaucaire is a pumping station that extracts 75 cubic meters of river water a second to supply the whole Occitanie plain with its coastal tourist zones, many of the built-up areas between the cities of Nîmes and Montpellier, as well as the agricultural regions of the Petite Camargue and the arboricultural Costières plateau (one of the largest in Europe). The water is abstracted by BRL Exploitation, which manages and operates the regional water network concession.

With the extension of the Aqua Domitia[12] project, water from the Rhône, which is of strategic importance to this entire part of the Occitanie region, is now carried beyond Montpellier and may in the future continue as far as the Pyrénées-Orientales to provide a lasting solution to a department that, as we have seen, is struggling with the effects of persistent drought.[13]

More than ever, the Rhône is playing the role of the main artery for southern regions and Rhône-Alpes, where all those drawing water will have to pay particular attention to the

12 Launched in 2008 this is a project unlike any other in Europe, with the Aqua Domitia network drawing water from the Rhône to provide a long-term supply to the Gard and Hérault departments.

13 Abstractions from the Rhône (2024). Compagnie d'aménagement du Bas-Rhône et du Languedoc (BRL).

new realities they face. This is notably reflected in exceptional measures to limit or suspend water use through prefectural orders under the terms of articles L.211-3 II-1° and R R211-66 of the Environment Code. As of June 30, 2023, all installations requiring environmental protection certification are also subject to varying degrees of restrictions depending on the gravity of the situation.

But over and above industrial users, it is the water footprint of agricultural activities that will need to change drastically. Accounting for 44% of water use in France, agriculture and livestock are by far the largest users of water resources.

"In 2022, there was, for example, a 30% fall in olive oil production and a 7.4% drop in the harvest of the durum wheat essential for pasta."

In 2022, water shortages had a significant impact on farm yields in France and neighboring Italy, whose northern regions were particularly affected. There was, for example, a 30% fall in olive oil production and a 7.4% drop in the harvest of the durum wheat essential for pasta. These decreases cost transalpine agriculture an estimated €6 billion in lost revenue.[14]

TOWARD INDIVIDUAL AND COLLECTIVE SOLUTIONS FOR CROSS-BORDER BASINS

The facts indicate that entire sectors of the economies of France and its European neighbors must adapt to increasing resource scarcity, requiring better planning for the impacts of extreme climate events as well as changes in how resources are used. This proactive approach involves measures at both the individual and collective levels.

Individual, because water users need to accelerate their shift towards efficient water use, a transformation driven by awareness-raising campaigns, technologies for reusing wastewater and digitizing networks, and new techniques for reducing leaks.

However, these approaches must also be collective, ensuring that needs are understood on all sides and analyzing the downstream and upstream interdependencies that arise when water becomes scarce.

Further, there is likely a need to think collectively about building new hydraulic reservoirs to support low flows and secure usage. Severe low flows are expected to be more common in France, with flow rates falling anywhere from 14% to 40% in some areas.[15] For the Villerest and Naussac dams, managed by Etablissement Public Loire, which played such a crucial role during the summer of 2022, this will entail more frequent demands and the release of two to three times the usual amount of water.

Then comes the need for stronger cooperation within river basins, including across borders. Take the River Meuse, which obviously does not stop flowing the moment it passes the French-Belgian border. Meeting the water needs of stakeholders in France, Belgium and the Netherlands is becoming a critical challenge. It is essential for drinking water supplies, agricultural water, and water for what we could term "convenience" uses since it is needed for home and industrial air-conditioning systems or cooling data centers. Regional energy security must also be taken into account by ensuring continuity of activity at nuclear plants in Belgium and France, as well as navigability on the Meuse with the rise in importance of the Liège river port, already Europe's third largest after Duisbourg on the Rhine and Paris on the Seine.

In this way, the Meuse example imposes a new framework for strategic dialogue between the river's users, one that could equally be applied to the Moselle, Doubs, Rhine and Rhône rivers.

CONCLUSION

As we have seen, extreme weather events resulting from climate change are causing widespread disruption to water resources. Extended droughts, dry waterways, and devastating flooding not only have an impact on drinking water supplies but also on many sectors that use and/or consume water. Projections agree that many more events of this type will occur in the years up until 2040, highlighting the growing severity of these issues.

While the effects of such disruption to our water resources can sometimes only be seen indirectly (via increased pressure on production and treatment systems, interruptions in supply, etc.), they can also pose a direct threat to human health (usage restrictions, outright bans on consumption, etc.). These disruptions call for the development of solutions that guarantee the well-being and resilience of our societies in the face of such environmental challenges.

It is through individual water-saving measures by users and collective resilience efforts at the river basin level – such as the creation of new infrastructure, the use of shared forecasting data, the renegotiation of cross-border cooperation agreements, and the strengthening of regional dialogue bodies – that we will mitigate the consequences of extreme climate events on water-consuming human activities.

14 Courrier International. (2022, July 14). Comment la sécheresse détruit le made in Italy alimentaire [How drought destroys Made in Italy foods]. https://www.courrierinternational.com/article/climat-comment-la-secheresse-detruit-le-made-in-italy-alimentaire#:~:text=En%202022%2C%20la%20production%20d,euros%20aux%20entreprises%20agricoles%20italiennes.

15 Rhône Mediterranean Corsica Water Agency (2023). Minimum flow rates in the Rhône are falling because of climate change. Hydrological study of the River Rhône and climate change. https://www.eaurmc.fr/upload/docs/application/pdf/2023-03/aermc_plaquette_rhoene_reugime_hydrologique_v9_bigbang_web.pdf.

3 The impacts of climate change on societies and organizations: adaptations to protect health

Organizational resilience has become vital in the face of climate change and its effects on human health and the environment. It is defined as "the capacity of a certain organization to maintain a state of dynamic stability, which allows it to continue its operations during and after a major incident or in the presence of a major stress."[1] To develop this capacity, societies and organizations have to tackle four types of challenges: cognitive, by accepting change; strategic, by imagining new options; political, by channeling resources to tomorrow's activities, and ideological, by promoting a proactive search for opportunities.[2]

The third part of FACTS explores solutions developed by societies and organizations to grow their resilience and protect human health and the environment in the face of ecological crises. In response to these challenges, the Draghi Report recommended that Europe invest 750 to 800 billion euros annually, with over half directed to the ecological transition.[3] Similarly, the UNEP's 2024 Adaptation Gap Report[4] estimates that developing economies need between 215 and 387 billion dollars in financing a year up to 2030 to help adapt to climate change, a sum far greater than the 28 billion invested in 2022. This shows that an ambitious, collective approach is essential to generating meaningful change.

Despite widespread acceptance of the global threat posed by the ecological crisis, resistance and divisions persist, pitting supporters of a slow transition against advocates of its acceleration. There is however, as presented by **Laurence Bedeau** with the results of the second Elabe Ecological Transformation Barometer, an emerging public consensus about the need to act quickly if our health is threatened.

In this context, there is a vital need for adaptations to our urban and living environments. With 55% of the world's population living in towns and cities – an ongoing trend set to rise to 70% by 2050[5] – urban habitability is emerging as an essential factor in protecting human health. **Melanie Lowe** examines strategies for urban resilience, underlining the importance of transforming infrastructure to cut CO_2 emissions, improve quality of life, mitigate climate risks and adapt to them. **Beta Paramita** describes the take-up of urban adaptation strategies in Indonesia, a country heavily exposed to the consequences of climate change, with help from BeCool, a reflective paint used to reduce indoor and outdoor temperatures. **Choo-Yoon Yi** and **Chengzhi Peng** suggest adapting and installing heat-health alert systems in care homes to protect elderly residents who are particularly vulnerable to heatwaves. This need to adapt involves every type of organization, even prisons – often seen as something of an environmental policy blind spot. **Anouk Mousset** and **Julien Sipra** explain the different ways in which penal establishments are trying to adapt to grow their resilience and protect prisoners' health in the face of climate risks. There is a particular need to pay attention to adapting environments and living spaces located in the most vulnerable places and used by the most at-risk groups.

Responsible for 5% of global carbon emissions, health systems are also affected by the impacts of climate change and have to make efforts to decarbonize. This topic is explored by **Sandrine Bouttier-Stref**, who takes a broader look at the question of the resilience of health systems. Her contribution shines a light on specific challenges climate change poses to health systems, including extreme climate events and the exacerbation of chronic diseases, and stresses the need to ensure the continuity and effectiveness of care.

Guaranteeing adaptation also involves preventing and covering the climate risks that threaten human health. **Françoise Gilles** and **Julia d'Astorg** offer insights from a major insurance company into the complex interactions between climate and health risks that have to be understood to continue providing insurance in the world of tomorrow. Supporting research is clearly key to achieving this, for instance, by sponsoring scientific projects.

Organizations of all types, not only in the insurance industry, need to innovate and ramp up their research and development efforts to boost their resilience. This subject is explored by **Geneviève Leboucher** and **Sandrine Oberti**, who examine the issues facing water service operators in an era of climate change. The authors highlight innovative solutions for tackling growing pressure on vital water resources while simultaneously ensuring that supply and sanitation systems are managed sustainably. Research and development efforts are resulting in the emergence of countless technological innovations. One example is Leko, an innovative, connected tool for monitoring biodiversity and ecosystem health, presented by **Sandrine Oberti** and developed by Birdz. **Lalit Gautam** stresses the advantages artificial intelligence offers in anticipating the impacts of climate change on agriculture as part of efforts to bolster food security.

1 Hollnagel *et al* (2006) *Resilience Engineering: Concepts and Precepts*, doi.org/10.1201/9781315605685.

2 Hamel G., Valikangas L., *The Quest For Resilience*, Harvard Business Review, vol. 81, no. 9, 2003, pp. 52-63.

3 Mario Draghi, European Commission, *The Future of European competitiveness*, 2024.

4 United Nations Environment Programme. (2024). *Adaptation Gap Report 2024: Come Hell and High Water.* Retrieved from: https://www.unep.org/resources/adaptation-gap-report-2024.

5 World Health Organization, Urban health, https://www.who.int/health-topics/urban-health#tab=tab_1.

Health, the new horizon for a desirable future

Laurence Bedeau
Associate director of ELABE, a research consultancy specializing in communications strategy

Laurence Bedeau is associate director of ELABE, a research consultancy specializing in communications strategy. A specialist in listening to and analyzing opinion trends with expertise in ecological issues and corporate responsibility, she helps listed businesses, public companies, professional federations, and institutions with their transformation challenges, crisis management, and corporate communication.

While the ecological crisis has gradually moved to the top of everybody's agenda – driven in large part by the realization of the health impacts – ecological transition seems to have become a new source of social division. There are two opposing blocs in many countries: advocates of an environmental pause on the one hand, adding fuel to the ecological backlash,[1] and on the other hand those who argue in favor of speeding up the rate of transition.

However, it would be wrong to view the ecological crisis simply through the prism of this conflict. The truth is that, alongside differences that are sometimes genuine and often overinterpreted, there are also areas of real convergence. As shown in the second edition of the Ecological Transformation Barometer, conducted by ELABE for Veolia, the severity of the health threat posed by the ecological crisis is now a universal certainty and an individual fear. 75% of people around the world believe that "climate change is the greatest health threat facing humanity." 64% feel exposed and vulnerable to risks to their physical or mental health.

This feeling of vulnerability to health risks is not the sort of fear that prevents people from acting. Quite the opposite! The prospect of living in better health is the number one driver for the acceptability, and even desirability, of ecological transformation.

INTRODUCTION

Are we (still) ready for ecological transformation? To find the answer to this question, Veolia and ELABE conducted a second round of research for the Ecological Transformation Barometer in 26 countries, targeting 60% of the global population.

As we experience a "climate collapse in real time"[2] and with half of the world's population heading to the polls in 2024, environmental policies are causing tensions and divisions worldwide. These tensions are further fueled by voices calling for an "ecological pause".

Do these voices represent public opinion around the world? Although there is certainly a rise in a form of climate denial, almost 9-in-10 people in the world share the belief that an ecological crisis is under way. A large majority fears the health consequences for themselves and their close ones. And this means that they are ready to act!

1 A term referring to people's resistance to environmental initiatives and policies.

2 tatement by António Guterres, Secretary General of the United Nations, in November 2023.

THE DAY ECOLOGY BECAME EVERYBODY'S PROBLEM... AND ECOLOGICAL TRANSITION A NEW FAULT LINE IN OUR SOCIETIES

The day ecology became everybody's problem

Prior to 2020, the environmental crisis was a cause championed by a minority – a growing minority, but still a minority – with a small majority feeling an intermittent sense of anxiety.

The politics of ecology emerged in the 1970s and were ignored during two decades by the majority of public opinion. It was only in the 1990s that opinion polling started to show clear signs of concern about the environment as a result of awareness-raising campaigns, its growing importance in national and international political agendas, and a number of traumatic events. The origin of these events is not always to be found in climate change, but at the time, they were attributed to it (flooding in 1992, storms in 1999, the 2000 oil spill and the heatwave in the summer of 2003). But people eventually get tired of feeling scared. Anxiety ebbs, echoing the descreasing number of images in the media and the fading of emotion, genuine yet inevitably temporary. This backlash is also fueled by the relentless pressure of economic and social demands, which quickly and legitimately shift attention to making ends meet.

"Between 2011 and 2016, the number of French people who felt their local environment was in good condition fell from 58% to 34%. Over the same period, the proportion of French people stating that they felt personally the consequences of the climate crisis in their daily lives rose from 43% to 60%."

Subsequently the "end of the world" made its presence felt more often, and with increasing violence. It became a tangible part of people's daily lives, affecting everybody's health.

The general public's understanding of the links between health and pollution accelerated ecological awareness in the 2000s. This awareness grew steadily once our day-to-day lives (and no longer the all-too abstract "planet") were regularly turned into dress rehearsals for what may become a permanent state: heatwaves, droughts, wild fires, spikes in pollution, flooding, and so on.

Between 2011 and 2016, the number of French people who felt their local environment was in good condition fell from 58% to 34%.[3] Over the same period, the proportion of French people stating that they felt personally the consequences of the climate crisis in their daily lives rose from 43% to 60%.[4]

The consequences of the climate crisis, particularly in terms of health, are no longer hypothetical. Previously felt to be a matter for future generations, they are very much part of the here and now. We shifted from theory to lived experience: chronic respiratory diseases, cardiovascular problems, zoonotic viruses, etc. Pollution and climate events make no distinction, they care nothing for origin, class, beliefs, or religion. The environment has become an issue that conditions personal wellbeing, and thus a global concern.

The Covid-19 pandemic was the high-water mark for awareness of the threat posed by the ecological crisis, not so much for the planet but for the quality of life of the women and men who live on it.

This crisis cemented the centrality of health concerns – a subject that has ranked very high in every opinion poll since 2020 of French people's priorities – and triggered a (re)discovery of humanity's vulnerability. 4.6 billion women and men, 60% of the planet's inhabitants, were forced into lockdown to protect their lives and the lives of their nearest and dearest.

Whereas previously we lived in the belief that our heath was dependent on the quality of our health systems, Covid-19 was a stark reminder of the close relationship between human health, animal health, and ecosystem health. We already knew that we lived on "one planet".[5] We then discovered that we were only "one health"[6].

When ecological transition became a new fault line in our societies

It would be naive, dishonest even, to ignore dissenting voices, the enduring resistance of climate skepticism, and the environmental unfriendly decisions made at individual and public levels. They are legion, all around, and liable to surface at any moment. Because feeling fearful is not enough to cause people to renounce lifestyles forged by previous generations. But also because other fears, whether financial, social or safety-focused, can also be in competition with the feeling of ecological vulnerability.

These are the mechanisms that feed into today's ecological backlash.

The recent spike in inflation in western economies, which had not experienced in several decades, triggered by the return of war to the European continent and its impact on energy and food prices, have downplayed the priority given to the ecological matters. These kinds of crises have made it acceptable once again to claim that concerns about making ends meet and those about the the end of the world are mutually exclusive.

3 INSEE. (2011 & 2016). Annual barometer of environmental opinions and practices in France. Statistical Data and Studies Department (SDES).

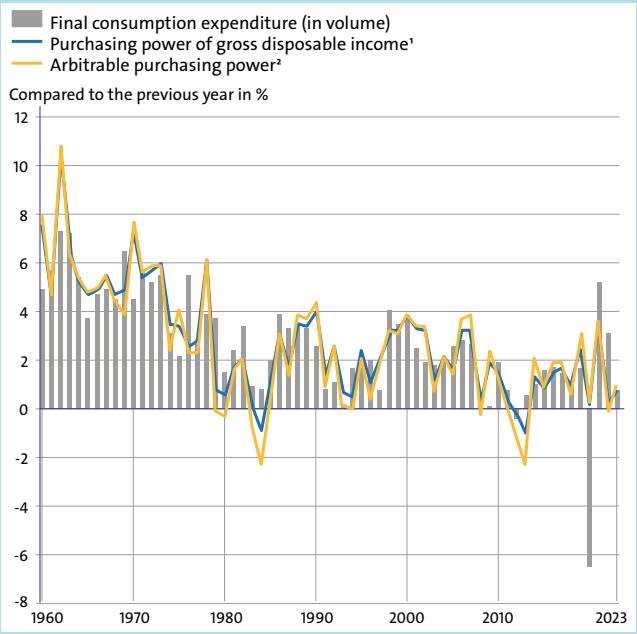
4 INSEE. (2011 & 2016). Annual barometer of environmental opinions and practices in France. Statistical Data and Studies Department (SDES).

5 In December 2017, two years after signature of the Paris Climate Agreement, political leaders, private sector executives, international organizations, foundations, and NGOs declared: "we are ONE planet."

6 One Health, a principle outlined by the One Health High-Level Expert Panel.

In France, household spending power has consistently been people's number one worry for the past two years ***(Figure 1)***.

Figure 1: Trends in household expenditure and purchasing power, 1960 to 2023



1. Change deflated by the price index of household final consumption expenditure.
2. Change deflated using the price index of non "pre-committed" household consumption expenditure.

Reading: in 2023, household final consumption expenditure increases by 0.8% in volume; purchasing power of gross disposable income increases by 0.8%.

Scope: France, households including individual companies.

Source: reproduced from INSEE, National accounts – baseline 2020.

While "climate change" is still cited by 35% of French people as a priority issue for the EU, it comes well behind "migration crisis" (42%) and only just ahead of "the future of agriculture" (35%),[7] which some, taking advantage of the agricultural protests that shook Europe in early 2024, have tried to oppose to the ecological transition.

In some ways we have returned to the same situation as in the 1990s: people are concerned about the environment, but public opinion is more focused on issues deemed more violent, more intense, and convinced that, to extinguish fire, one must choose the right battles.

But unlike the 1990s, neither the advocates for an ecological pause nor those arguing for accelerating the transition are able to summon an overwhelming majority. The two blocs oppose each other in most western countries.

This opposition between those who consider the environmental question to be their number one priority and those who think it is secondary can now be thought of as the major fault line running through modern (western) societies. According to Catarina Heeckt and Francesco Ripa, researchers at the London School of Economics, "ambitious climate action has become the new frontline of the culture wars."[8]

The transition has divided people between, on the one hand those whose financial, social and cultural capitals protect them from crises and allow them to dive deeper into personal and collective ecology, and on the other hand those who are more vulnerable, feeling change is imposed on them, and who are emboldened by politicians - seeking electoral advantage - to turn their backs on transition.

In every part of the world, politicians are seeking to use people's worries about this perceived disenfranchisement to turn them against the idea of ecological transition. These political groupings flourish based on the failure to create a desirable ecological imaginary and instrumentalize people's resentment of environmental policies which, because they have not been designed from a systemic standpoint, weaken them financially and challenge the way they live. There is also a rise in climate denial, particularly among less well-off people.[9]

However, it would be wrong to view ecological transition simply through the prism of this conflict. While the pathway to transition (norms, pace, etc.) is a matter for debate, the feeling of ecological vulnerability is still shared by all.

EVERYWHERE AND FOR EVERYBODY, HEALTH RISKS OF CLIMATE DISRUPTION AND POLLUTION ARE A CERTAINTY

From North to South, the gravity of the danger to health is now a universal certainty

On October 11, 2021, a few days before the opening of the United Nations Climate Change Conference (COP26) the World Health Organisation declared that **"climate change is the greatest health threat facing humanity."**

This is a statement that 75%[10] of the world's population agree on. No country will be immune from health risks. Although felt more keenly in southern hemisphere countries, this worry is shared by a large majority in every country. The larger GDPs and better-performing health systems in northern hemisphere countries no longer shield their inhabitants from this fear.

Four continents are represented among the eight countries where this sentiment is shared by over 80% of the population: India (87%), Colombia (86%), Brazil (85%), China (85%), Mexico (84%), Italy (82%), Chile (81%) and Nigeria (80%).[11] Even in countries where this statement meets with less universal agreement, it is nonetheless a concern shared by over 6 in 10 people: 62% in the Czech Republic (where climate denialism has risen 5 points in the past two years), 63% in the USA and Australia (two countries where belief in the existence of the climate crisis is below the worldwide average) ***(Figure 3)***.

7 Fourth edition of the IPSOS poll conducted in partnership with Cevipof, Institut Montaigne, Fondation Jean Jaurès and Le Monde.

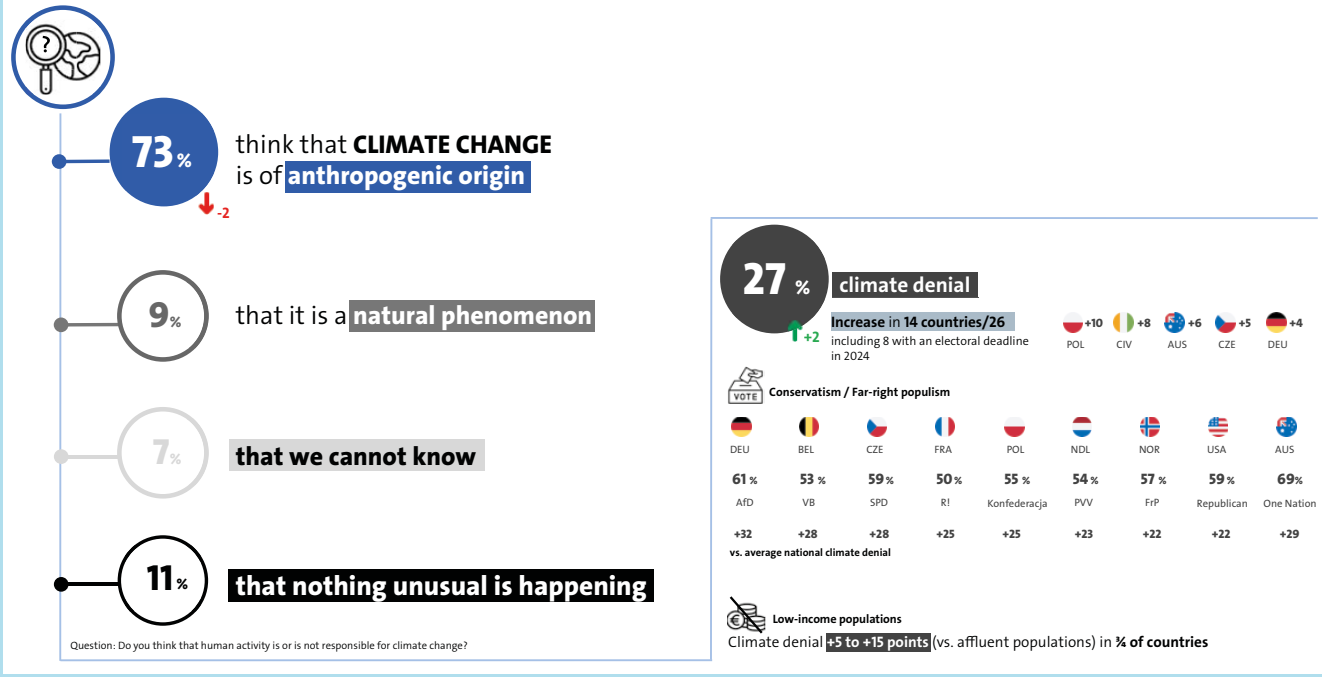
8 Heeckt, C., & Ripa, F. (2023, November 8). Is Europe's green wave turning blue? Making sense of the rightward shift in European cities. The London School of Economics and Political Science.

9 Elabe & Veolia. (2024). Ecological Transformation Barometer. Retrieved from https://elabe.fr/baro-transformation-ecologique-2/.

10 Elabe & Veolia. (2024). Ecological Transformation Barometer. Retrieved from https://elabe.fr/baro-transformation-ecologique-2/.

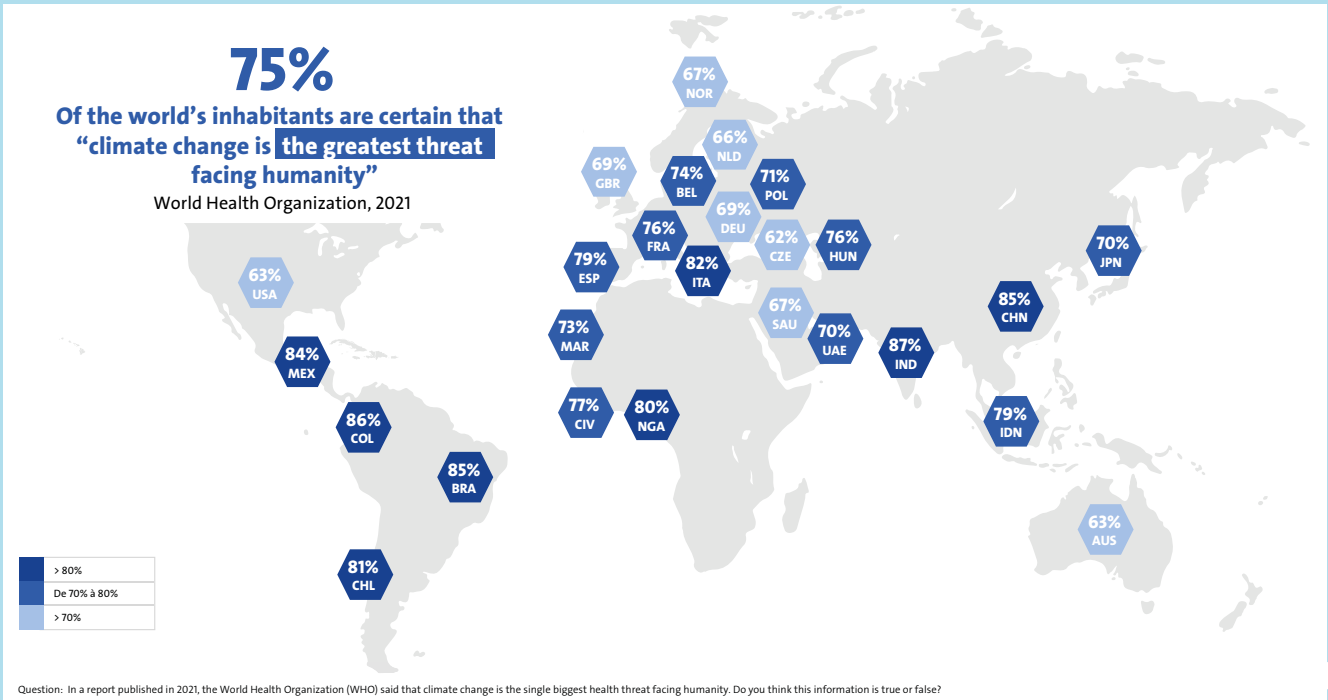
11 Elabe & Veolia. (2024). Ecological Transformation Barometer. Retrieved from https://elabe.fr/baro-transformation-ecologique-2/.

Figure 2: Climate denial is on the rise among conservatives and populists worldwide



Source: ELABE study for Veolia, Ecological Transformation Barometer, 2024.

Figure 3: The severity of the health threat has become a global certainty



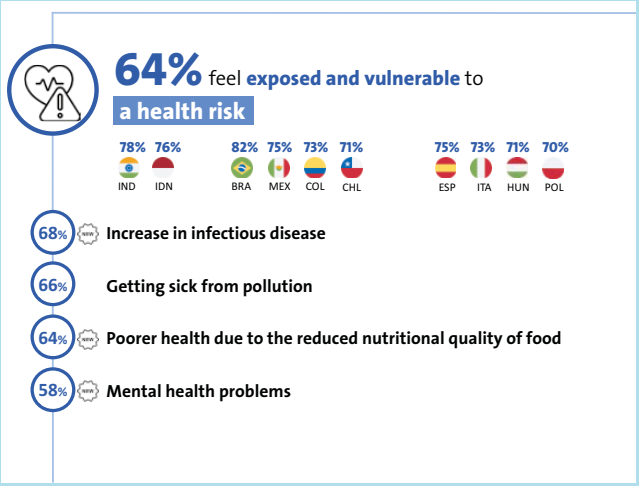
ELABE study for Veolia, Ecological Transformation Barometer, 2024.

The health risk posed by the ecological crisis is a universal fear as well as an individual feeling

There is nothing abstract about the fear of climate emergency and pollution's effects on health. **It is not only "humanity" that is under threat, so am "I, personally"**.

64% of the world's population feel exposed and vulnerable to risks to their physical or mental health. And over and above a collective fear for humanity, the sense of individual vulnerability transcends north-south differences. It is as much felt in South America, South-East Asia, southern Europe as in parts of eastern Europe ***(Figure 4)***.

Figure 4: The severity of the health threat has become a global certainty



Source: ELABE study for Veolia, Ecological Transformation Barometer, 2024.

However, concern about health risks is not the sort of fear that prevents people from acting. Quite the opposite: more than any other determining factor, it spurs them to action.

HOPES FOR HEALTH INSPIRED BY ECOLOGICAL TRANSFORMATION ARE A LEVER FOR INCREASING ITS DESIRABILITY

Prospects for better health: the first expected benefit from ecological transformation

Creating an ecology imaginary remains a vast task, with few thinkers and doers, and seems to be deteriorating rather than improving. 62% of people worldwide (up 2 points since 2022) find it hard to imagine what daily life could be like after ecological transformation.[12]

But they are very clear about the foundations of a desirable future shaped by ecological transformation: **wanting to live a healthier life is the number one aspiration (77%)**. And in a seeming echo of the growing sense of eco-anxiety, 70% want a more serene life".[13]

The desire for better physical and mental health is felt more keenly than the desire for happiness (70%) and comfort (63%), both of which are frequently presented as modern societies' only goals. This is not to say that people around the world are prepared to trade happiness and comfort for health – an imagined threat conjured up by critics of a so-called health dictatorship. It does, however, mean that they are convinced that all forms of prosperity, collective as well as individual, can only be built upon the foundations of good health, protected from pollution and climate events.

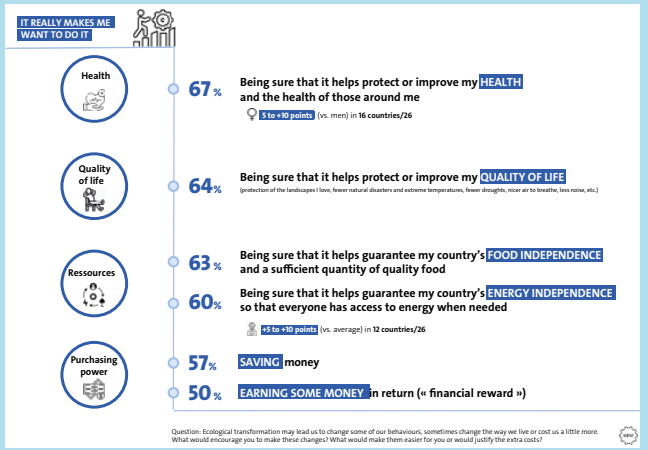
Protecting health: precondition for the acceptability, even the desirability, of ecological transformation solutions

Everywhere in the world, non-climate-skeptic governments as well as sociologists, political scientists and philosophers all face the same question: what conditions are needed to ensure the acceptability of ecological policies?

Of all the avenues suggested, one of them is often underestimated: the promise of better physical and mental health. **If they are sure that ecological actions would help protect their health and the health of their families, 67%**[14] **of people around the world would like to act and are prepared to put up with the additional costs and changes in behavior that most of these actions would entail.**

The health benefits of actions in favor of ecological transformation are a slightly more effective argument than improvements in quality of life (64%), and markedly more effective than a potential increase in spending power (50 to 57%) ***(Figure 5)***.

Figure 5: Protecting health and quality of life to make ecology desirable



Source: ELABE study for Veolia, Ecological Transformation Barometer, 2024.

12 Elabe & Veolia. (2024). Ecological Transformation Barometer. Retrieved from https://elabe.fr/baro-transformation-ecologique-2/.

13 Elabe & Veolia. (2024). Ecological Transformation Barometer. Retrieved from https://elabe.fr/baro-transformation-ecologique-2/.

14 Elabe & Veolia. (2024). Ecological Transformation Barometer. Retrieved from https://elabe.fr/baro-transformation-ecologique-2/.

Health impacts drive ecological transformation in all the countries surveyed, where people are in favor of taking action despite the additional financial costs and behavioral shifts ecological transformation involves. This applies to all populations, genders, generations and income levels. The level of acceptability when it comes to additional financial costs is of course influenced by individual income levels: in the low-income categories, acceptability is systematically 10 to 20 points lower than the average – while still remaining above 50%.[15] This desire for action is, however, far more developed among women compared to men (around 5 to 10 points higher in 16 of the 26 countries surveyed). Woman often feel ecologically vulnerable to a far greater degree (5 to 10 points more than men in 10 of the 26 countries surveyed).

While health benefits are always the main motivation for making individual efforts, they are also central to the roadmap the world's inhabitants are asking their leaders to follow. They are urging their local representatives and leaders to take account of health protection (97%) in the decisions they take regarding water, waste and/or energy management. In every country around the world and for all categories of the population (including those on the lowest incomes), health concerns must play a more crucial role in decisions than the price paid by consumers.[16]

This is demonstrated by the examples of micropollutants in water and soil pollution. The world's inhabitants are ready to pay more for their water and food to finance the implementation of solutions for treating these forms of pollution, which they consider as unacceptable.

CONCLUSION

Spinoza, writing in the 17th century, tells us that "there can be no hope without fear, and no fear without hope." The situation today is that ecological transition could tip the scales toward hope if its promoters succeed in getting the message across and proving that it is indeed the path to better health for everyone. The ecological crisis is causing a large part of the world to feel that they are exposed to health risks, a feeling that is bolstering a radically new desire to take action.

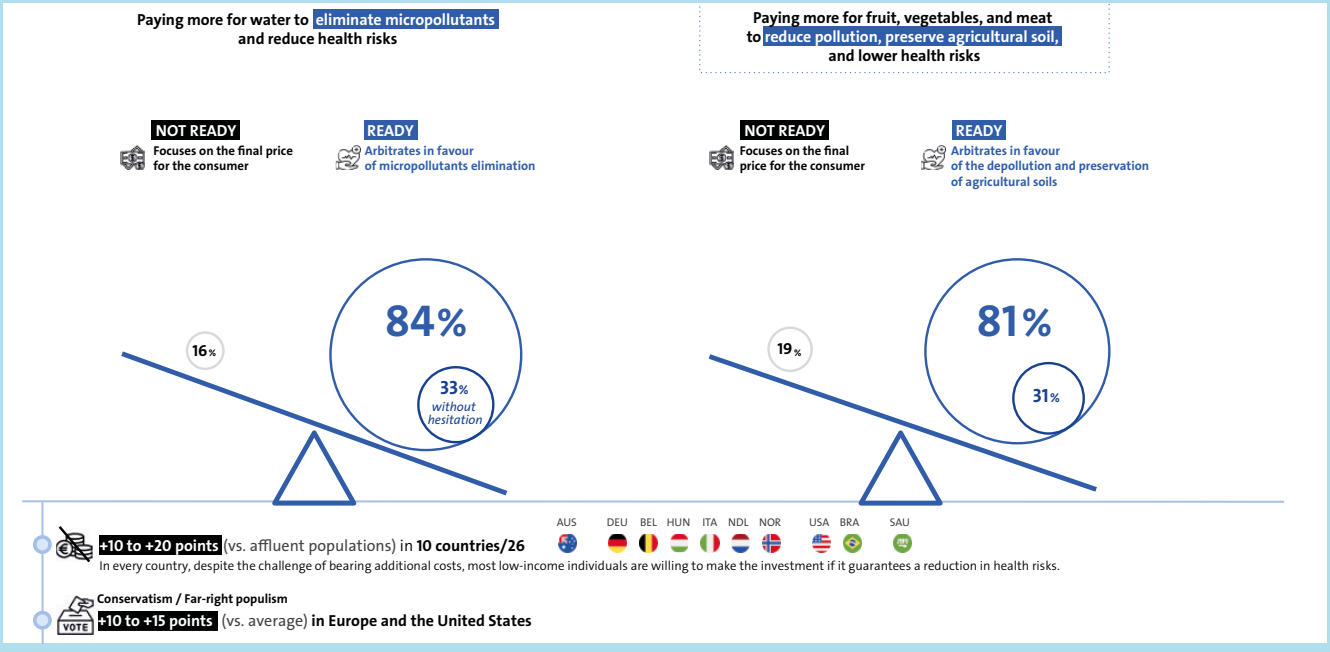
And here we have the final third of the path, leading from desire to action. Some people are concerned that we are setting out on the path, with all its difficulties, a little late. The truth is that we had to go through various lengthy stages before arriving here: it has taken nearly four decades to introduce environmental awareness into public debate. Then a few more years for anguish to become agreement. We have certainly wasted too much time. But we have acquired a great deal of experience, removed a number of obstacles, and started to outline an ecological imaginary. While there is still a gap between consent and change, we now have more tools to build the bridges we need to cross it.

Are we (still) ready for ecological transformation? Yes, absolutely: we are ready and we are getting closer.

15 Elabe & Veolia. (2024). Ecological Transformation Barometer. Retrieved from https://elabe.fr/baro-transformation-ecologique-2/.

16 Elabe & Veolia. (2024). Ecological Transformation Barometer. Retrieved from https://elabe.fr/baro-transformation-ecologique-2/.

Figure 6: **Micro-pollutants and soil pollution: unacceptable health risks motivate acceptance of additional costs, beyond socio-economic divides**



Source: ELABE study for Veolia, Ecological Transformation Barometer, 2024.

Ensuring the resilience of health systems in the face of the effects of climate change

Sandrine Bouttier-Stref
Corporate Social Responsibility (CSR) Director of the Sanofi Group

An engineering graduate from the Université de Technologie de Compiègne (UTC), Sandrine Bouttier-Stref has over twenty years' experience, including eight years with Sanofi, in the fields of Health, Safety, and Environment (HSE), environmental protection, and sustainability. Corporate Social Responsibility (CSR) Director for the Group for over three years, she leads the company's global CSR strategy and governance, particularly addressing issues related to global health, health equity, and resilience/adaptation to environmental risks.

The health of the planet and that of people are inextricably linked. As the environment deteriorates, human health is directly and indirectly impacted by the increased prevalence and severity of existing and emerging diseases.

More specifically, climate change is one of the major challenges we have to address in order to safeguard future health as well as to ensure continuity of care and the effectiveness of health systems.

Health systems suffer direct impacts from climate change and face four distinct challenges.

1. **Becoming resilient: heath infrastructures are impacted by the effects of climate change, such as the need to cool premises during heatwaves, disruptions to energy supplies, and securing logistics chains.**
2. **Preparing for the exacerbation of chronic diseases that will lead to an overload of the health system.**
3. **Identifying faster and more effective treatments for patients affected by the effects of climate change.**
4. **Finding a way to embed prevention into patient pathways.**

Equally, health systems must cut their environmental impacts, particularly their greenhouse gas emissions: they are responsible for around 5% of total global emissions, equivalent to the world's fifth largest emitting country.

It makes for a complex equation. All stakeholder groups, each with a specific role to play, must be involved in designing and adopting solutions while also accelerating the implementation of "carbon neutral" health systems that are equitable and prioritize patient well-being.

INTRODUCTION

The environment is being increasingly impacted by anthropic activities, triggering significant disruptions to a long-established equilibrium between the health of the planet and the health of populations. The changes this has led to can be summarized as a threefold planetary crisis: pollution, climate change, and loss of biodiversity.

These changes are already resulting in an increase in the number of patients and deaths, a trend likely to continue. For example, they lead to propagation of vector-borne diseases in new parts of the world, deterioration of health conditions as a result of severe climate events, and the emergence of new threats linked to human activities such as urbanization or intensive agriculture.

Just like the people they serve, health systems are vulnerable to climate change. But they are also responsible for 5% of global CO_2 emissions. This means that as well as becoming more resilient in the face of the effects of climate change, they also need to innovate in terms of care pathways to address the rising number of patients.

To combat the global threat that climate change poses to the planet, human health, and health systems, we need to think of them in terms of one integrated system.

CLIMATE CHANGE: A CHALLENGE FACING HEALTH SYSTEMS

Climate change poses one of the greatest threats to human health. Its effects on people, exacerbated by climate injustice, are spreading across the world at an increasing rate and entering a spiral seemingly beyond control, leading to an increase in the number of patients and deaths, displaced and vulnerable people.

Just like the people they serve, health systems too are vulnerable to climate change and subject to a wide range of new pressures, including:

- their own vulnerability to extreme weather events that may impact infrastructure, including logistics chains, lead to power outages and a decrease in labor productivity;
- increased hospital admissions and deaths caused by rising temperatures;
- the growing number of climate refugees which disrupts access to healthcare. In 2022, 32 million people became climate refugees because of weather-related disasters;[1]
- the evolving patterns of water-borne and vector-borne diseases which threaten to unravel decades of progress in the control of infectious diseases;
- the growing prevalence of infectious diseases and their spread into new regions;
- the exacerbation of chronic diseases caused by climate change (asthma, chronic obstructive pulmonary diseases, hypertension, diabetes, and mental illnesses) which increase the pressure on healthcare facilities and the use of medical care.

By 2050, climate change is likely to cause 14.5 million deaths and 12.5 trillion dollars in economic losses worldwide.[2] Climate-induced impacts will account for a further 1.1 trillion dollars in extra costs to healthcare systems, creating a significant additional burden on already strained infrastructures and medical and human resources.

"By 2050, climate change is likely to cause 14.5 million deaths and 12.5 trillion dollars in economic losses worldwide. Climate-induced impacts will account for a further 1.1 trillion dollars in extra costs to healthcare systems, creating a significant additional burden on already strained infrastructures and medical and human resources."

At the same time, health systems are responsible for almost 5% of global CO_2 emissions: 50% relates to supply chains and product manufacture; 45% to patient care pathways, and 5% to research and development, including clinical trials.[3]

Health systems thus have to tackle multiple challenges that require them to anticipate and adapt, improve scientific knowledge and predictive models (climate-health correlations), and invest in health-related interventions (prevention, diagnostics, products, etc.) that are better aligned with the risks. Sharing information on a large scale is also a priority so that all actors concerned can be alerted by public health campaigns.

There are reciprocal links between the climate and health/health systems. This means that actors from the health sector must play an active role in accelerating their resilience in the face of climate-related effects, and by altering care pathways in efforts to decarbonize. At the same time, they have to plan ahead to deal with the health crisis facing the world.

IMPROVING THE RESILIENCE OF HEALTH SYSTEMS

Health systems are vulnerable to climate change: extreme weather events such as floodings, fires and heatwaves can have an impact on infrastructure, personnel and supplies at a time when a larger number of patients will be streaming into health facilities.

This situation has already occurred in several parts of the world, highlighting the need to bolster the resilience of health systems, including the ability not only to tackle climate events but also to recover after them while continuing to guarantee continuity of care.

In the USA, the Federal Emergency Management Agency estimates that a single extreme weather event could cost a hospital between 600,000 and 2 billion dollars[4] in damage to equipment and infrastructure and create on-going disruption due to repairs at a time when every effort is being made to keep the hospital running. As an illustration, in 2012 hurricane Sandy led to the evacuation of more than 6,400 patients from six hospitals and 31 residential care facilities. NYU Langone Medical Center, one of the hardest hit hospitals, suffered nearly a billion dollars in damage,[5] remaining fully closed for two months and without an emergency room for a year and a half.

1 Office of the United Nations High Commissioner for Refugees (2023). *Climate change and displacement: the myths and the facts*. UNHCR. https://www.unhcr.org/news/stories/climate-change-and-displacement-myths-and-facts.

2 World Economic Forum (2024). *Quantifying the impact of climate change on human health. World Economic Forum*. https://www.weforum.org/publications/quantifying-the-impact-of-climate-change-on-human-health.

3 M. Romanello, A. McGushin, C. Di Napoli C *et al.*, Lancet 398(10311): 1619-62, The 2021 Report of The Lancet Countdown on Health and Climate Change: Code Red for a Healthy Future, *The Lancet*, vol. 398, no. 10311, pp. 1619-62, 2021.

4 Earthzine (June 28, 2011). *Code Grey: Protecting Hospitals from Severe Weather.* https://earthzine.org/code-grey-protecting-hospitals-from-severe-weather-2/.

5 Seltenrich, N. (2018). *Safe from the storm: Creating climate-resilient healthcare facilities. Environmental Health Perspectives*, 126(10). https://doi.org/10.1289/EHP3810.

It is important to focus on anticipation, and the accessibility and effectiveness of care. This includes adaptation planning, infrastructure resilience, improving capacities for access and delivering care, and preparing emergency rooms so they are ready for climate events.

Mechanisms to monitor, predict and respond to diseases as well as innovative solutions for healthcare and drug delivery must also be put in place.

As an example, respecting the cold chain when storing and distributing certain vaccines can be a challenge in some countries: access to the energy needed to maintain the temperature that ensures the quality and safety of products can be a real struggle when outdoor temperatures keep soaring.

In India, flooding in the state of Kerala in 2018 had a major impact on the state's public health system. In many countries the back-up electricity supply is designed to last for 72 hours. In Kerala, hospitals had to deal with power outages lasting from three to nine days, which caused refrigerated storage systems to shut down unexpectedly. Many hospitals reported that their entire stocks of vaccines and other essential medical supplies requiring refrigeration had been damaged, as has IT hardware, leading to the loss of patient records at several hospitals. The public health administration estimated that public hospitals sustained losses of over 15 million dollars.[6]

To put all this in place requires authorities and health stakeholders to be aware of the issues and have access to financial and human resources that can appear outsized relative to their capacities. But what will happen if nothing is done? Health stakeholders have to make substantial investments today to respond to current and future impacts on their health systems and avoid the cost of inaction further down the line. This also requires changes in government policies.

"In India, flooding in the state of Kerala in 2018 had a major impact on the state's public health system. In many countries the back-up electricity supply is designed to last for 72 hours. In Kerala, hospitals had to deal with power outages lasting from three to nine days, which caused refrigerated storage systems to shut down unexpectedly."

INNOVATING TO CHANGE CARE PATHWAYS

Care pathways account for 45% of CO_2 emissions of health systems in France (estimated at 50 million metric tons of CO_2 equivalent, or over 8% of all French emissions).[7] Transforming the way care is delivered to anticipate and cover the growing demands of patients impacted by climate change is a major challenge. Meeting it may have revolutionary effects on health policies and people's behaviors.

This transformation must also be paired with collection on a massive scale of real-world data[8] on the links between climate change and health. It will improve understanding of these links, raise awareness of the scale of the looming crisis, and help finding rapid and effective solutions.

Seven levers for reducing emissions in care pathways

There are possibilities for decarbonization at every stage of the care pathway, which can be summarized as seven priority levers that also contribute to delivering quality care. These levers can be grouped into three main themes:

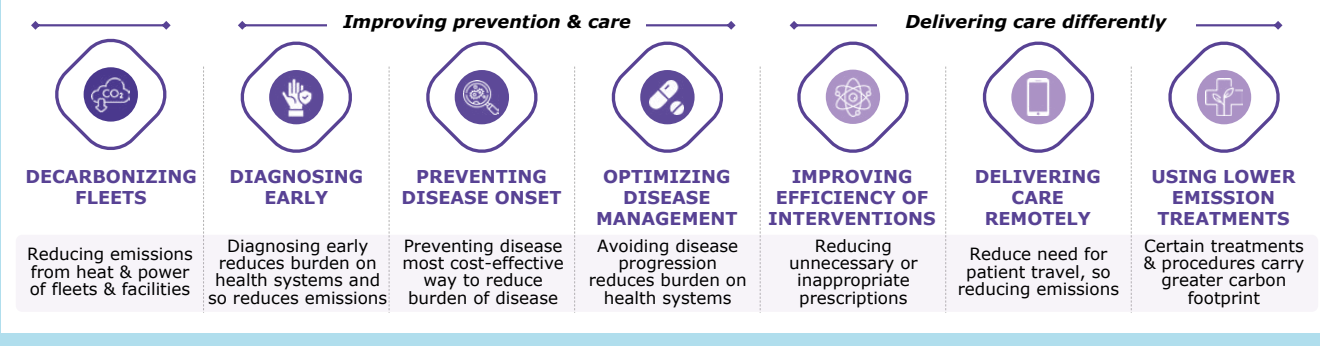
- decarbonizing health facilities and vehicle fleets (renewable energies and electric ambulances) and adopting circularity principles in health treatments (such as using reusable and recyclable materials);
- improving disease prevention and management to reduce their frequency and severity and increasing the efficiency of treatments;

6 Nair P. (August 29, 2018). Kerala floods: Health directorate estimates Rs110 crore loss. Kochi News – *Times of India*.

7 French Ministry of Health and Solidarity (2023). Presentation of the PESS program: priority on Prevention, Environment, Health and Health security. https://sante.gouv.fr/IMG/pdf/dp_pess.pdf.

8 Real-world data is information that is not collected as part of an experiment but when patients receive treatment, reflecting actual practices.

Figure 1: 7 levers to reduce emissions in care pathways



- delivering care differently, by improving the overall efficiency of healthcare provision and selecting interventions with a lower carbon footprint, while simultaneously delivering similar or improved outcomes in terms of patient care.

We describe below how prevention and innovation via digitalization are levers for improving care pathways.

Improving prevention and care: preventing the appearance of diseases

Reducing risk factors and preventing the appearance of diseases are the most effective strategies for reducing the disease burden facing our societies, particularly in relation to non-communicable diseases. At the same time, these actions also help to shrink the carbon footprint of healthcare.

Addressing the causes, such as air pollution, is a necessity. Rolling out effective measures on a massive scale (such as healthy and sustainable environments in towns and cities, regular physical exercise, and a varied diet) requires unstinting backing from public bodies and considerable resources if we want to see rapid improvements.

In terms of prevention, vaccination programs are effective in safeguarding health. As well as cutting patient numbers, hospitalizations and even deaths, vaccination can also be a potential source of cuts in CO_2 emissions. A study run by Sanofi[9] in the United Kingdom illustrates this potential, highlighting health-environment prevention co-benefits in the choice of an early vaccination scenario for all infants at birth against bronchiolitis, compared to other immunization programs. By simplifying care pathways and reducing hospitalizations and primary care visits, the "all newborns" vaccination scenario could deliver a 68% fall in CO_2 emissions compared to the current situation.

Health prevention efforts targeting the most vulnerable, victims of the effects of climate change and inhabitants of the areas most impacted is also central, bearing in mind that approximately 3.6 billion people in the world live in areas exposed to climate risks.[10]

Delivering care differently

Delivering care remotely as well as locally, where appropriate, offers alternatives to be explored in greater depth. Using solutions such as telemedicine and wearable devices can reduce the need for patient travel and increase access to specialist care, reducing CO_2 emissions without compromising quality of care. A study launched in Egypt[11] into a patient cohort suffering from asthma and atopic dermatitis has shown that telemedicine delivers a fall of almost 74% in CO_2 emissions relating to their care (when taking into account the impact of digital technology on the environment). Furthermore, patient well-being is enhanced by not having to travel and risk exposure to air pollution or stigmatization due to the appearance of their skin.

"A study launched in Egypt into a patient cohort suffering from asthma and atopic dermatitis has shown that telemedicine delivers a fall of almost 74% in CO_2 emissions relating to their care. Furthermore, patient well-being is enhanced."

Remote monitoring for non-communicable diseases has also been shown to improve health outcomes.

However, attention must be paid to the impact on accessibility for different population groups.

Local treatment provision also helps reduce CO_2 emissions. The role of pharmacists, community nurses, and local healthcare structures is crucial to decarbonization, a reality that calls for changes in national and community health policies.

Eco-design for health products

Today's health systems pay close attention to the climate footprint of health products and increasingly require manufacturers to provide products with positive environmental performances as a lever for improving the carbon footprint of patient pathways. This requires the establishment of recognized assessment methods approved by committees representing various stakeholders. Work under way at present is targeting the publication of an international standard in 2025. This major advancement, initially intended for health industry professionals to help them embed eco-design as far upstream as possible, is now widely supported by buyers, health authorities, insurance providers, etc.

It is nevertheless important to avoid focusing on the wrong targets:

- a product's climate footprint is not enough in itself to characterize the impact a product has on the environment;
- equally, it is a mistake to assess the climate footprint of a care pathway simply by looking at the climate footprint of a product. The product's contribution to improving the environmental footprint of the overall car pathway must be examined, along with the activation of other intervention levers;
- improvements in patient health remain the overarching priority when determining a health treatment.

THE NEED FOR DATA COLLECTION

Although there is ever-growing acknowledgement of the links between climate and health, gaps remain in the production, collection and sharing of data on mechanisms that trigger or exacerbate climate change-related diseases.

9 Hudson R et al. (December 2023). Assessing the Carbon Intensity Profile of an Immunization Program Against RSV in Infants in the United Kingdom to Show the Reduction in Emissions Versus Standard of Care, Value in Health, Volume 26, Issue 11, S2.

10 Intergovernmental Panel on Climate Change. (2023, March 20). Sixth assessment report: Synthesis report. https://www.ipcc.ch/report/sixth-assessment-report-working-group-ii/.

11 For more information, visit the DCarbon website, Sanofi's partner for the study - https://dcarboneg.com/cop27side-events/accelerating-healthcare-de-carbonization/.

Sanofi has recently undertaken a study[12] that seeks to identify links between disease areas and the impacts of environmental change. The study concentrates on treatment and prevention in five therapeutic fields: immunology, infectious and vector-borne diseases, pandemic pathogens, chronic non-communicable diseases (such as cardiovascular diseases and cancer), and allergies.

This study examined 6,843 published reports and highlighted the fact that, of all the environmental risks identified, air pollution has the greatest negative impact on the disease areas concerned. It also showed that cardiovascular diseases and diabetes are the two main therapeutic fields that will be impacted by environmental risks, with two primary indicators: transient ischemic attacks and type 1 diabetes. Respiratory indicators such as chronic obstructive pulmonary disease (COPD) and asthma are also heavily affected by environmental risks.

"Although there is ever-growing acknowledgement of the links between climate and health, gaps remain in the production, collection and sharing of data on mechanisms that trigger or exacerbate climate change-related diseases."

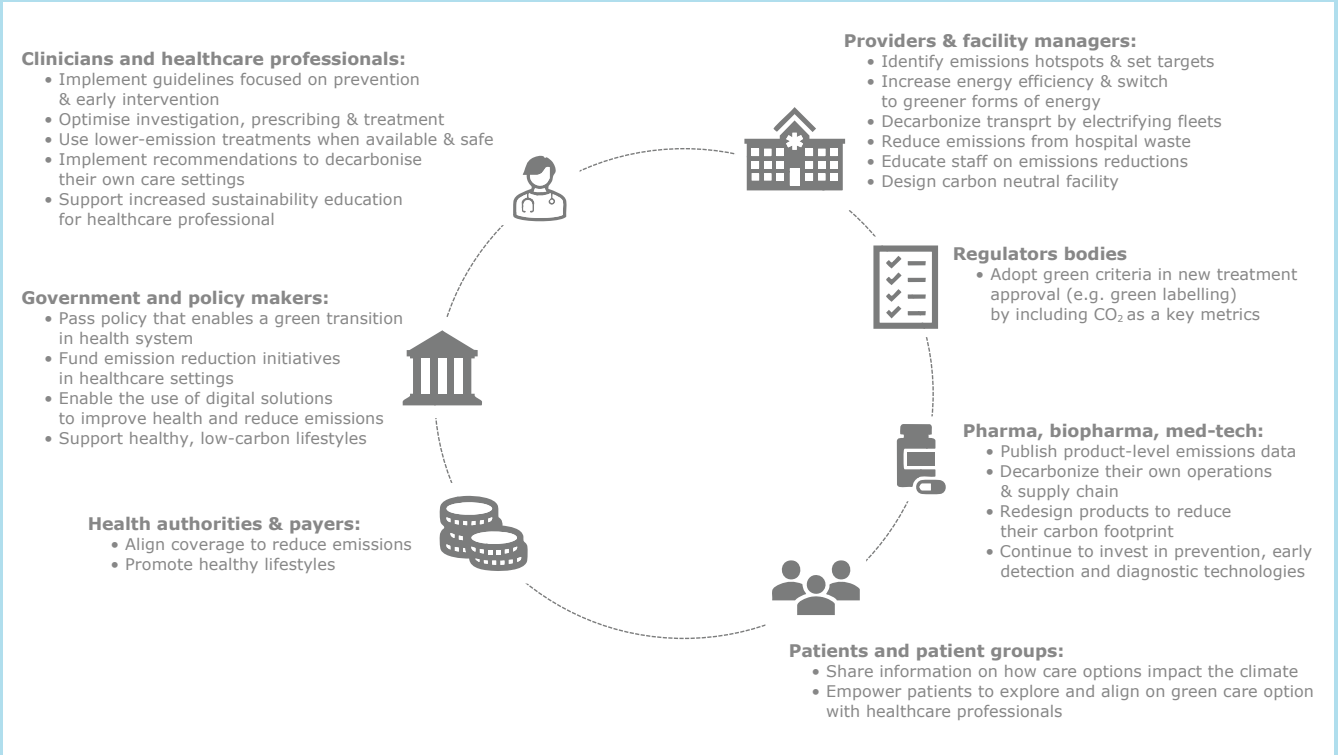
The scientific data can be used, for example, to inform R&D choices and predict necessary changes in the development and availability of health solutions. It is essential for healthcare and policymaking actors to incorporate environmental health data into their strategic decision-making.

Furthermore, using new technologies (artificial intelligence and real-world evidence) to improve predictions about how climate change will impact patients and health systems is required, not only to help guide policymakers in the construction of health policies and improve how diseases are anticipated and controlled, but also to highlight the importance of making targeted investments in actions to ramp up adaptation and boost resilience.

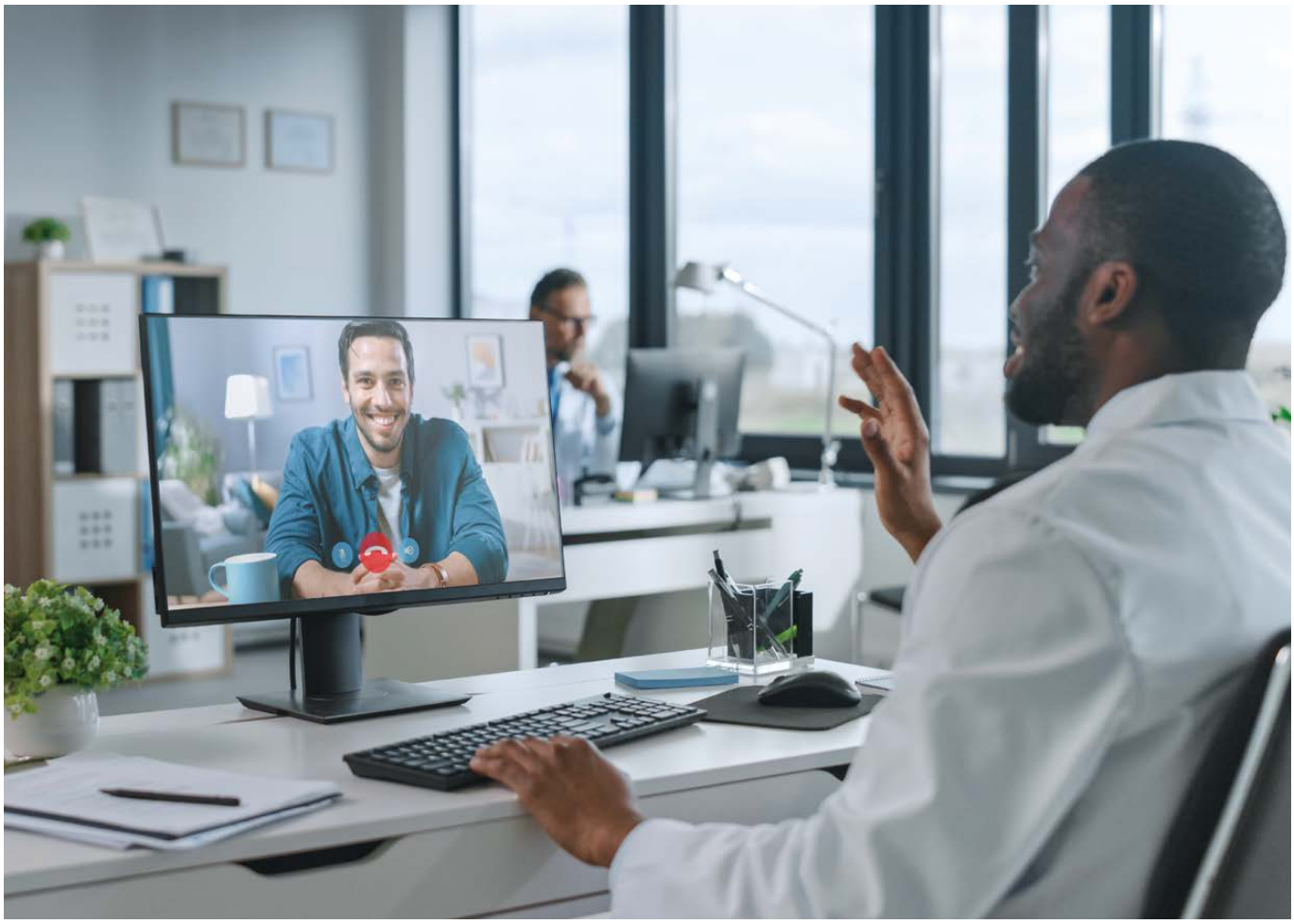
Since 2023, Sanofi has been working with a panel of experts in respiratory diseases on a major study to identify the impacts of environmental factors (temperatures, air pollution, soil composition, etc.) on the exacerbation of case of COPD and asthma in France. The study cross-references real-world data from the French health system (PMSI) with publically available data on climate factors. The resulting correlations will point to the extent to which exposure to different environmental factors influences the risks of exacerbating chronic respiratory diseases, and allow forecasts of current and future impacts on the saturation of health systems depending on how climate change evolves.

12 Sanofi (June12, 2024). *The Link Between Climate and Health: We Chart a New Course* https://www.sanofi.com/en/magazine/social-impact/climate-health-new-course.

Figure 2: The role of health stakeholders



Source: Healthcare Without Harm, WHO, academic literature, BCG analysis.



This type of study can improve knowledge sharing and research in a domain that remains under explored, improve prevention among groups who are potentially the most impacted or risk becoming impacted, and strengthen health structures. Towns and cities might also find this type of data of interest for their urban planning.

COORDINATING THE ACCELERATION OF COLLECTIVE ACTION

Health systems must become more aware of the importance of embedding recognition of the environmental value of health products and care pathways and the need to invest in prevention while also ensuring that progress toward meeting environmental targets does not compromise the prospects of achieving better outcomes for patients.

This is not something that can be achieved by any one organization or a one-size-fits-all strategy. Health systems are complex and all stakeholder groups, each with a specific role to play, must be involved in designing and adopting innovative and sustainable solutions.

CONCLUSION

The effects of climate change have a major influence on our living environment and our health. Extreme climate events (heat waves, floods, etc.) have well-known impacts on societies and overall environmental deterioration, leading to air and water pollution, food insecurity, the occurrence of vector-borne diseases, as well as an increase in the prevalence and severity of existing diseases. Many inequalities exist with regards to the impacts of climate change, requiring targeted action to assist vulnerable groups.

The level of action being taken by health industry professionals is unprecedented. In addition to their commitments to reducing their own emissions, they are actively engaging with stakeholders in health systems to educate, raise awareness and promote the sharing of best practices, data and even technical skills by issuing recommendations and assessment guidelines.

There is still enough time left for the world's economy to make a decisive reduction in emissions and adopt strategies to protect human health against the impacts of climate change. It is however imperative that policymakers recognize and address the currently inadequate level of preparation of health systems.

Developing indoor heat-health warning systems for vulnerable populations

Choo-Yoon Yi, Building Physics and Liveability researcher and AXA Research Fund Fellow
Chengzhi Peng, Senior Lecturer and Director of Postgraduate Research at Sheffield School of Architecture

Dr. Choo-Yoon Yi is a Building Physics and Liveability researcher with interests in optimizing bioclimatic design through building energy modelling and climate change projections. Dr. Yi was awarded an ESRC (Economic and Social Research Council) Postdoctoral fellowships in 2020, following the completion of his PhD at the Sheffield School of Architecture in 2019. As an AXA Postdoctoral Fellow, he currently collaborates with Professor Darren Robinson and Dr. Chengzhi Peng on the "Renovating Care Homes Fit for the Future" project. Dr. Peng, a Senior Lecturer and Director of Postgraduate Research at Sheffield School of Architecture, specializes in Architectural-Urban Science and Climate.

With respect to the changing environmental conditions and extreme heat events associated with climate change, this article presents a review of existing heat-health warning systems[1] and discusses how such systems can be further augmented to account for indoor environmental conditions. The development of indoor heat-health warning systems is urgently needed to enhance the health and social care for vulnerable populations who spend long hours indoors. As a proof-of-principle study, we first introduce an indoor heat-health warning system developed for the general population in the UK, demonstrating its use case based on the 2013 heatwave event. Focusing on older people living in residential care — one of the most vulnerable populations worldwide — we illustrate the capabilities of an indoor heat-health warning system through a modelling framework which evaluates the impact of climate (change) on a building's heat and energy performance, from neighbourhood to city scales. An indoor heat-health warning system deployed at care homes should be able to foretell residents' indoor heat exposures given forecasts of impending heatwave events.

INTRODUCTION

Heat is a significant environmental and occupational health hazard, being the leading cause of weather-related deaths. Due to climate change, the number of people exposed to extreme heat is rapidly increasing worldwide. Between 2000 and 2019, about 489,000 heat-related deaths occurred each year.[2] For people over 65 years old, the mortality rate increased by about 85% between 2017-2021 compared to 2000-2004,[3] making this age group particularly vulnerable.

However, *"the negative health impacts of heat are predictable and largely preventable with specific public health actions. Action on climate change combined with comprehensive preparedness and risk management can save lives now and in the future"*[4] emphasizes the World Health Organization (WHO), highlighting the need for immediate action.

1 Heat health warning systems (HHWSs) are weather-(forecast)-based alert system designed to notify decision-makers and the public about upcoming heat events. They provide guidance on preventing heat-related health effects when forecasts predict that temperatures (and/or humidity) will reach or exceed thresholds at which significant health impacts are likely.

2 Zhao, Q., Guo, Y., Ye, T., Gasparrini, A., Tong, S., Overcenco, A., Urban, A., Schneider, A., Entezari, A., Vicedo-Cabrera, A. M., & others. (2021). Global, regional, and national burden of mortality associated with non-optimal ambient temperatures from 2000 to 2019: A three-stage modelling study. The Lancet Planetary Health, 5(7), e415–e425. https://doi.org/10.1016/S2542-5196(21)00081-4.

3 Lancet Countdown. (2023). Heat-related mortality. Lancet Countdown Data Platform. https://www.lancetcountdown.org/data-platform/health-hazards-exposures-and-impacts/1-1-health-and-heat/1-1-5-heat-and-sentiment.

4 World Health Organization. (2024). Heat and health. Retrieved from https://www.who.int/news-room/fact-sheets/detail/climate-change-heat-and-health.

HEAT-RELATED HEALTH RISKS - WHO IS THE MOST VULNERABLE?

Due to climate change, many countries have been encountering an increased occurrence of extreme heat events. Even in countries with predominant heating needs like the UK, a new record-high temperature was recently observed in July 2022, surpassing 40°C. Consistent evidence indicates that human exposure to heat is directly linked to an increase in excess mortality and morbidity. Everyone faces health risks during a heat event, but a more thorough understanding of the contributing factors is essential to identify specific triggers for interventions aimed at reducing these potential risks.

Apart from the range of wider risk factors encompassing personal, environmental, and socio-economic elements, the causal pathways to heat-related illness and deaths clearly initiate with human exposure to heat. While this is a complex physical and physiological phenomenon in response to ambient environments, the human body utilises four main physiological mechanisms to keep itself cool: radiation through infrared rays, convection facilitated by water or air on the skin, conduction through contact with a cooler object, and evaporation of sweat. However, these thermoregulatory mechanisms can be impaired in specific populations and thus, certain factors increase their vulnerability[5]. These include older age, chronic illnesses (e.g., heart conditions, diabetes, respiratory or renal insufficiency, Parkinson's disease, severe mental illness), infancy, and an inability to adapt behaviour to stay cool (such as Alzheimer's, disabilities, and being bedbound).

These individual risk factors compound the susceptibility to heat-related health risks, often exacerbated by a lack of air conditioning, poor building thermal characteristics, and insufficient ventilation systems, especially *indoors* where those vulnerable individuals spend most of their time. For instance, according to an article published in 2022,[6] just 3 percent of homes in Germany and less than 5 percent of homes in France have air conditioning. In the UK, government estimates suggest that less than 5 percent of homes have mechanical cooling systems, such as air-conditioning (1%) and heat pump (1%), while 80% of households primarily rely on opening windows and doors to cool their homes.[7] Furthermore, within urban settings, the variation in local microclimate influenced by the urban heat island (UHI) effect[8] is critical, particularly at night when this effect is typically more prominent due to an increased sensitivity to heat exposure when sleeping.

> *"Indoor temperature is a more accurate predictor of heat exposure than outdoor temperature, especially for vulnerable populations whose cooling systems primarily depend on natural ventilation."*

It is well understood that studies have predicted a significant rise in human exposure to heat due to climate change, potentially resulting in an increase in mortality. However, indoor exposure to heat and the corresponding health outcomes have received relatively less attention. Several studies have evaluated indoor overheating and associated health risks in present and future climates. Notably, a field study affirmed that indoor temperature is a more accurate predictor of heat exposure than outdoor temperature, especially for vulnerable populations whose cooling systems primarily depend on natural ventilation.[9] This suggests that preventing heat-related health risks for vulnerable people requires a better understanding of occupants' *indoor* heat exposure during excessive heat events.

AN INTRODUCTION TO HEAT-HEALTH WARNING SYSTEMS

To address the challenges posed by climate change and associated extreme heat events, the World Health Organization's (WHO) Regional Office for Europe has developed Heat-Health Action Plans (HHAPs).[10] These plans aim to mitigate the negative health impacts of excessive heat. To do so, they utilise accurate and timely alert services such as meteorological early warning systems designed to analyse and identify weather- and climate-related risks and hazards. Additionally, they implement a health information strategy to provide valuable insights for medium and long-term development and urban planning.

5 UK Health Security Agency. (2024). Adverse Weather and Health Plan: Supporting evidence. https://assets.publishing.service.gov.uk/media/65fdb71af1d3a0001d32ae74/Adverse_Weather_and_Health_Plan_supporting_evidence__1_.pdf.

6 The Washington Post. (2022, July 20). Why European homes (usually) don't have air conditioning. https://www.washingtonpost.com/world/2022/07/20/europe-uk-air-conditioning-ac/.

7 Department for Business, Energy & Industrial Strategy. (2022). BEIS public attitudes tracker: Heat and energy in the home winter 2021. UK Government. https://assets.publishing.service.gov.uk/media/62960be8e90e070397a00faa/BEIS_PAT_Winter_2021_Heat_and_Energy_in_the_Home_REVISED.pdf.

8 The UHI effect is a phenomenon describing the elevated temperatures felt in towns and cities compared to rural surroundings and particularly felt at night-time as the heat retained by artificial surfaces is slowly released, keeping temperatures higher than in the countryside, combined with other impacts such as the reduced cooling effect of vegetation in urban areas, and the compounding effect of anthropogenic heat. (Royal Meteorological Society).

9 Zuurbier, M., Dons, E., Lanki, T., et al. (2021). Street temperature and building characteristics as determinants of indoor heat exposure. Science of The Total Environment, 766, 144376. https://doi.org/10.1016/j.scitotenv.2020.144376.

10 World Health Organization Regional Office for Europe. (2008). Heat-health action plans: Guidance. World Health Organization. https://www.who.int/publications/i/item/9789289071918.

For instance, Heat Health Warning Systems (HHWSs) are weather-based alerts designed to warn decision-makers and the public of impending extreme heat events and to advise them on preventable negative health outcomes. These systems assess the likelihood of exceeding of an 'action trigger', such as a threshold temperature at which there could be significant health impacts.

However, the metrics determining 'action triggers' for warnings are typically based on the correlation between outdoor weather conditions and reported critical outcomes, such as excess mortality and hospital admissions. Additionally, the spatial scale of these early warnings depends on the availability of local/regional weather forecasts. Therefore, the existing metrics may underestimate urban dwellers' exposure to heat, potentially leading to inadequate prevention of heat-related health risks. This is especially true for vulnerable populations in *indoor environments*, such as individuals aged 65 and older with existing health conditions and/or disabilities.

Indoor climates of buildings are determined by various factors such as the thermal characteristics of the building's envelope, its geometric configuration, internal heat loads resulting from occupants' activities, electric appliance usage, and the surrounding weather. These factors imply variations of indoor climates at room level. Taking these characteristics into consideration in Heat-Health Alerts services is crucial, especially for vulnerable populations that predominantly spend their time indoors. Moreover, this is particularly significant in regions like Europe and the Global South, where mechanical cooling measures are not widely adopted.

"Understanding the relationship between climate, buildings, and occupants is crucial for protecting and promoting the health and wellbeing of urban dwellers over time, as climate change projections evolve."

INDOOR HEAT-HEALTH WARNING SYSTEMS (CASE STUDY)

How can indoor heat-health warning systems (iHHWSs) be developed to account for building characteristics and urban microclimatic diversity? As a case study, we have performed a proof-of-principle study[11] of iHHWSs for urban dwellers in the city of Birmingham (UK).[12] In this study, we suggested combining the virtues of dynamic building energy simulations—a method to measure a building's energy performance—with an approach that can be practically applied to existing local Heat-Health Warning Systems (which action triggers are currently defined based on outdoor air temperatures). This combination provides a basis for a high-fidelity of indoor heat-health warning systems.

Two urban neighbourhoods were selected in Birmingham to highlight the largest differences in average recorded air temperature and the estimated Universal Thermal Climate Index (UTCI). The UTCI is a physiological heat balance model that considers the relationship between the human body and ambient environmental factors including air temperature, wind, radiation, and humidity. We compared these two neighbourhoods, which are the warmest and the coolest in the city. For this comparison, we referenced existing data on housing physical characteristics and internal heat load profiles based on occupancy. We identified five types of housing ($H_1 – H_5$), each with four types of insulation ($I_1 – I_4$), resulting in 20 reference housing combinations ($H_1I_1 – H_5I_4$), in each of the two neighbourhoods.

Based on these settings, we first estimated the effect of housing physical characteristics and urban microclimates on indoor heat stress among urban dwellers. We considered a heat index above 26.7°C, which indicates that fatigue is possible with prolonged exposure and that continuing activity could lead to heat cramps. This temperature can be used as an 'action trigger' for the new alert model.

Next, we investigated the relationship between outdoor temperatures and indoor heat stress to probabilistically identify outdoor temperature thresholds that affect indoor heat exposure at the urban neighbourhood scale. Finally, we compared our findings with the local (UK) heat-health alert service to illustrate potential indoor heat stress warnings and discussed the implications for long-term heat-health planning, particularly for vulnerable populations affected by heat.

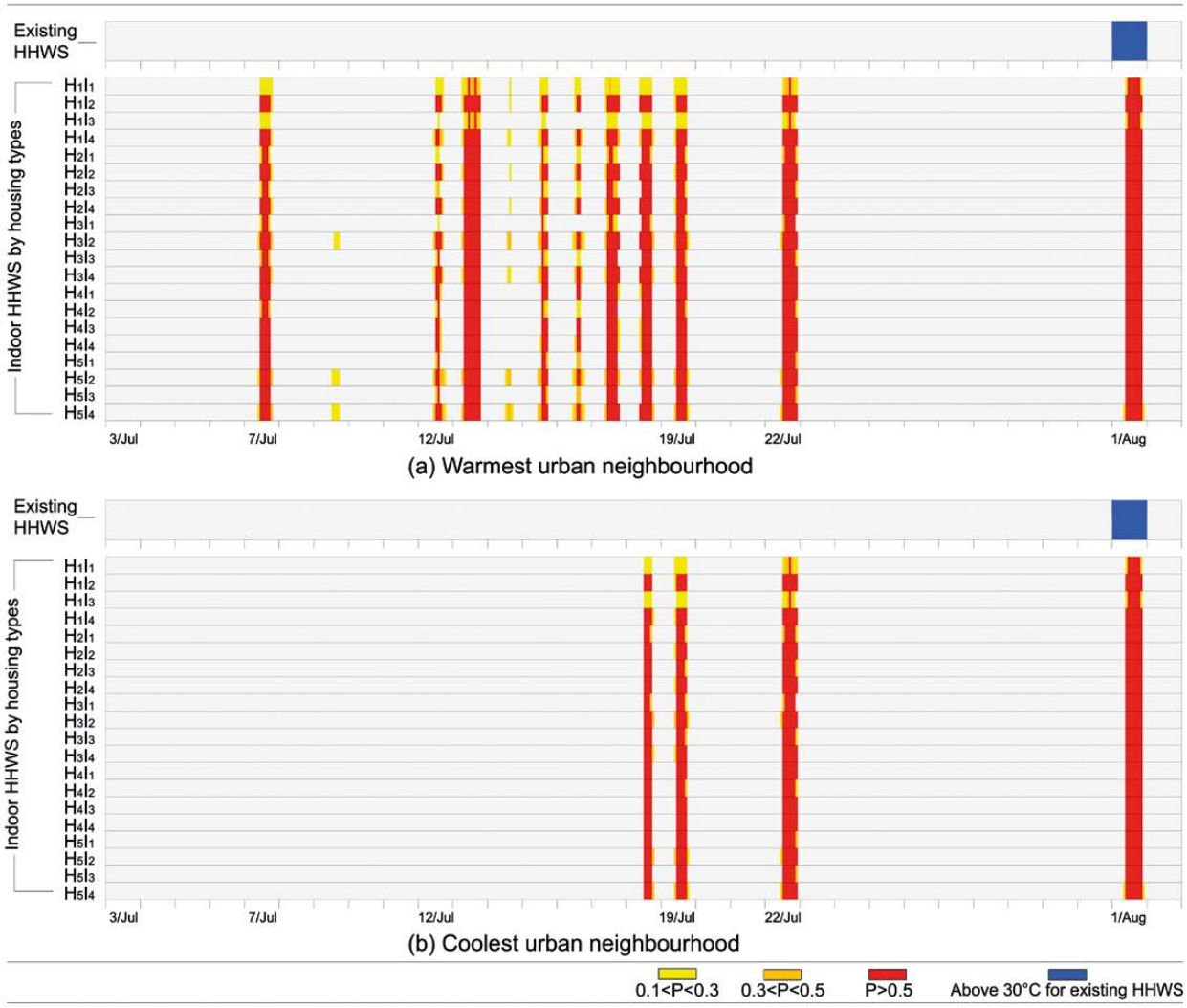
The results revealed significant variations in outdoor temperature thresholds affecting indoor heat stress across the 20 reference housing types locally. Based on these findings, we mapped probabilities-based indoor heat health warnings for each housing type and compared them to the existing local heat-health alerts ***(Figure 1***).

Furthermore, for future years, we predicted the number of days when urban dwellings would experience indoor heat stress in the two neighbourhoods during summer (June 1st to Sep 15th, i.e., 107 days) based on projected daily maximum temperatures available at the local scale (e.g., UKCP18). To account for uncertainties in selecting the most appropriate climate change scenario for the local context, we used all available climate models (12 scenarios) to illustrate the overall trend of local heat exposure.

11 A proof-of-principle is a demonstration that aims to verify that certain theories have the potential for real-world application. Its purpose is to prove the feasibility of a theory, it is usually one of the first step of the development of an innovation/ process/theory. Here, our "proof of concept" is based on a study we carried out in 2023 in the UK

12 Yi, W., Liu, H., Zhang, L., et al. (2023). Modelling urban dwellers' indoor heat stress to enhance heat-health warning and planning. Building and Environment, 245, 110623. https://doi.org/10.1016/j.buildenv.2023.110623.

Figure 1: Comparison of potential indoor heat alerts between the warmest and coolest neighbourhoods of Birmingham relative to existing HHWS (2013)

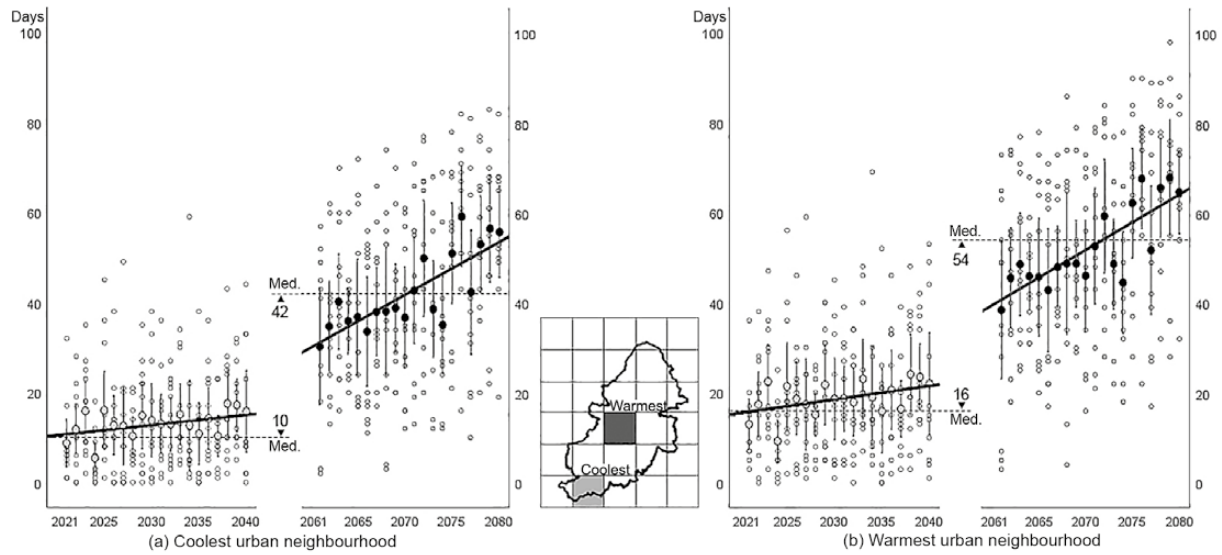


As part of short-term planning, a probability-based (colour-coded) Indoor Heat Health Warning System (iHHWS) was developed for the general populations of each housing type ($H_1I_1 - H_5I_4$) in Birmingham. This system was applied from July 3rd to August 2nd 2013, at the neighbourhood scale (warmest and coolest neighbourhoods). This approach was compared to the local Heat Health Warning System (HHWS), which issues alerts based on a 30°C daily maximum air temperature threshold during daytime. The figures above illustrate how the factors such as building characteristics and urban microclimate would have influenced the issuance of a HHWS alert. The colour-coded (yellow-amber-red) bars show the probability-based hourly occurrence of indoor heat stress (on the x-axis) when an alert should have been issued for each housing type (y-axis), while the blue square indicates the actual day the alert was issued.

Source: Yi et. al, 2023.

Finally, ***Figure 2*** proves that Heat-Health Planning needs to account for the urban dwellings' indoor heat stress at the local level, considering both medium- (2021-2040) and long-term (2061-2080) differences. It also shows that even within a single local climatic context, the diversity of urban dwellings' indoor exposure to heat stress at each housing level can be highly diverse. Understanding the relationship between climate, buildings, and occupants is crucial for protecting and promoting the health and wellbeing of urban dwellers over time, as climate change projections evolve. By enhancing heat-health planning, we can better assess and identify who is at risk, when, and where in both present and future climates. This will enable the development of effective, context-sensitive on-site environmental designs as adaptation or mitigation strategies.

Figure 2: Comparison of projected indoor heat stress duration between the warmest and coolest neighbourhoods of Birmingham, mid- and long-term



These graphs illustrate local differences in the predicted number of days urban dwellings will experience indoor heat stress ('caution' threshold set at >26.7°CHI) during the summer period (June 1st to September 15th) for the two selected local areas (the warmest and coolest urban neighbourhoods) in Birmingham, UK, in future years. They highlight that the disparity between cool and warm neighbourhoods is expected to widen in the future (with the difference in the median values of 6 to 12 days between neighbourhoods). This is due to temperatures projected to rise over the coming decades, with local variations expected.

Source: Yi et. al, 2023.

APPLICATION TO RESIDENTIAL CARE SETTINGS

This proof of concept demonstrates the feasibility of using building energy simulation techniques to assess indoor heat health across different scales, from neighbourhoods to entire cities. This approach could enhance the public health system's ability to respond to climate change. Further research is however necessary to address different clusters of population vulnerability.

Considering the heat-health factors noted earlier, particular attention can be given to people living in care homes. According to a census of the UK's care home residents,[13] approximately 82% of all care home residents in England and Wales were aged 65 years or older in 2021. Special consideration must be directed towards health conditions: only 18.7% of care home residents aged 65 years or older reported being in good or very good general health, while 31.8% reported being in bad or very bad health. Furthermore, among the older care home population, 70.9% were disabled, implying a lack of adaptive capacity to stay cool. Especially noteworthy is the average prevalence of people living with dementia in UK care homes, which stands at about 70%,[14] suggesting a limitation in their ability to communicate or express thermal discomfort.[15] Consequently, care homes saw a sharper rise in deaths (9.2% above the five-year average) during the heat events in 2022 ***(Figure 3)***.

"The likelihood of increasing cooling demand will be a significant challenge to net zero readiness in the future years. This requires renovating care homes resilient to climate change for balancing heat-health risk mitigation with minimising energy for space cooling."

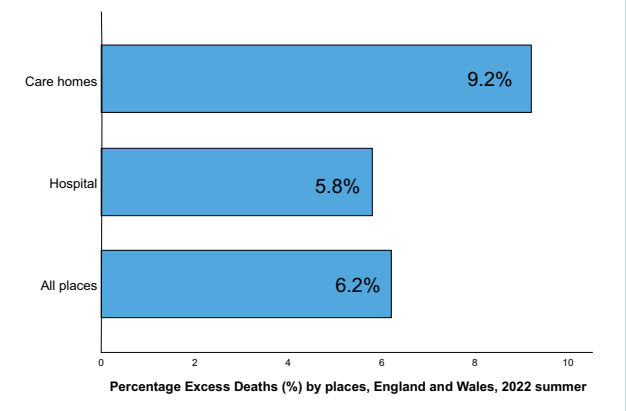
How to reduce risks for those living in residential care settings in response to climate change? WHO's general principles for Heat-Health Planning suggest adopting long-term strategies to mitigate climate change by adapting the built environment. This means that these strategies should

13 Office for National Statistics. (2023). Older people living in care homes in 2021 and changes since 2011. https://www.ons.gov.uk/peoplepopulationandcommunity/birthsdeathsandmarriages/ageing/articles/olderpeoplelivingincarehomesin2021andchangessince2011/2023-10-09.

14 Alzheimer's Society. (2019). Facts for the media about dementia. https://www.alzheimers.org.uk/about-us/news-and-media/facts-media.

15 Yi, W., Liu, H., Zhang, L., et al. (2022). Thermal comfort modelling of older people living in care homes: An evaluation of heat balance, adaptive comfort, and thermographic methods. Building and Environment, 207, 108550. https://doi.org/10.1016/j.buildenv.2021.108550.

Figure 3: **Percentage excess deaths (%) by places, England and Wales, 2022 summer**



This graph presents the percentage of excess deaths (%) above the five-year average by places in England and Wales during the five heat-periods between June and August 2022, including days when a record-breaking temperature was reached.[16]

Source: Office for national statistics, 2022.

align with the global goal of achieving Net Zero CO_2 emissions by 2050, consistent with limiting global warming to 1.5°C above preindustrial level. Given the suggested modelling framework's capacity to identify which building types (and for whom) are at risk, specific interventions to provide optimal space cooling can be developed at the building and even room level.

For instance, keeping cool indoors can be a possible solution to reduce heat-related health risks. While passive cooling measures can be considered first, they may be limited in their ability to provide vulnerable populations with a safe and comfortable indoor environment in certain climatic contexts, such as hot and humid regions where mechanical cooling must be used. The likelihood of increasing cooling demand will be a significant challenge to net zero readiness in the future years. This requires renovating care homes resilient to climate change for balancing heat-health risk mitigation with minimising energy for space cooling. This is the focus of our research project "Renovating Care Homes Fit for the Future Balancing Indoor Heat Stress Risk Mitigation with Net Zero Ready by 2050",[17] funded by the AXA Research Fund.

While building energy simulation can inform context-sensitive strategies and renovation pathways for care homes fit for the future, it requires a finer spatial discretisation of local climate change projections. Once this work is completed, we would have a solid basis to evaluate the effectiveness of renovation measures in reducing this vulnerability through on-site adaptation.

CONCLUSION

In this article, we addressed the growing necessity for a robust framework to facilitate heat-health warning and urban planning efforts. It is crucial to demonstrate the variations in indoor heat-related health risks over the projected timeline of climate change. Our study reveals that outdoor weather conditions can predict distributions of local indoor heat stress in present and future climates. A further application of this approach to vulnerable populations living in care homes is needed, considering heat-health vulnerability factors.

This indoor consideration approach is becoming increasingly important due to an ageing society: 22% of the global population will be over 60 years by 2050, compared to 12% in 2015.[18] Globally, life expectancy[19] has increased by more than 6 years between 2000 and 2019, moving from 66.8 years to 73.4. Healthy life expectancy has also increased by 8% to attain 63.7 in 2019, implying that individuals may require clinical support or care from others from this age.

To respond to a rapid demographic shift as well as climate change, it is urgent to remodel care homes' indoor heat exposure at the city to regional scale. This will facilitate existing heat-health warnings and plannings. The project "Renovating Care Homes Fit for the Future" is currently carried out to balance heat stress mitigation with the goal of achieving net zero care homes by 2050. A better understanding of the relationship between climate, buildings and people will help protect and promote health and wellbeing of older populations living in residential care settings.

16 Office for National Statistics. (2022). Excess mortality during heat-periods: 1 June to 31 August 2022. https://www.ons.gov.uk/peoplepopulationandcommunity/birthsdeathsandmarriages/deaths/articles/excessmortalityduringheatperiods/englandandwales1juneto31august2022#excessdeaths-during-heat-periods-by-place-of-occurrence.

17 AXA Research Fund. (2023). Future-ready care homes: Reducing indoor heat stress while achieving net zero. https://axa-research.org/funded-projects/climateenvironment/future-ready-care-homes-reducing-indoor-heat-stress-while-achievingnet-zero.

18 World Health Organization. (2022). Ageing and health. https://www.who.int/news-room/fact-sheets/detail/ageing-and-health#:~:text=The%20pace%20of%20population%20ageing,from%2012%25%20to%2022%25.

19 World Health Organization. (2021). Global health estimates: Life expectancy and healthy life expectancy. World Health Organization. https://www.who.int/data/gho/data/themes/mortality-and-global-health-estimates/ghe-life-expectancy-and-healthy-life-expectancy.

Healthy, climate resilient urban environments:

Evidence to action

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Urban environments and infrastructure play a key role in shaping human and planetary health. Climate resilient cities can have multiple health benefits by supporting active, low-carbon lifestyles, and enabling urban populations to survive, adapt, and thrive in the face of climate change. Indicators like those shared by the Global Observatory of Healthy and Sustainable Cities, can inform urban and transport policy and help monitor progress towards healthy, climate resilient cities. City governments and leaders should prioritise interventions that promote active and public transport, deliver mixed land use neighbourhoods, support urban greening and biodiversity, and reduce residents' exposure to air pollution, heatwaves and other extreme weather events. Reducing inequities in risk exposure and access to climate resilient urban environments should be at the heart of city planning. The necessary transformation of urban environments to mitigate the health impacts of climate change requires an evidence-informed and coordinated approach across sectors and levels of government.

INTRODUCTION

Home to most of the world's population, urban environments are a key human habitat. Health and climate change are among the biggest challenges facing urban areas in the 21st century, as reflected in the United Nations' Sustainable Development Goals (SDGs). Cities are a major driver of climate change, as they produce 75% of global energy-related greenhouse gas emissions, with 24% of global emissions coming from transport.[1] Meanwhile, urban populations face escalating health impacts from climate change. Extreme weather events, climate-related illnesses, involuntary displacement, food insecurity, physical damages to buildings and income losses pose direct and indirect health threats.

However, it is also possible to transform urban environments to promote health and climate resilience. This article outlines the need for urban climate resilience to protect and promote health, the importance of indicators for tracking progress, and key urban and transport planning interventions that can maximise benefits for human health and the environment.

1 Giles-Corti, B., Moudon, A. V., Lowe, M., Cerin, E., Boeing, G., Frumkin, H., et al. (2022). What next? Expanding our view of city planning and global health, and implementing and monitoring evidence-informed policy. The Lancet Global Health, 10(6), e919–e926. https://doi.org/10.1016/S2214-109X(22)00158-1.

THE CHALLENGE OF URBAN CLIMATE RESILIENCE

Our 2022 *Lancet Global Health* Series on Urban Design, Transport and Health highlighted the urgent need for cities to develop and implement policies that prioritise healthy and resilient urban environments through evidence-informed approaches.[2] City planning policies across a range of sectors shape urban environments, including transport, housing, public open spaces and urban design. Urban environments, in turn, influence travel behaviours, lifestyles, access to services and economic opportunities, as well as greenhouse gas emissions. Some health risks associated with urban environments, such as air pollution, heat islands, biodiversity loss and infrastructure failure, are further exacerbated by climate change. For example, more frequent and severe heatwaves increase risk of heat stress, especially in areas with limited green space and tree canopy cover.

Globally, climate risks and mitigation imperatives have been inadequately considered in city planning, as highlighted in the most recent Intergovernmental Panel on Climate Change report. In many cities, this has resulted in unchecked urban expansion in flood- or fire-prone areas, car-dependent suburbs, and housing densification with insufficient green spaces and amenities. There are significant inequities in risk exposure, as disadvantaged communities often have poorer access to high-quality and resilient urban environments. In Australia's major cities for example, disadvantaged areas are less walkable and liveable than more affluent areas.

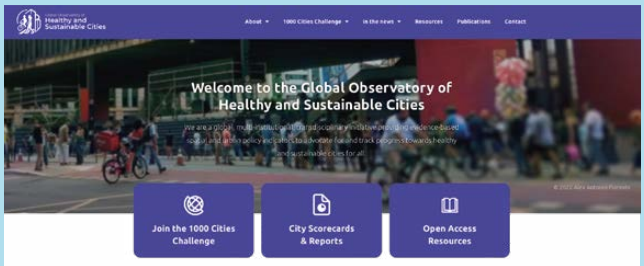
"Globally, climate risks and mitigation imperatives have been inadequately considered in city planning."

It is essential for city planning to focus on creating resilient urban environments in the face of climate change-related health impacts. Urban resilience refers to the ability of cities and their inhabitants to withstand, adapt and positively transform in response to shocks and stresses, including climate change-related disruptions.[3] From this perspective, the threat of climate change should be used as an opportunity for positive transformation of urban environments to optimise health and future resilience. Climate resilient cities can have multiple health benefits, by supporting active, low-carbon lifestyles, and enabling urban populations to survive, adapt, and thrive in the face of climate-related acute shocks and chronic stresses. Climate change and health can therefore be addressed synergistically in cities. City governments and leaders have essential roles to play in developing comprehensive and evidence-informed policies that optimise outcomes for human and planetary health.

INDICATORS TO MEASURE AND MONITOR URBAN ENVIRONMENTS

Indicators can assist city leaders to set evidence-informed priorities and assess progress on actions that affect urban health and climate resilience. Key urban indicator endeavours at the global level include UN-Habitat's Global Urban Monitoring Framework released in 2022, which measures the objectives of safe and peaceful, inclusive, resilient and sustainable cities. The UN SDGs include a specific goal and associated indicators focused on cities (SDG 11, Sustainable cities and communities). There are also now numerous urban observatories and indicator tools developed by government, non-government and research organisations. I co-direct one such effort: the Global Observatory of Healthy and Sustainable Cities.[4] This initiative is an international, collaborative, open-data platform for sharing policy and spatial indicators that assess the health, resilience and sustainability of cities worldwide. Created by an international collaboration of researchers and practitioners, the Global Observatory provides comparable and evidence-based indicators, city scorecards and reports, to help inform urban policy and planning. We are scaling up the number of cities included through the 1000 Cities Challenge, which invites researchers, city planners, advocates, and geospatial data scientists to use our open-source tools to generate indicators for their city. Using an open science approach and engaging local collaborators, our central aim is to build capacity to positively influence city planning policies and practices that affect human, ecosystem and planetary health.

Figure 1: **The Global Observatory of Healthy and Sustainable Cities**



2 Lowe, M., Adlakha, D., Sallis, J. F., Salvo, D., Cerin, E., Moudon, A. V., et al. (2022). City planning policies to support health and sustainability: An international comparison of policy indicators for 25 cities. The Lancet Global Health, 10(6), e882-e894. https://doi.org/10.1016/j.lancetgh.2022.04.013.

3 Lowe, M., Bell, S., Briggs, J., McMillan, E., Morley, M., Grenfell, M., et al. (2024). A research-based, practice-relevant urban resilience framework for local government. Local Environment, 1-16. https://doi.org/10.1080/13549839.2024.2092341:contentReference[oaicite:0]{index=0}:contentReference[oaicite:1]{index=1}.

4 Global Healthy and Sustainable City-Indicators Collaboration. (2022). Global Observatory of Healthy and Sustainable Cities. Washington University in St. Louis. https://www.healthysustainablecities.org/.

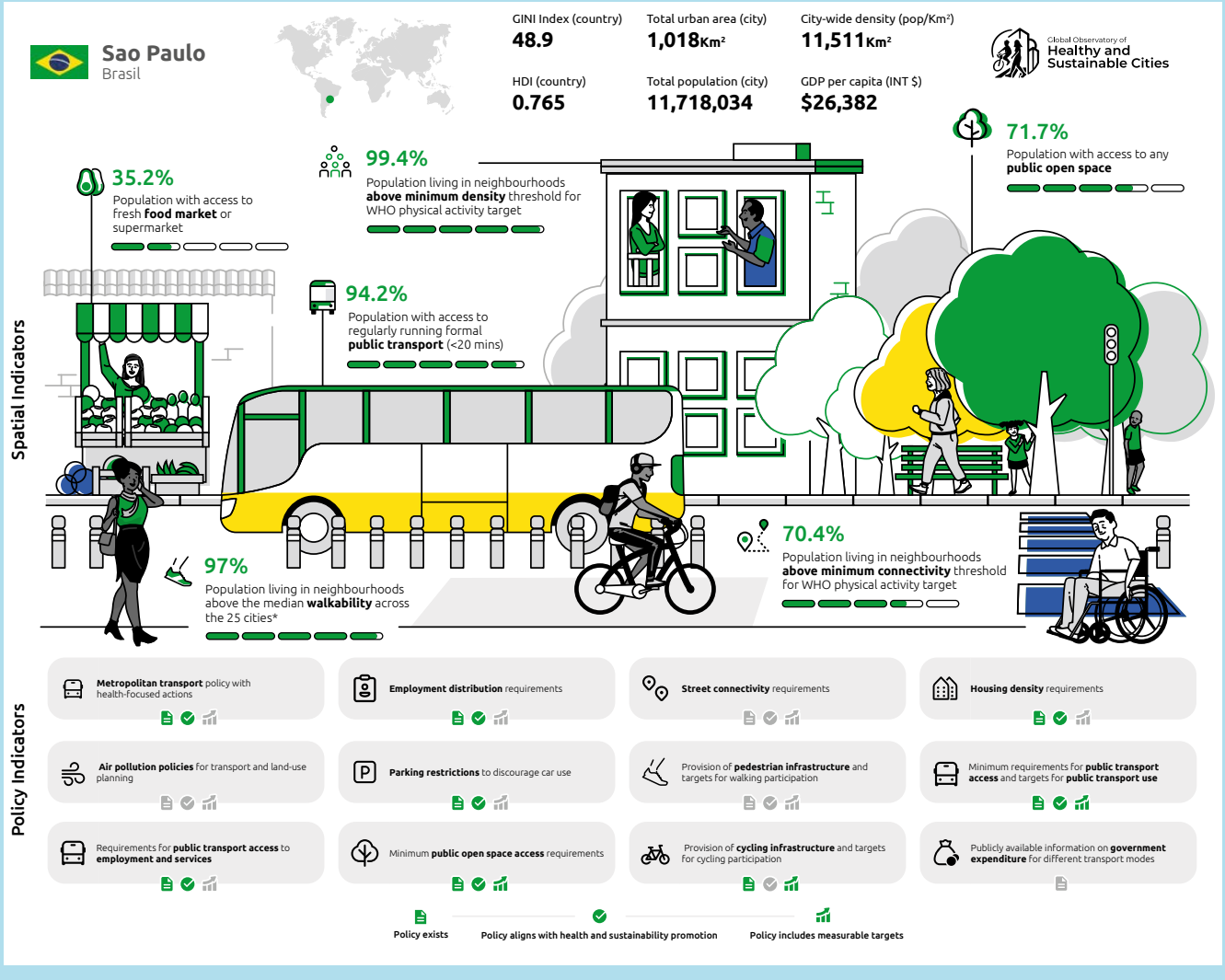
The Global Observatory's policy indicators assess a wide range of policies that shape the health and resilience of urban environments. These include requirements for housing density, pedestrian infrastructure provision, public transport access, public open space access, disaster risk adaptation and reduction, air pollution, urban greening, and biodiversity protection and promotion. The indicators help identify policy strengths and limitations. As an example, initial testing of the indicators on 25 cities showed that São Paulo in Brazil had higher quality policies compared with many cities in high income countries, in terms of being specific, measurable, and aligned with healthy cities research evidence.[5] As part of policy quality assessment, the indicators identify whether cities have evidence-informed policy targets. For example, we found that Odense in Denmark had an exemplary cycling participation target of 45% of work trips by 2028. On the other hand, Melbourne in Australia had a housing density target of 20 dwellings per hectare, which is too low to support walkability.

5 See reference cited in footnote #4.

Spatial indicators available from the Global Observatory measure access to urban design and transport features such as public open space, public transport, walkability, street connectivity, and healthy food stores. Through research supported by the AXA Research Fund, new globally applicable, open-source climate resilience spatial indicators are being developed, including urban greening, air quality and heat vulnerability. Spatial indicators can be mapped to highlight disparities within and between cities. For example, many US and Australasian cities included in the Global Observatory to date have relatively low walkability, especially in their outer suburban areas. As another example, the public transport indicator was able to show that 62% of the population of Bangkok in Thailand has access to a regularly serviced stop, whereas in Chennai, India it is only 3%.[6] The spatial indicators can be used by cities globally to set evidence-informed

6 Boeing, G., Higgs, C., Liu, S., Giles-Corti, B., Sallis, J. F., Cerin, E., et al. (2022). Using open data and open-source software to develop spatial indicators of urban design and transport features for achieving healthy and sustainable cities. The Lancet Global Health, 10(6), e907–e918. https://doi.org/10.1016/S2214-109X(22)00072-9:contentReference[oaicite:0]{index=0}.

Figure 2: São Paulo's scorecard included in the Global Observatory of Healthy and Sustainable Cities



urban design, urban planning and transport policy goals. When repeated over time, these assessments allow tracking of urban environment changes and guide necessary policy adjustments to achieve healthier and more resilient cities.

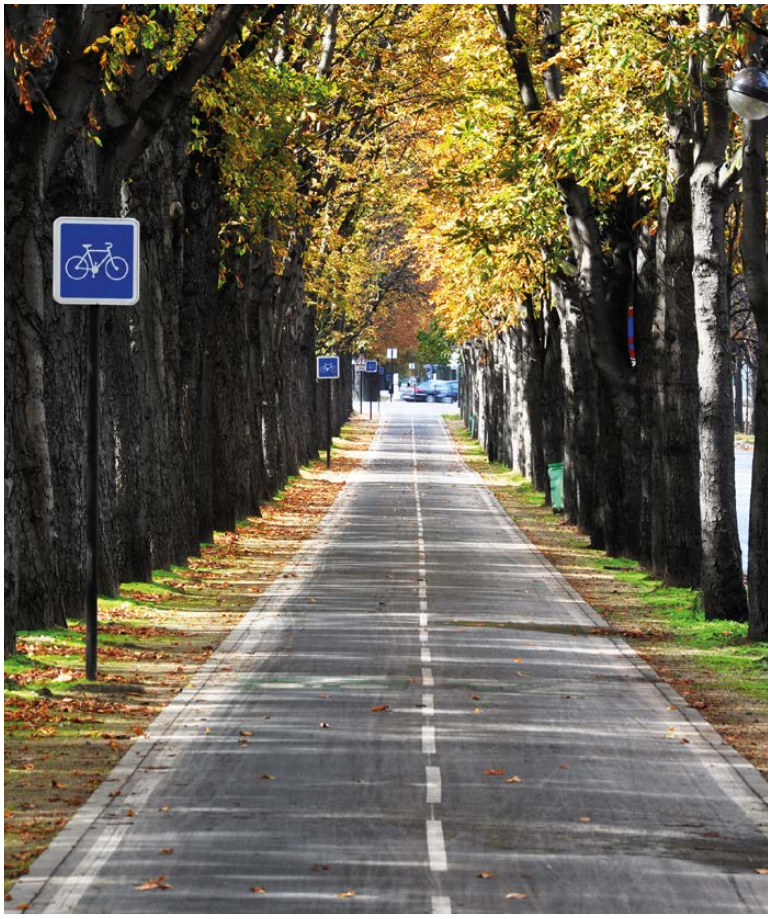
CREATING HEALTHY, CLIMATE RESILIENT URBAN ENVIRONMENTS

City planning has a key role in creating healthy and climate resilient urban environments. To protect health, city planners and leaders need to ensure urban areas can withstand and quickly recover from inevitable disruption. This includes emergency management, ensuring the robustness of housing and critical infrastructure and banning or significantly restricting development in areas at high risk of climate hazards such as flooding and bushfire. However, achieving urban health and resilience will also require adaptation and large-scale innovation and transformative change to the planning, delivery and management of existing and new urban environments. Pilot projects and tactical and temporary changes to public spaces, such as converting car parking spaces into parklets, are important for testing ideas. When shown to be effective, pilots need to be scaled up, embedded in policy and strategy, and funded for the long-term.

"City planning has a key role in creating healthy and climate resilient urban environments. To protect health, city planners and leaders need to ensure urban areas can withstand and quickly recover from inevitable disruption."

There are several priorities for adapting and transforming city planning to deliver healthy and resilient urban environments. Transport planning and urban design should promote active and public transport ahead of private motor vehicle transport. Active, low-carbon transport such as walking and cycling has multiple health and environmental co-benefits[7], including mitigation of climate change through reduced greenhouse gas emissions, improved air quality and increased physical activity. Convenient and frequent public transport is also essential for ensuring equity of access to jobs, shops and services at the regional scale. The transition to electric vehicles is important for reducing carbon emissions and air pollution. However, private electric vehicle use foregoes the physical activity co-benefits that can be achieved from active transport modes, so should be viewed as only one part of transport de-carbonisation. Car use demand can be managed through approaches such as congestion charges, parking restrictions, traffic calming measures and closing streets to cars. Congestion charges are fees payable by drivers to enter city centres. Since their implementation in 2003, central London has seen its traffic reduced by 33%. However, most successful cities use a combination of different policy instruments that both encourage more sustainable travel choices and restrict driving and parking.

Neighbourhoods with diverse land uses support walkable access to daily living destinations. Local living policy goals have attracted increasing policy interest as part of COVID-19 response and recovery efforts and have been framed in various ways internationally. For example, cities like Paris have focused on creating 15-minutes cities, whereby residents can access daily necessities and services within a 15-minute walking or cycling trip from home. Delivering 20-minute neighbourhoods is a strategic planning objective in Melbourne and Portland, Oregon in the US has accelerated progress towards creating 'complete neighbourhoods'. To optimise health benefits, neighbourhoods need a mixture of destinations, and high-quality walking and cycling infrastructure, underpinned by well-designed high-density housing that protects residents from extreme weather and air pollution. Exposure to air pollution can be further managed by siting apartment buildings and schools away from major highways and roads and limiting industrial pollution in residential areas (e.g., regulating buffer distances). Opportunities to reduce greenhouse gas emissions from land use changes and construction of built environments should be accelerated, including retrofitting existing buildings and public spaces rather than demolishing and rebuilding.



7 Co-benefits are achieved where a policy or intervention simultaneously delivers positive impacts towards multiple goals (e.g., human health promotion and environmental sustainability).

Nature-based solutions[8] can help green cities and enhance biodiversity, with co-benefits of reduced urban heat and air pollution, carbon sequestration, and mental health promotion from access to nature.[9] Evidence-informed interventions include creating new green spaces in underserved areas, which can also promote social and physical activity. Increasing tree canopy and vegetation cover (e.g., tree retention and planting, green walls and street verges) can help cool urban environments. Biodiversity-sensitive design is required to protect natural areas and green corridors from urban expansion and development, and maintain and enhance native species diversity. For example, to enhance citizens' health and liveability during droughts and heat waves, Barcelona's Master Plan for Trees 2017-2037 promotes green infrastructure, particularly through an extensive tree-planting initiative. The plan aims to ensure that 40% of tree species are resilient to climate change and to mitigate urban heat islands by expanding the city's tree canopy from 5% to 30%.

"Geographic and health equity should also be at the heart of priority setting and decision-making, to ensure that everyone has access to healthy and climate resilient urban environments."

Delivering these urban design and transport interventions requires evidence-informed, integrated policy and coordinated implementation between governments and the private and community sectors.[10] Alignment of policy actions and funding commitments across sectors and all levels of government responsible for city planning can help avoid unintended contradictions and negative health and environmental effects. Health impact assessment to scope out potential health impacts from major development proposals, projects or policies is a specific approach to ensure health considerations are embedded in all aspects of city planning. It can be used alongside, or combined with, environmental impact assessment to address health and environmental issues synergistically.

Inclusion is a key quality of resilient urban systems.[11] Communities need to be involved in city planning decisions that impact their neighbourhoods and daily lives. Government should provide opportunities for community engagement in all planning stages from identification of problems, through to designing and implementing solutions on-the-ground. Participatory budgeting[12], particularly through "co-decision" measures, enables citizens to actively engage in local urban governance. Since its first experiments in Latin America in the late 1980s, the region now accounts for nearly one-third of global participatory budgeting initiatives. In Paris, this model of collective decision-making will facilitate the creation of the city's third urban forest.

Geographic and health equity should also be at the heart of priority setting and decision-making, to ensure that everyone has access to healthy and climate resilient urban environments. Neighbourhood-level spatial information can help inform targeted policies and interventions to reduce inequities in access to urban design and transport that supports health and well-being.

8 Nature-based solutions are actions to address societal challenges through the protection, sustainable management and restoration of ecosystems, benefiting both biodiversity and human well-being (IUCN definition).

9 See reference cited in footnote #2.

10 See reference cited in footnote #4.

11 See reference cited in footnote #7.

12 Participatory budgeting is a democratic process in which communities decide how to allocate a part of the public budget.

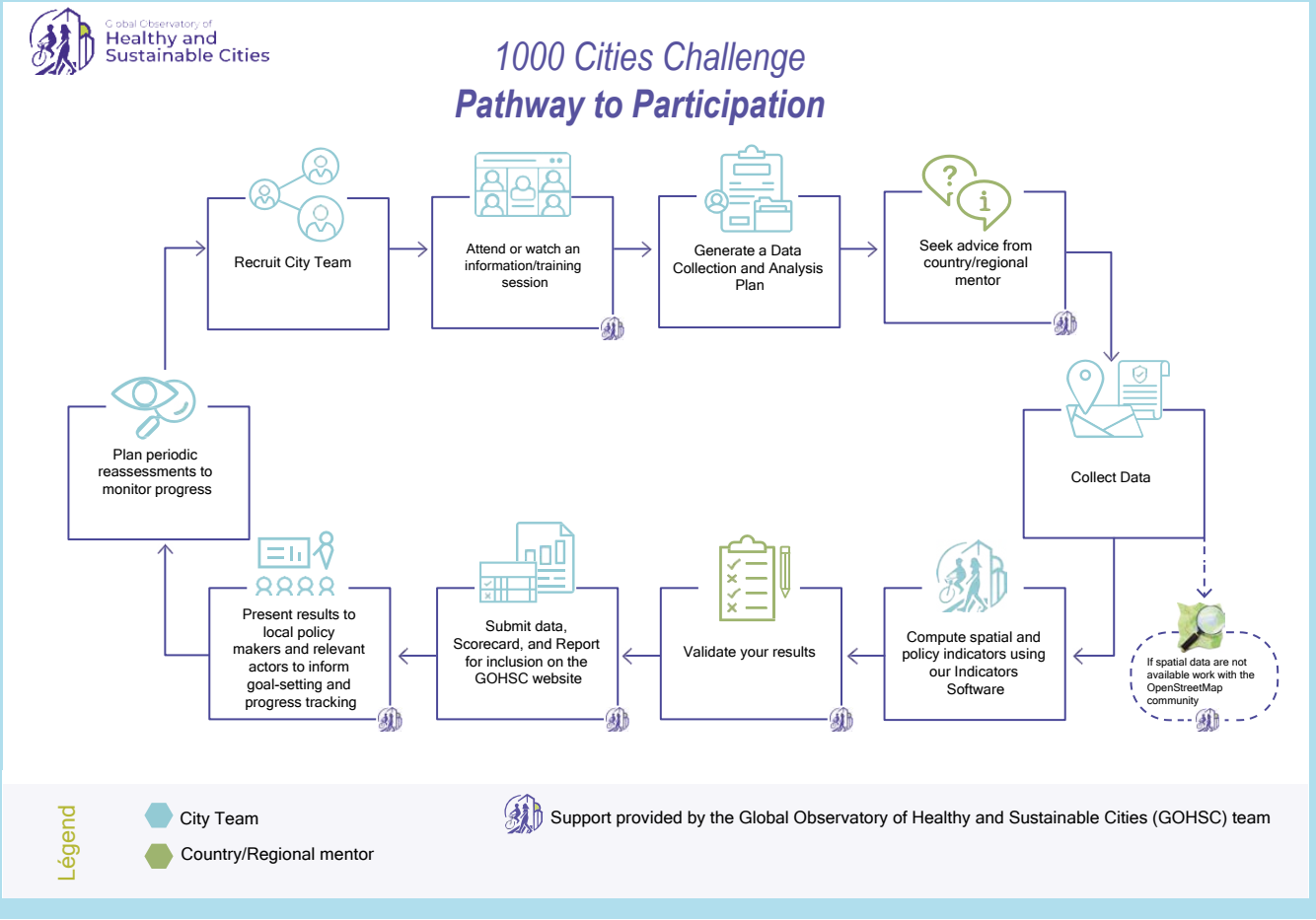
Clear, measurable targets should be included in policies to facilitate their implementation and ensure accountability. Such targets should be evidence-informed and sufficiently ambitious to drive the necessary changes and prevent cities from perpetuating unhealthy urban development patterns.[13] City planners and leaders should use indicators—like those in the Global Observatory of Healthy and Sustainable Cities—to identify priority issues and measure and monitor progress towards policy targets. Figure 3 below highlights the pathway to participate in the Global Observatory's 1000 Cities Challenge. Participants are supported to calculate indicators for their city, generate a city report and scorecard and present the findings to local policy makers and other relevant actors to ensure indicators help inform goal-setting and progress-tracking locally.

CONCLUSION

Urban areas contribute to and disproportionately experience the health impacts of climate change. However, urban environments can also spearhead climate resilience. Cities need to be able to persist, recover, adapt, and transform in ways that maximise health and climate co-benefits. This includes preparing for climate change impacts that cannot be avoided, while accelerating the transition to net-zero emissions and preventing run-away climate change. Integrated cross-sectoral coordination is needed to create neighbourhoods that support sustainable, local living, and reduce exposure to climate change-related hazards such as air pollution, urban heat and extreme weather events. Cities need to work together to mitigate and prevent the health consequence of climate change, and share policy insights and best-practice approaches with their peers and through relevant networks such as C40 Cities. Policies and their implementation should target health inequities and be guided by measurable targets and evidence-informed indicators to benchmark and track progress over time.

13 See reference cited in footnote #4.

Figure 3: **Pathway to Participation in the 1000 Cities Challenge launched by the Global Observatory of Healthy and Sustainable Cities**



Building climate resilience in Indonesia:

The role of cool roofs

Beta Paramita
Associate Professor in the Architecture Department at Universitas Pendidikan Indonesia (UPI)

Workers painting a roof with BeCool solar-reflective paint

Beta Paramita is an Associate Professor in the Architecture Department at Universitas Pendidikan Indonesia (UPI), with a Doctorate in Engineering from The University of Kitakyushu, Japan. She is currently chair of the center of excellence for low carbon building material and energy in UPI. Her research focuses on sustainable cities and green buildings, particularly building performance and outdoor thermal comfort. In 2022, she won the Million Cool Roofs Challenge and founded BeCool Indonesia, a start-up promoting passive cooling designs across Indonesia through BeCool solar reflective paint produced by PT Driya in collaboration with Universitas Pendidikan Indonesia.

The urban population in Indonesia is characterized by rapid growth, while urban microclimates are developing in the context of climate change, increasingly having a detrimental impact on human health, especially due to significant heat-related challenges. BeCool's solar reflective paint allows for a cooler surface on painted roofing materials, similar to the effect of wearing white clothes during the day. This innovative technology helps make a concrete contribution to global warming mitigation efforts in Indonesian cities, as it combats the urban heat island effect and its negative impacts, thereby preserving the health of urban dwellers. By reflecting sunlight back into the atmosphere, applying paint can reduce outer surface temperatures by 15°C and inner space temperatures by 3°C, resulting in an 80% reduction in ozone warming.

BeCool's commitment to mitigating global warming extends beyond developing innovative products. The company actively participates in various programs, including painting public buildings, residences, worship and educational buildings. Additionally, BeCool provides education to students across different regions in Indonesia and builds solar reflective houses. These initiatives aim to foster sustainable environmental improvements, ultimately enhancing the health and quality of life within the community.

INTRODUCTION

As urban populations grow, so does urban development, which accounts for 40% of the world's energy consumption. The densely populated urban areas in Indonesia suffer from poor ventilation, leading to the trapping of heat in buildings throughout the day. This trapped heat is only released at night, resulting in what is known as the urban heat island effect. Consequently, achieving thermal comfort becomes challenging, especially when humidity levels are high and air conditioning is lacking, leading to various respiratory diseases.

Unfortunately, these conditions persist and have a detrimental impact on health, often going unnoticed. Ironically, the use of air conditioning to achieve thermal comfort further negatively contributes to global warming. The lack of proper air circulation allows diseases to thrive and circulate in a repetitive pattern. Therefore, concrete measures are necessary to mitigate global warming and preserve the environment and well-being of the community.

INDONESIAN CITIES AND URBAN DWELLERS FACE IMPORTANT HEAT-RELATED CHALLENGES, WHICH ARE EXPECTED TO WORSEN DUE TO CLIMATE CHANGE

Indonesia's urban population has now reached 59%.[1] Cities face higher potential disaster losses than rural or suburban areas due to the concentration of population and economic activities.[2] The United Nations Environment Program (UNEP) reported that the built environment is responsible for 40% of global energy consumption, 30% of greenhouse gas emissions, waste production, and natural resource utilization. This energy is released as heat, leading to the formation of urban heat islands, where temperatures are higher than those of the surrounding areas.

"The incorrect choice of building materials and design can lead to adverse effects caused by high ambient temperatures and humidity. This, in turn, can contribute to the prevalence of different diseases."

Urban villages in Indonesia's major cities are characterized by a rapid growth in residential areas. The high building density and extensive surface area contribute to the formation of a unique urban microclimate, leading to a noticeable increase in local temperatures. The lack of proper air circulation systems in densely built urban villages hinders the quick dissipation of heat trapped within the structures. Consequently, the heat is released during the afternoon and evening, causing nighttime air temperatures to be higher than in the morning.

The increasing development of such urban microclimates in the context of a changing climate has a detrimental impact on the living conditions of the communities, as evidenced by the elevated thermal discomfort index in outdoor areas. Furthermore, the lack of proper ventilation exacerbates humidity levels, resulting in increased reliance on air-conditioning systems that contribute to global warming.

Furthermore, Indonesia, as a tropical archipelago, is known for its hot and humid climate. The duration of daylight and nighttime is almost equal throughout the year, resulting in consistently high temperatures, high humidity, and relatively calm winds. Consequently, the cities in Indonesia generally struggle to provide comfortable outdoor spaces.

Typically, coastal cities in Indonesia experience a peak air temperature of 33°C, while lowland cities have a maximum air temperature of 30°C. On the other hand, cities situated in hilly areas have the lowest maximum air temperature ranging from 25-28°C. The incorrect choice of building materials and design can lead to adverse effects caused by high ambient temperatures and humidity. This, in turn, can contribute to the prevalence of different diseases, particularly in densely populated residential areas affected by the urban heat island phenomenon.

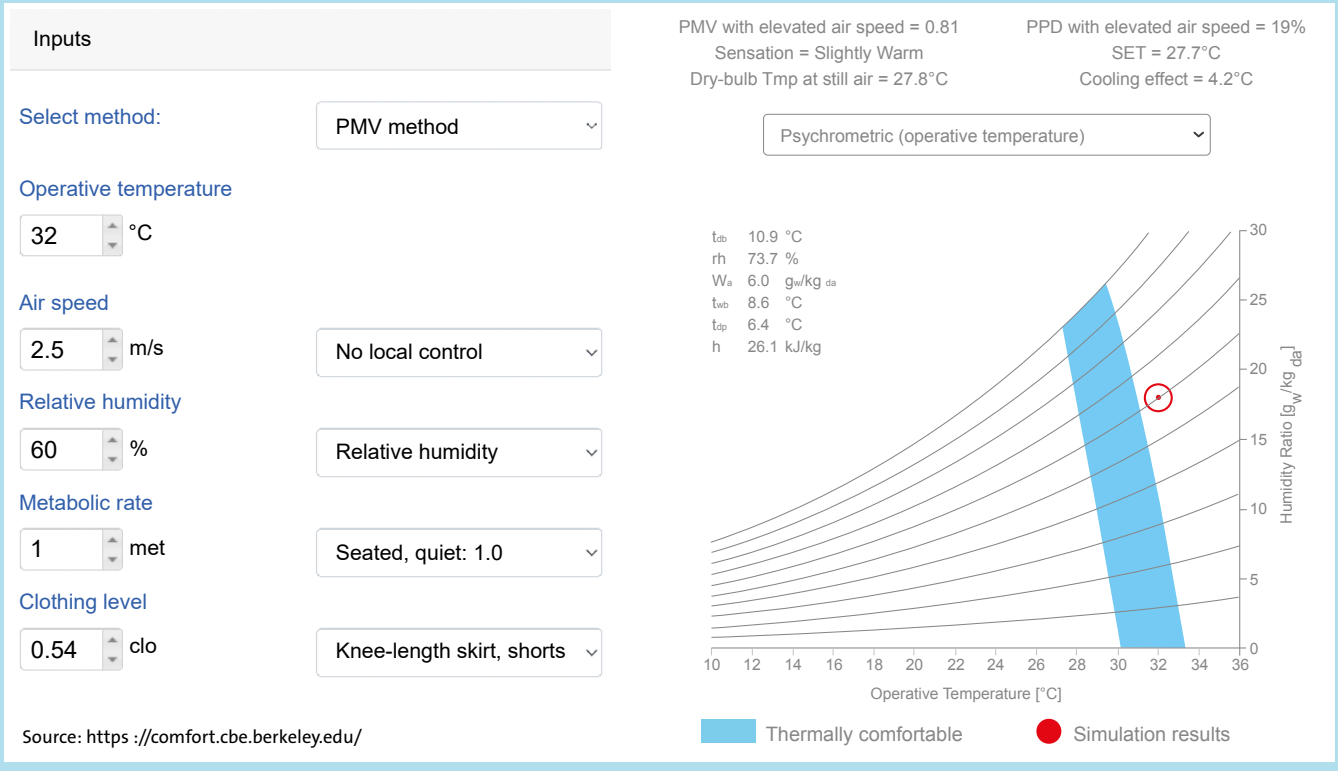
Indonesia ranks second globally in terms of tuberculosis cases, according to the World Health Organization's 2023 report.[3] Various studies have revealed that the environment, including

1 Statista. (2024). Share of the urban population in Indonesia 2014-2023. Statista. https://www.statista.com/statistics/761113/share-of-urban-population-indonesia/.

2 Dickson, E. (2012). Urban risk assessments: Understanding disaster and climate risk in cities. The World Bank.

3 World Health Organization. (2023). Global tuberculosis report: Tuberculosis incidence. World Health Organization. https://www.who.int/data/gho/data/themes/mortality-and-global-health-estimates/ghe-life-expectancy-and-healthy-life-expectancy.

Figure 1: **Thermal Discomfort Index (Simulation in Bandung Dense Housing Area at 12.00 AM with CBE Thermal Comfort Tool)**



Source: https ://comfort.cbe.berkeley.edu/

houses and residential areas, plays a significant role in the transmission of tuberculosis, with a potential impact up to 35 times higher.[4] This is due to the region's high population density, elevated temperatures, and limited airflow, resulting in heat being retained within the building materials. This accumulation of heat contributes to increased humidity levels in the air, which can lead to health issues. Furthermore, the use of air conditioners in such conditions can contribute to the spread of airborne diseases. Typically, respiratory tract diseases are the most common health issues associated with unhealthy living spaces.

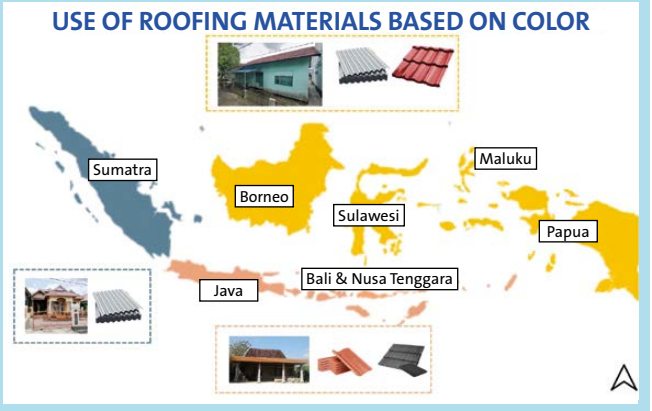
The low latitude region of Indonesia, situated close to the equator, experiences a hot, humid climate heavily influenced by solar radiation. The intense sunlight in this region drives significant heat transfer, making it a key factor in determining outdoor conditions.

The expansion of urban villages is steadily rising each year, necessitating the implementation of passive design strategies to minimize the heat absorbed from solar radiation. It is crucial for materials in urban areas to possess specific qualities such as high u-value,[5] high albedo value,[6] and a high SRI (solar reflectance index) value. Utilizing materials such as BeCool solar reflective paint, which fulfills these requirements, can serve as an effective solution for urban villages characterized by dense slums.

MATERIAL USED FOR ROOFING HAVE A SIGNIFICANT IMPACT ON INDOOR TEMPERATURE, AND THEIR CHOICE IS INFLUENCED BY ENVIRONMENTAL AND CULTURAL FACTORS

Indonesia, made of 17,508 islands, exhibits a diverse architectural approach in each region. The design philosophy considers the unique attributes of each area, including natural calamities potential, climate conditions, and the socio-cultural fabric of the local community.

Figure 2: **Use of roofing materials across Indonesia**



4 Wahyudi, A. S., Raufuddin, & Suarilah, I. (2019). The relationship between healthy housing conditions and pulmonary tuberculosis. Proceedings of the International Conference on Environment and Urban Sustainability, 657–663. https://doi.org/10.5220/0008330506570663.

5 The U-value (or thermal-transmittance) measures how effective a material is an insulator.

6 The albedo value indicates how well a surface reflects solar energy, varying between 0 and 1. Albedo commonly refers to the "whiteness" of a surface, with 0 meaning black and 1 meaning white.

Natural calamities are very likely to occur in the country due to its location in the "Ring of Fire" region, where four major tectonic plates interact. The country comprises three primary islands: Java Island, Sumatra Island, and Kalimantan Island (Borneo).

Sumatra, the westernmost island in Indonesia, is particularly prone to earthquakes and tsunamis. These factors greatly influence the selection of roof covering materials, favoring lightweight options like zinc, alderon, and zincalume. In contrast, in Java Island, clay or asphalt roof tiles are more commonly used. There exists a belief within the community in Sumatra that using roof materials derived from soil is equivalent to self-burial, leading to the avoidance of clay roof tiles by certain populations on the island.

On the other hand, in Kalimantan Island, the choice of roof covering materials differs, ranging from clay, asphalt, or metal roof tiles to lightweight options. This variation is due to Kalimantan Island being less susceptible to risks compared to its counterparts, as it is not situated within the Pacific Ring of Fire.

The temperature of the indoor space of a building is influenced by the roof coverings used. Structures featuring lightweight roof coverings like zinc, alderon, or zincalume tend to be warmer as these materials lack efficient thermal conductivity unless treated. Nevertheless, these lightweight materials are extensively employed in Java and Kalimantan, particularly in regions with high residential density and low economic conditions due to their affordability. Industrial buildings also commonly use these materials.

Buildings featuring clay or asphalt roof tile coverings, which possess low thermal conductivity, lead to lower room temperatures in the space below compared to structures with other roofing materials.

CASE STUDY: ENHANCING URBAN RESILIENCE AND HUMAN HEALTH IN INDONESIA WITH SOLAR REFLECTIVE PAINT

a. Solar reflective paint for cooler, healthier indoors

BeCool produces solar reflective paint that works by reflecting a greater amount of solar radiation and absorbing less heat compared to a typical roof. Similar to wearing light-colored clothing in the daytime, roofs treated with such a paint will remain cooler than dark-colored roofs, resulting in lower room temperatures below and decreasing the need for air conditioning, thus offering thermal comfort to occupants.

The use of dark-hued materials on roofs results in a 38% contribution to atmospheric warming, whereas the use of solar reflective paint leads to only 10% of heat being absorbed into the atmosphere, with 80% of sunlight being reflected back through invisible waves, thus helping prevent global warming on Earth.

BeCool's global warming mitigation initiatives, implemented from 2019 to 2023, have taken place on numerous Indonesian islands like Sumatra, Kalimantan (Borneo), Sulawesi, and Nusa Tenggara. These initiatives encompassed residential areas, industrial zones, educational institutions, public buildings, and more, targeting primarily clay tile and metal materials. These efforts benefited not only the occupants of the structures but also the environment at large.

Figure 3: Map of BeCool's actions in Indonesia from 2019 to 2023

1. Tangerang
- Industrial Building
- Elementary School
- Low-cost housing
- Religious building
- Government building

1. Jakarta - Elementary School
2. Jepara - Elementary School
3. Wantilan, Subang
- Elementary School
- Low-cost housing
- Gymnasium

4. Bandung - Junior High School
5. Cikelet, Garut - Senior High School
6. Pameungpeuk, Garut - Senior High School
7. Sukabumi - Elementary School
8. Kupang, NTT - Religious building
9. Manado - Junior High School
10. Pontianak - Orphanage Building
11. Bangka Belitung - University Building
12. Langsa, Aceh - School (elementary, junior, senior)
13. Tasikmalaya - Industry Building
14. Subang - Industry Building

1. Banda Aceh - Universitas Syiah Kuala
2. Langsa - Universitas Samudra
3. Jambi - Universitas Adiwangsa Jambi
4. Palembang
- Universitas Tridinanti Palembang
- Universitas Indo Global Mandiri
- Universitas Sriwijaya

5. Jakarta - Universitas Tanri Abeng
6. Bandung - Universitas Pendidikan Indonesia
7. Semarang - Universitas PGRI Semarang
8. Malang - Universitas Brawijaya
9. Mataram - Universitas Mataram
10. NTT - Universitas Nusa Nipa
11. Gorontalo - Universitas Negeri Gorontalo

1. Mamuju, Aceh - Mosque Al Munawaroh
2. Deli Serdang - Church Injili Nusantara
3. Sikakap, Mentawai - Mosque Al Ikhla
4. Indragiri, Riau - Mosque Baitur Rahma
5. Bengkulu - Mosque Fathul Jannah
6. Tangerang - Mosque Arrahman
7. Cimahi - Mosque Al Hanif
8. Kolikapa, NTT - Mosque At-Taqwa
9. Nagakeo, NTT - Church GMIT Ebenhaezer
10. Banggai, Sulawesi - Mosque Nurul Jamil

Kampung BeCool
1. Bengkulu - Pasar Bengkulu
2. Kab. Bandung - Tipar
3. Gorontalo - Tanjung Kramat

Applying reflecting paint can indeed lower the roof surface temperature by approximately 10-15°C and decrease indoor temperature by 1-3°C. This leads to a decrease in air conditioning usage, resulting in reduced carbon emissions and lower indoor humidity levels, positively impacting the occupants' health.

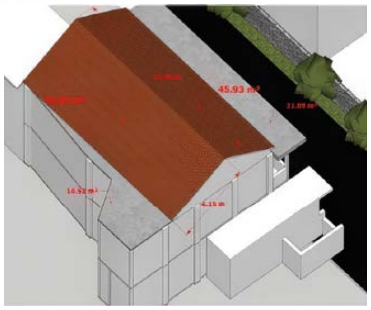
Figure 4: BeCool solar reflective paint

BeCool led multiple initiatives to provide better living conditions for Indonesians and help improve society's adaptation to climate change.

For example, the utilization of solar reflective paint on an office's roofing material in Bandung reduced the surface temperature by 13°C, thereby lowering the indoor temperature from 29.8°C to 27.7°C ***(Figure 5)***. This cooling effect not only curtails the reliance on air conditioning units but also enhances the overall thermal comfort experienced by the employees.

Figure 5: BeCool Project on Aaksen architecture building office

βeCool **Pilot Projects: AAKSEN Studio, Bandung**



AAKSEN ARCHITECTURE CONSULTANT
https://aaksenstudio.com/
https://www.instagram.com/aaksenstudio/

Indoor temperature after being painted on Cool Roofs is 29.8°C and the result using a FLIR camera is 27.7°C which was carried out on January 20, 2022. Previously, it was 44.2°C. Then the roof surface temperature that has been coated is 38.3°C and that not coated is 51.3°C.

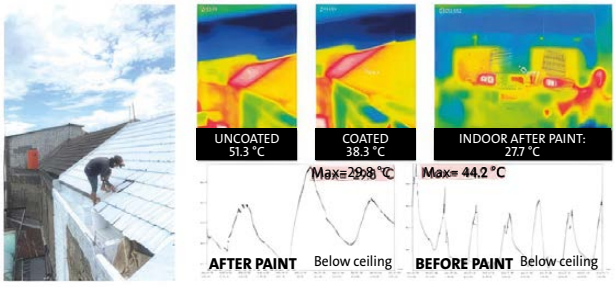
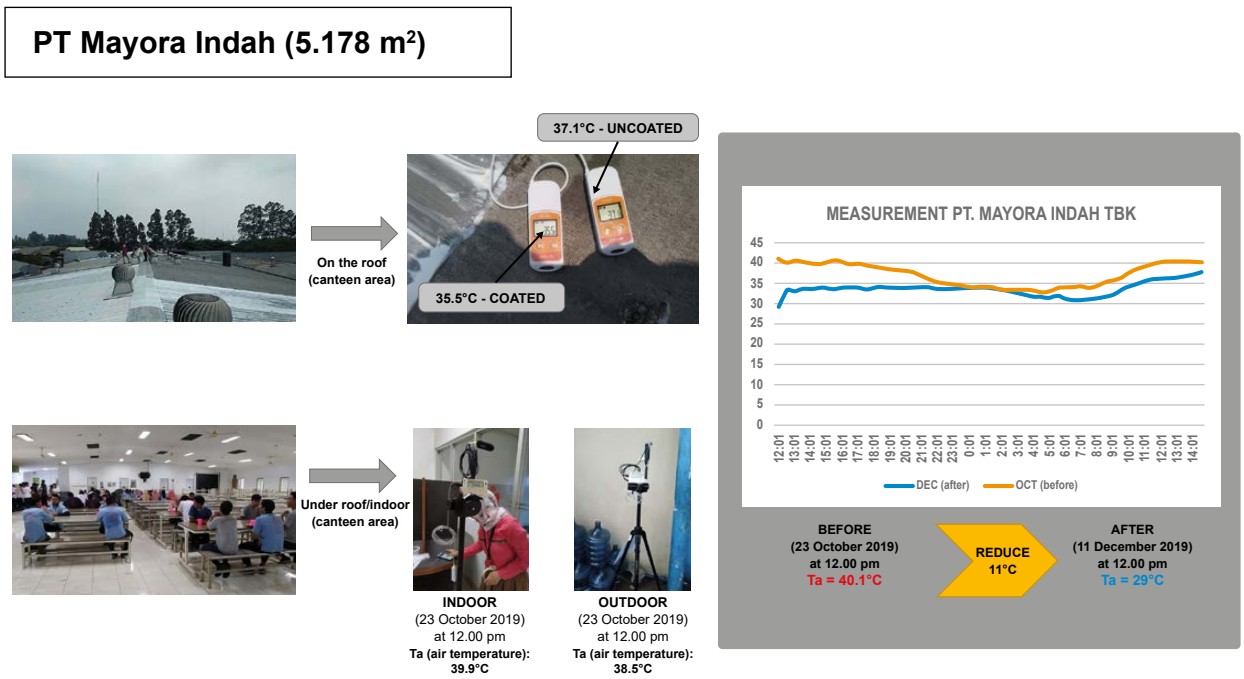


Figure 6: Results of a painting experiment conducted on and under the roof of an industrial facility



On a broader scale, BeCool was also utilized on the rooftop of an industrial facility situated in Tangerang. The application covered an area of 5,178 m² and resulted in a significant reduction in surface temperature by 11°C, thereby creating a cooler ambiance within the building.

The BeCool Village project ***(Figure 7)***, implemented in 2023, aimed at enhancing the microclimate of various residential areas across Indonesia, including Bandung, Bengkulu, and Gorontalo, by applying reflective paint on multiple roof surfaces. As a result, the indoor temperature in the residents' homes was reduced, providing a more comfortable living environment.

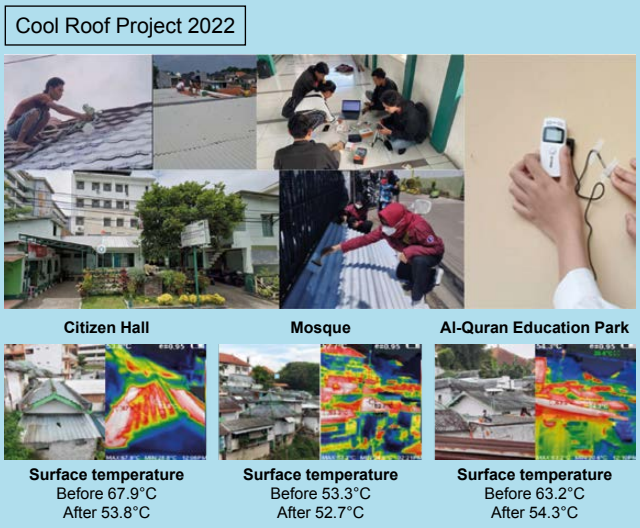
Figure 7: BeCool Village project

b. The Cool Roof Project: articulating painting projects and community engagement

Throughout 2022, BeCool led another project called the Cool Roof Project, collaborating with multiple universities in Indonesia to contribute to environmental improvements through the Global Warming Mitigation learning program. A series of lectures were conducted over a span of 16 weeks to teach students about urban heat islands and how to mitigate their impact. These lectures featured renowned practitioners and academics from both national and international backgrounds.

During the first quarter, online presentations were organized for students from different regions in Indonesia. In the subsequent weeks, the knowledge imparted during these presentations was put into practice by educating the community about global warming and undertaking painting projects on 70 buildings across 15 cities.

Figure 8: Cool Roof Project led in 2022: Pictures and results in surface temperature



A total of 267 students and 43 lecturers actively participated in this program, working together to raise awareness about the significance of global warming mitigation. The painting process involved not only the students and faculty, but also the local community, fostering knowledge sharing and enhancing the microclimate in the area. The choice of roof covering materials for the painting projects was tailored to suit the specific characteristics of each region.

The reduction in surface temperature achieved varied between 5 and 15°C, while the decrease in indoor temperature ranged from 1 to 3°C. This is anticipated to enhance the thermal comfort of the area for various activities such as living, working, and studying. A visual representation comparing the surface temperature of painted and non-painted surfaces is provided. ***(Figure 6)***

c. Extending activities beyond the painting of roof surfaces to ensure cool and resilient indoors

BeCool's activity goes beyond the painting of roofing surfaces. In collaboration with the metal industry, the company developed a metal sheet product coated with solar reflective paint, which can serve as a building envelope for walls and roofs. The result of this partnership is the creation of RAFLESIA (abbreviation for Indonesian solar reflective house).

Figure 9: RAFLESIA, a 100% solar reflective house in Indonesia

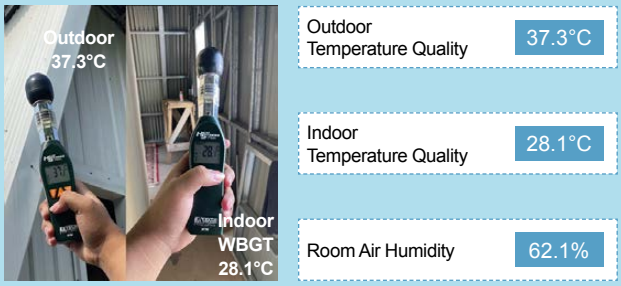
RAFLESIA has successfully built two residential units and a BeCool Lab in the West Bandung Regency. These houses serve as a residential aid for individuals who are living in inadequate housing conditions due to their physical health.

RAFLESIA houses stand out from typical Indonesian homes, which are built with concrete frames and brick walls. This unique dwelling is designed with a solar reflective concept, featuring an iron frame enveloped in metal cladding coated with BeCool paint. Despite its metal composition, the house maintains a pleasant indoor temperature, with a notable temperature difference of up to 9°C compared to the outside. As a result, it not only promotes energy efficiency but also contributes to the well-being of its occupants.

The striking design of RAFLESIA houses attracts attention within a residential neighborhood. This opportunity is leveraged by residents who establish a commercial space in front of their homes, thereby indirectly enhancing the community's quality of life.

Furthermore, RAFLESIA is tailored to suit the geographical conditions of Indonesia, a country prone to natural disasters like earthquakes. By incorporating lightweight materials, the vulnerability to earthquakes can be lessened. RAFLESIA serves as a pioneering concept for housing in Indonesia, dispelling the belief that houses must be built using bricks. Additionally, the construction expenses for RAFLESIA are lower than those for brick houses. The objective is for RAFLESIA to be used as a preventive measure in disaster-prone areas, providing safer and more sustainable housing options for communities at risk.

Figure 10: Difference between outdoor and indoor temperatures – RAFLESIA solar reflective house



CONCLUSION

BeCool contributes to improving environmental quality and addressing the effects of global warming in Indonesia, through efforts tailored to the diverse needs and characteristics of the archipelago.

The application of its solar reflective paint can lower external and internal building temperatures, which helps lower humidity levels, thus minimizing the risk of disease transmission. Moreover, by reflecting solar radiation back into the atmosphere, BeCool's technology contributes to global warming mitigation. As of 2024, the paint has been applied to approximately ±300.000 m² of surfaces through community outreach programs, excluding commercial applications.

Beyond these measures, efforts have been undertaken to educate students in Indonesia through collaborations with professionals and academics, and real action is taken to involve the community in environmental conservation. The construction of RAFLESIA, an Indonesian solar reflective house with metal walls and roofs coated in reflective paint, is envisioned as the initial step towards introducing metal housing in Indonesia and further mitigating the effects of global warming.

Becool's ultimate goal is to enhance housing quality for middle- to lower-income families in Southeast Asia while contributing to global efforts to reduce energy consumption and lower carbon emissions. Additionally, to maximize environmental benefits and improve living standards, we encourage all segments of society to participate in these efforts through tangible actions, including by applying solar reflective paint to building surfaces.

Insuring new climate risks that affect health

Françoise Gilles, Chief Risk Officer of the AXA group
Julia d'Astorg, Director of the AXA Research Fund

With almost 25 years of experience in financial services, including ten within the AXA Group, Françoise Gilles has been Chief Risk Officer for over a year and sits on the company's management committee. She oversees all the key phases of an insurer's core business for a group present in over 50 countries, from initial risk identification and analysis to defining quantification and mitigation methods.

Julia d'Astorg leads the AXA Research Fund. Coming from a healthcare background, she has held operational roles internationally. As head of international medical assistance division at AXA Partners, she was responsible for responding to health crises, emergency evacuations, and medical innovation. Under her management, the AXA Research Fund team works to improve the understanding of emerging risks by funding research, thereby helping to inform public and private decision-making.

This joint interview highlights the growing challenges insurers face in understanding and covering all the risks associated with climate change and their impact on health. The many risks that have appeared recently are interconnected and combine with existing threats, making them particularly complex to manage. It is in this context that AXA is striving to find innovative solutions to offer protection to as many people as possible, thereby increasing society's overall resilience.

Understanding and managing risk is in the DNA of an insurer. AXA is committed to deciphering emerging risks and new impacts on humankind, drawing on its internal resources and supporting science at a very early stage in laboratories so that it can make sense of the complexity of the world around us. For 16 years, the AXA Research Fund has been accelerating the exploratory capacity of science by supporting researchers through grants. By promoting open, cross-disciplinary and independent science, it enables exploration in new areas of risk science relating to health, the climate, and the economy. This support for the academic world is part of a broader approach – a major focus for AXA – involving alliances between private and public players to tackle the major challenges facing society, particularly climate change and its impact on human health. In this context, insurers play an increasingly crucial role in the economy and the protection of individuals and the environment, driving resilience and innovation for a more sustainable future.

As an insurer, how does AXA approach the risks associated with climate change and their interconnections with health risks?

F.G. Our risks are clearly evolving and becoming increasingly interconnected.
The climate changes we are seeing, for example, have close links with the geopolitical risks and health issues that our policyholders are facing or will face in the future. In our latest Future Risks Report, climate change and infectious diseases once again feature in the top 10 risks identified.[1] Our report highlights the importance of acting now to better understand and manage these risks and their correlations. The impacts of climate change are already palpable: water deficits were responsible for a 10% increase in migratory flows between 1970 and 2000, while unpredictable rainfall increases the risk of flash floods. This need to act is also reflected in investments. According to the Potsdam Institute, every dollar invested today in environmental transition could avoid six dollars in future costs.[2] However, expenditures on health, welfare and pensions for an ageing population limit targeted investments in the ecological transition. To achieve a better understanding of these links and anticipate both their impacts and our ability to respond and support our customers, we are working with the scientific world and various experts to advance research focused on improving our understanding of health issues.

"The consequences of climate change are vast. Day-in day-out, we are making significant efforts to improve our understanding of these consequences by calling on scientific experts, the academic world and our in-house experts, and by forging valuable partnerships."

We remain humble in recognizing that these risks are highly complex and constantly evolving. We acknowledge that we do not always fully grasp their connections and cross-impacts, necessitating a review of how we understand and quantify them. By forging closer ties with academic partners, insurers, public authorities and the healthcare sector, we are seeking not only to drive progress for AXA but also to foster collective intelligence and a shared understanding of the current state of the world.

At the same time, we are testing numerous scenarios to measure our company's resilience in the face of past or foreseeable situations. In 2023, we took part in the second climate stress test organized by the Autorité de Contrôle Prudentiel et de Résolution (ACPR),[3] France's insurance sector regulator. This initiative was another opportunity to enhance our in-house expertise in assessing the risks associated with climate change and their impact on health.

Our ongoing focus on controlling our risks enables us to provide cover for our customers while offering us a unique opportunity to deepen our understanding of risks, their interconnections and how we can provide a relevant response before and after a loss occurs.

The consequences of climate change for health are wide-ranging in terms of their nature and impact. Do you pay particular attention to certain risks, geographical areas or categories of policyholder?

F.G. We conduct business in over 50 countries worldwide, with a significant presence in Europe. Our customers include individuals and businesses. We strive to provide innovative solutions, tailoring our responses to the diverse needs of our various categories of policyholders.

The consequences of climate change are vast. Day-in day-out, we are making significant efforts to improve our understanding of these consequences by calling on scientific experts, the academic world and our in-house experts, and by forging valuable partnerships.

Internally, for example, AXA Climate[4] is helping us improve our understanding of the consequences of climatic events and their impact on society, and deliver prevention and protection solutions that are increasingly tailored to our customers and the wider public through public-private partnerships. Finally, AXA Essenti'All also helps us provide inclusive insurance solutions that will help people in cases where our traditional solutions are not suitable.

You mentioned the notion of inclusive insurance. What are you doing more broadly to strengthen society's resilience and promote a certain universality of protection in a context of increasing complexity and heightened risks?

F.G. Improving society's resilience means improving understanding, prevention, coverage and protection for all its stakeholders, both individuals and companies.

When we look at how to make our products and services more inclusive, what we are actually doing is aiming to improve the way we meet populations' needs. And the way we do it is by focusing on their fundamental needs to create products that are not only more financially accessible, but also provide the financial and material support before and after a claim that ensures we can better respond to the challenges people face.

The reason why some people decide not to take out insurance is usually a lack of financial means or awareness. In this case, simplifying and tailoring our products means reducing financial

1 AXA. (2024). Future risks report 2024: The annual review of the major risks ahead.

2 Potsdam Institute for Climate Impact Research (2023). 38 trillion dollars in damages each year: World economy already committed to income reduction of 19% due to climate change. https://www.pik-potsdam.de/en/news/latest-news/38-trillion-dollars-in-damages-each-year-world-economy-already-committed-to-income-reduction-of-19-due-to-climate-change.

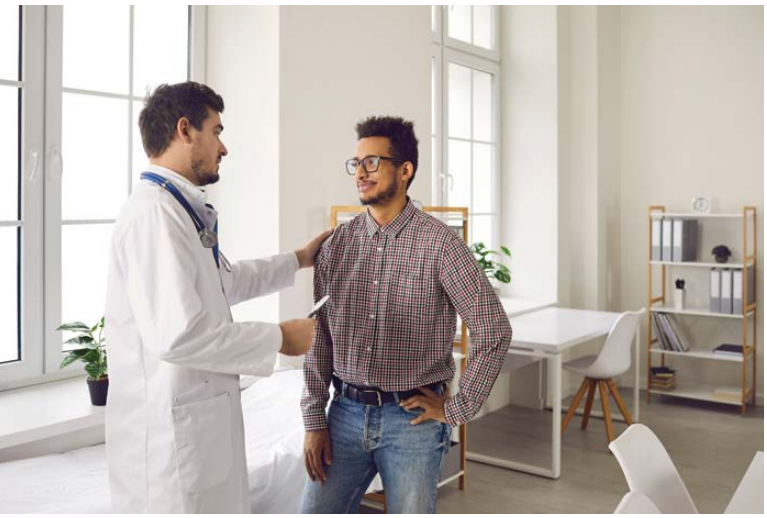
3 Stress tests under different ecological transition scenarios aimed at measuring the vulnerability of the financial sector (banking and insurance) to the physical and transitional risks associated with climate change.

4 AXA Climate. https://climate.axa/.

obstacles while also taking a more targeted approach to our distribution channels. In China, for example, the authorities of a large city developed a compulsory health insurance scheme for all residents, making the solution more accessible by pooling risks and thus preventing adverse selection.

The strength of the AXA group still lies in our ability to offer a range of products and services tailored to a vast array of needs.

In addition to universality, prevention also significantly helps strengthen society's resilience. AXA has been investing in this area for a long time, providing a different response that is fair for policyholders and insurers while reducing the potential occurrence or severity of the events covered. We also need to innovate and develop a wide range of expertise, whether in our property insurance products and the prevention of physical phenomena (e.g., floods and fire) or in our healthcare products, designed to provide our customers with dedicated services that facilitate access to treatment and improve lifestyle over the long term.



You mentioned the importance of collaboration between stakeholders. How do you collaborate with public and/or private stakeholders to help moving forward on these issues?

F.G. Faced with a subject as complex as climate change, we acknwoledge that we cannot alone tackle related phenonema. We therefore work alongside public organizations.

Public authorities play a major role in ecological transition and in preventing the risks associated with climate change by, for example, restricting development in areas highly exposed to natural hazards. We provide them with our expertise to improve all parties' understanding of these risks, and propose a joint response covering regulation, preventive action and hybrid solutions combining state and private insurance so that we can offer an adequate level of cover.

We have regular discussions with governments, regulators and private partners to challenge and fine-tune our approach.

Why did a major insurer like AXA decide to set up a corporate philanthropy fund specifically to support research?

J.A. AXA took the decision to support science because it sits at the heart of our core business. AXA's mission is to protect the real economy. The multiple risks we face are constantly evolving, making necessary to look ahead: when it comes to the risks we will have to adapt our businesses to, what will they look like in five, ten and fifteen years' time? To meet these challenges, AXA has a long tradition, particularly in Françoise's teams, of understanding and deciphering current and emerging risks, because a risk we understand is a risk we can insure against. This strong belief in science and the central role it plays in our strategy underpin the AXA Research Fund's mission. Since 2008, our fund has supported research projects in health, socio-economy, climate, and environment.

We are a patron of science with a clear philosophy. As an entirely philanthropic organization, our independent Scientific Committee looks first and foremost for scientific excellence and transformative potential of projects. We support an open, independent, cross-disciplinary – and therefore pioneer – science. We partner with researchers of the highest international level as well as promising young post-doctoral researchers from all over the world thanks to a very strict selection process based on academic standards.[5]

Secondly, we believe in making science accessible to everyone. We encourage the researchers we support to ensure their published work is freely available and share it broadly. At its core, the Research Fund echoes our conviction that scientific research contributes to progress and human well-being. It is one of the tangible elements that enables AXA to say that the science of risk is at the heart of our strategy. Faced with the explosion of misinformation, identified as one of the greatest risks to humanity by the World Economic Forum[6] in 2024, we are convinced that supporting researchers, re-explaining how science is made, and basing our decisions on scientific facts is absolutely key.

During Axa Research Fund's first 16 years, we have allocated 256 million euros to financing over 720 projects in more than 40 countries.

How does the AXA Research Fund address the impacts of climate change on human health?

J.A. We constantly have our fingers on the pulse of the world of science, society and business concerns. The impact of climate change on health emerged as a weak signal a few years ago. We are exploring areas where business is not yet active, which means that we can position ourselves as forerunners. For example, the AXA Chair in Wildfires and Climate at the Technical

5 The AXA Research Fund Scientific Committee is made up of eight internationally renowned researchers.

6 J. Boitel (October 1, 2024). According to Davos, misinformation is a major global risk, *Les Echos*. https://www.lesechos.fr/monde/enjeux-internationaux/la-desinformation-risque-mondial-majeur-selon-davos-2045484.

University of Crete in Heraklion, Greece, existed well before the recent events in Australia and Canada. And forest fires are definitely a public health issue! Worldwide, it is estimated that nearly 500,000 deaths each year are due to pollutants emitted by fires,[7] similar to the number of deaths attributed to AIDS or malaria. Some of the worst episodes of air pollution in the world are currently associated with wildfires. In Southeast Asia, around half the days of the year during periods of severe El Niño events are marked by poor air quality, with concentrations of fine particles (PM2.5) exceeding the provisional WHO targets. Studies have also shown that exposure to heavy smoke during wildfires increases the risk of cardiac arrest by up to 70%.[8] Even more disturbing is the fact that wildfires can affect the health of human beings even before they are born by reducing the birth weight of newborns.

We were also the first to support a global observatory on communicable diseases at the London School of Hygiene & Tropical Medicine. Today, dengue fever – I managed many emergencies related to this particular disease in the Medical Assistance Department – is moving from South to North because of climate change. Since 1940, four billion people in 120 countries[9] have been exposed to dengue, but we lack global databases. The observatory, developed with our support, will make it possible to anticipate dengue epidemics by up to three months in advance and counter the associated risks through concrete measures such as raising public awareness, removing mosquitoes from towns, and ensuring health systems can work on preventing new epidemics.

"Forest fires are definitely a public health issue! Worldwide, it is estimated that nearly 500,000 deaths each year are due to pollutants emitted by fires, similar to the number of deaths attributed to AIDS or malaria. Some of the worst episodes of air pollution in the world are currently associated with wildfires."

7 AXA ResearchFundLive (April 10, 2024). MasterScience: "The Battle Against Megafires" with Prof. Apostolos Voulgarakis, AXA Research Fund, YouTube video. https://www.youtube.com/watch?v=xMJCzVyo5AM.

8 Ibid.

9 Harish, V. et al. (2024). Human movement and environmental barriers shape the emergence of dengue. Nature Communications, 15(1). https://doi.org/10.1038/s41467-024-48465-0.

We also fund projects on many other related topics, such as eco-anxiety, urban adaptation and the social impacts of climate change, because we understand the importance of pre-empting these issues, particularly as an insurer. For example, we often hear about a lack of water or too much water during floods, but climate change is also affecting water quality. This is the topic of an AXA Research Chair at Vrije Universiteit Brussel in Belgium. The aim is to collate crucial monitoring data, which is currently lacking, in order to provide water management authorities with relevant information and limit health risks.

As well as funding research, what other actions is the Research Fund taking to improve knowledge and develop practical solutions to these issues?

J.A. Our second mission is to support knowledge-sharing. We train young researchers to speak to the media and use social media so that they can promote their research to a non-scientific audience. We also produce publications, masterclasses freely accessible on YouTube (such as the MasterScience series)[10] and other educational content aimed at promoting important scientific knowledge on major societal issues. Finally, we create opportunities for discussions with decision-makers and stakeholders from public and private sectors on the knowledge and management of major risks. We recently partnered with the Geneva Health Forum[11] to launch an award on the impact of pollution on human health. The University of Lausanne, which won the prize, is working on the emission of forever pollutants from urban waste management. Our aim with all these actions is to promote research on targeted subjects that have a major impact on society and the planet.

These initiatives reflect our philosophy of promoting science coalitions. I believe that we all have the same questions and by joining forces we will deliver more robust answers. For example, we have joined the UNESCO Foundations Dialogue and signed the Monaco Declaration 2023, an international coalition on oceans. It is crucial to protect the oceans because they play an essential role in the health of humans, animals and the planet. With the Research Fund and this coalition, we are encouraging all our in-house teams to take an interest in this subject and understand what it means to us. We want to raise awareness on the link between the health of the oceans and the health of life on earth. One of our key strengths is bridging the gap between research and our activities, and I am conviced that AXA can become a leader in the scientific coalition.

10 MasterScience, AXA Research Fund. https://axa-research.org/masterscience.

11 AXA (March 13, 2024). The Geneva Health Forum and the AXA Research Fund are launching the €50,000 Grand Jet d'Or de Genève prize to tackle the impact of pollution on human health. https://axa-research.org/news/the-axa-research-fund-and-geneva-health-forum-launch-50000eur-grand-jet-dor-de-geneve-award-to-address-pollutions-impact-on-human-health.

To what extent does the Research Fund's work influence AXA's decisions and actions on these issues?

J.A. The link between the research we support and AXA's core business is a key issue, all the more so for me as I come from the world of medicine and health crisis management. By bringing science out of laboratories and connecting it with the private sector, the whole of society benefits. This is why we encourage discussions with researchers, ensuring our managers and employees at AXA are better informed. We create direct links with supported researchers, universities and AXA through Learning Expeditions. Researchers come to AXA offices and AXA employees also visit the universities where the research is being conducted. Over the past six months, 1,500 AXA employees, including senior managers and employees involved in climate issues, have been in direct contact with researchers.

As mentioned above, we work on different ways of sharing this knowledge. We have media partnerships with The Conversation, a platform offering news analyses written by researchers.[12] A major advantage is that all the articles are free of copyright, which means our researchers can publish their work in national and international journals with a large readership. We are proud to see the researchers we fund sharing their expertise and raising awareness among a wide audience. Recently, Professor Carlos Perez Garcia, holder of the AXA Chair at the Barcelona Supercomputing Center, was featured in an Arte report on the Sirocco, highlighting his work on real-time modelling of dust storms and their movements. Thanks to his research, he can predict where these particles will settle within three days, information of crucial importance for people and their health.[13]

"Prevention should become an essential adjunct to insurance, making it even more important to implement joint public and private mechanisms to meet the needs of society as a whole."

One final question: what are the main challenges facing the insurance sector in the years ahead?

F.G. Our annual Future Risks Report enables us to gauge how our experts perceive the major challenges ahead, and to understand the key trends that will influence the insurance sector over the next few years.

Firstly, since risks are increasingly interconnected, insurers will seek to better understand them so they can assess impacts, anticipate, and diversify their portfolios across different categories of risks. This will allow them to manage risks sustainably while avoiding any potential overexposure to a specific region or type of risk. We also believe that protection deficits will rise, partly because public authorities will find it increasingly difficult to cover the needs of the entire population through social security mechanisms. Prevention should therefore become an essential adjunct to insurance, making it even more important to implement joint public and private mechanisms to meet the needs of society as a whole.

Demographic changes around the world, marked by both an ageing population, particularly in very mature markets, and a much younger population in emerging countries, more exposed to climate change, will also reshape customer needs.

Finally, technology, data and generative AI will have a profound impact on our operations, distribution and customer relationships, with the potential to significantly alter the competitive dynamics within the sector. These developments confirm the starting point of this interview: in an increasingly complex world, providing protection for individuals is becoming more and more essential.

J.A. The trend I'm seeing in philanthropy is to fund increasingly complex research with impacts that may even result in the creation of start-ups and spinoffs, thus extending into the real economy. There is also more research on systemic risks, i.e., risks that will lead to chain reactions throughout the system, potentially causing a general crisis in its functioning; two examples are cyberattacks and solar flares, which are still underestimated. For insurers, these risks can spread across various sectors and product lines, more complex to manage, as observed during the COVID crisis.

The Research Fund's mission is increasingly important: we need to share knowledge and encourage decision-making based on science, whether internally at AXA or externally with our customers, partners, and civil society. In the current climate of uncertainty and political tension, we must emphasize the extremely positive role of science and explain how it is done. Creating and disseminating scientific knowledge aids decision-makers and experts, who can then create coherent strategies with products adapted to future challenges based on precise knowledge of the issues we face.

12 The Conversation, Axa Research Fund. https://theconversation.com/fr/topics/axa-research-fund-francais-48666.

13 Elena Sender, Alexis Barbier-Bouvet, Arte documentary (August 2024). *Grands vents – Sirocco, le souffle du desert [High Winds – Sirocco, the breath of the desert].*

Imagining the future of prison administration in response to the climate emergency

Julien Sipra, Head of the Ecological Transformation Section at the Laboratory for Sustainable Development, Innovation, and Best Practices of the Directorate of French Prison Administration
Anouk Mousset, Project leader for future studies and ecological transformation at the Laboratory for Sustainable Development, Innovation, and Best Practices of the Directorate of French Prison Administration

***The Sustainability, Innovation and Best Practices Laboratory** at the Directorate of French Prison Administration is a public innovation laboratory. It focuses in particular on implementing ecological transformation within the French prison administration which, answering to the Minister of Justice, participates in the enforcement of judicial decisions, social reintegration of people entrusted to it by the courts, prevention of reoffending, and public safety.*

Prison authorities around the world are already confronting the direct and indirect consequences of climate change. Heatwaves, coastal and inland floods, storms, droughts and swelling-shrinking of clay soils are the main climate hazards identified as posing risks to French prisons. After a brief overview of the possible impacts of climate change on prisons, this article presents actions taken by the prison administration's laboratory to co-create a much-needed strategy for transformation that seeks to adapt to climate change as well as mitigate its impacts. The strategy, created by examining future environmental trends, aims to anticipate and suggest actions for different timescales: acquiring data and producing knowledge; visualizing what future prisons might look like and possible trajectories for their transformation; organizing collective discussions about prisons to establish a shared vision, and supporting appropriation of the results to assist in decision-making and action-taking.

INTRODUCTION

In 2024, over 250,000 people[2] are supervised by the prison services, which employs close to 42,000 staff. At the time of writing, 78,397[3] people are imprisoned. As well as prison staff, prison premises host a great number and variety of other users, including healthcare workers and teachers, trainers, arts teachers and religious representatives, employees of companies involved in running the establishments, prisoners' families and friends, and lawyers.

But climate change has, and will continue to have, direct impacts on the physical and mental health of all the people who live and work in prisons. These effects will also impact the prison administration's missions, how it carries them out, and the infrastructures and environments it relies on.

1 Public innovation laboratories. Interministerial Directorate for Public Transformation. https://www.modernisation.gouv.fr/diffuser-linnovation-publique/les-laboratoires-dinnovation-publique.

2 Close to 170,000 people are subject to open custody, meaning that they are persons awaiting trial or already convicted who are supervised outside the prison environment by the social insertion and probation services. Prior to judgement, they may be subject to judicial control with or without electronic surveillance. After judgement, they may be sentenced to public service work, home detention under electronic surveillance, etc. Open custody can also entail setting up training or discussion groups on specific topics such as addictions or spousal violence.
Source: Ministry of Justice – Justice in France – Open custody.

3 Ministry of Justice. (2024, August 1). Imprisonment numbers, key indicators.

Now that the need for transformation has been acknowledged,[4] what is the best way to jointly construct a strategy for transformation that takes sufficient account of future threats, reflects the specific nature and constraints of the prison environment, includes all stakeholders, and adopts an approach rooted in adaptation and mitigation?

DETERMINING THE IMPACTS OF CLIMATE CHANGE ON PRISON ESTABLISHMENTS AND THEIR USERS

Prison authorities around the world are already confronting the direct and indirect consequences of climate change and its specific impacts on prisons.[5] In France, risks and impacts related to climate hazards facing prisons, which are located in all parts of the country, vary in nature and degree of severity according to the geographical location, exposure, and specific vulnerabilities of each establishment.

A few key details about penitentiary establishments

There is not one prison, but many prisons
Although they may share a functional program, prisons are very diverse in terms of where and when they were built, their size, capacity, architecture, internal organization, and detention conditions.

For example:
- **Gap jail (37 places) is housed in a building that dates back to 1790;**
- **Caen-Ifs prison (691 places) entered service in 2023;**
- **Mauzac detention center (332 places) entered service in 1986 and comprises living quarters made up of 21 separate houses.**

Different detention conditions
Detention conditions vary according to the type of prison establishment: jail (provisional detention and short sentences), detention center (sentences longer than two years), prison (long sentence, suitable for certain prisoner categories), restricted freedom centers, establishments for minors, and halfway houses.[6]

Public management, delegated management
A series of support activities and services relating to penitentiary operations, other than management, registrar,[7] surveillance, and overseeing social insertion and probation, may be entrusted to a private operator or consortium of operators. These are essentially care services, and maintenance and cleaning services.

At this stage of the laboratory's work, heatwaves, coastal and inland floods, storms, droughts and swelling-shrinking of clay soils are the main climate threats identified as risk vectors French prisons are exposed to. Technological hazards related to human activities (industrial, nuclear and biological), some of them amplified by climate hazards, also increase the vulnerability of penitentiary establishments. Since these hazards are linked to the prisons' locations, imagining how they might adapt necessarily requires adjustments to the overall diagnosis by taking account of local parameters and phenomena in every case.

There are also variations in the **vulnerabilities** of prison establishments, as a function of:

- a set of characteristics specific to each establishment: year of construction, how rundown it is, architectural layout, category of security arrangements, detention conditions, prisoner capacity, occupancy rate, management method, staff availability, etc.
- a set of external factors: supply of energy, water and food (three daily meals per detainee), and access to the road network (primarily for access to courts and medical services, staff journeys, etc.).

Cross-referencing climate hazards with vulnerabilities makes it possible to identify **potential risks and impacts** that climate change will have on prison services, ***(Figure 1)***.

This means that any examination of how to adapt prison establishments in response to climate change involves dealing with a complex and highly variable system, its scale made all the greater by the diversity of the prisoner population. Prisoners have many different profiles, habits, behaviors, desires and needs that can be at odds with each other. An additional complexity lies in the fact that the prison population is very diverse in terms of age, gender, state of health, social, financial and cultural background, etc.

Prisons have to adapt, just like any other infrastructure. This effort to adapt prison services to climate change entails an approach that combines an overall vision with local characteristics, meaning the ability to set an overarching trajectory for transformation and to translate it into action plans tailored to the specific situation.

Given this goal, and challenge, which methods should be adopted to support the adaptation of prison services to climate change and roll out their ecological transformation?

ADAPTING AND TRANSFORMING PRISON ESTABLISHMENTS IN RESPONSE TO CLIMATE CHANGE: FROM METHODS TO ACTIONS

To support the adaptation of prison services to climate change and roll out their ecological transformation, the laboratory conducts several complementary approaches simultaneously, all of them ultimately aimed at moving to the action phase.

From environmental forecasting to taking action

The laboratory's environmental forecasting approach is designed to produce knowledge, suggest actions to take for different timescales, organize a collective conversation, encourage decision-making, and offer visions for the future of the prison administration based on transformation trajectories shared by all actors involved.

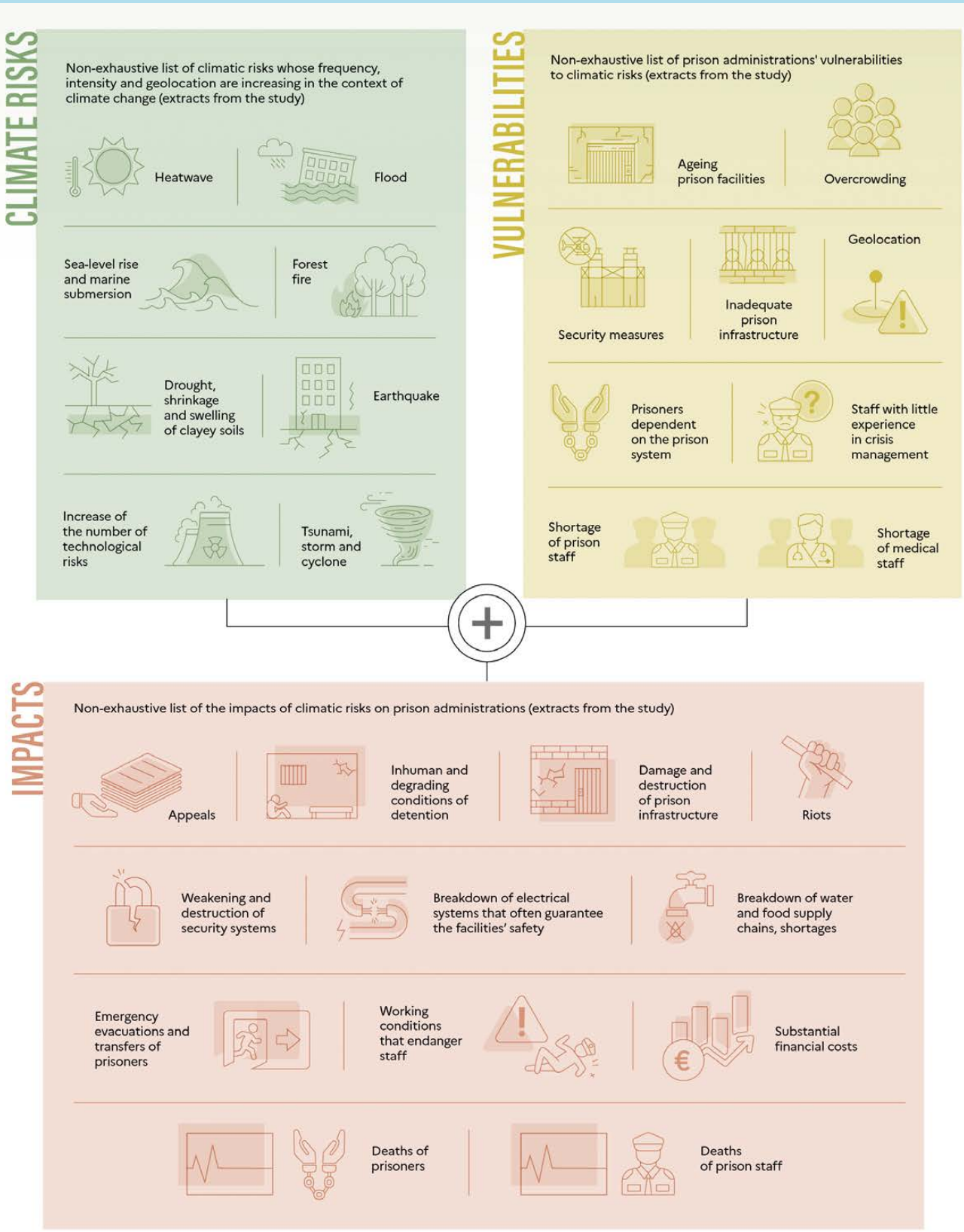
4 National plan for ecological transformation (2024). Interministerial Directorate for Public Transformation. https://www.modernisation.gouv.fr/presse/plan-de-transformation-ecologique-de-letat.

5 For example, "the Committee against Torture and the European Court of Human Rights have both stated that any temperature beyond the median, be it high or low, is considered inhuman and degrading treatment. Overcrowding further exacerbates hotter temperatures. This combination of problems can lead to higher rates of violence and suicide." Source: Prison Insider. (2024, March 12). If you neglect your prisons, you do that at your own peril. Prison Insider. https://www.prison-insider.com/en/articles/if-you-neglect-yourprisons-you-do-that-at-your-own-peril.

6 For more information, see: Guide to detention. Ministry of Justice. https://www.justice.gouv.fr/justice-france/prise-charge-personnes-condamnees-ou-prevenues/prise-charge-detention.

7 The primary responsibility of the prison registrar is to understand prison law, penal law and procedures, and how to use specialist software, including for managing prisoners' status.

Figure 1: Climate change: risks, vulnerabilities and impacts for prison administrations



Source: Prison Insider – Prison Administration Responses to the Climate Crisis.
Study financed by the French Directorate of Prison Administration, July 2023 to February 2024 / Graphic design: Elise Milonet.

Methodology: production of knowledge, exploratory exercises and collective intelligence

Based on the complementarity between user expertise[8] and professional expertise[9] in terms of studying climate change, the approach centers on three phases, deployed from 2023 to 2027.

1) The scientific phase produces or deepens knowledge about the impacts of climate change on prison services. Its main features include:

- a ***comparative study*** looking at how prison authorities around the world take account of climate change;[10]
- a ***retrospective study***;
- a ***literature review***;
- ***immersive visits and enquiries in the field***;
- an ***analysis of vulnerabilities*** to climate hazards.

2) The forecasting phase sets out to construct and describe threat scenarios as well as explore what a desirable future for the prison administration might look like. To deliver these results, this phase includes:

- ***scenarios*** using data from the scientific phase to define hypotheses for change according to a range of different timescales;
- ***impact assessments for the scenarios***;
- ***production of narratives*** and ***artifacts***: manifestations of the scenarios produced to transform them into narratives.

3) The activation phase aims to draft a strategic and operational roadmap. This phase is divided into three main stages:

- ***retro-projective analysis of the scenarios***: constructing transition trajectories relating to each of the chosen scenarios; imagining the various stages needed to achieve them;
- ***choice of a trajectory***: defining a desirable transition trajectory for prison administration services;
- producing and implementing an ***action plan***.

This comprehensive environmental forecasting approach is multidisciplinary. It has to be put into operation in very close collaboration with the people who use prisons on a daily basis, prison service stakeholders,[11] and ultimate decision-makers. This is one of the keys to successfully producing a transition trajectory that is desirable and deliverable.

An example in practice: heatwaves in prison establishments

Summer is often a relatively complex time of year for prison establishments: lessons and workshops run by the national education service cease during school holidays, there are fewer activities offered by outside providers, and families and friends are not always able to come during visiting hours. The combined effect of these factors means that time seems to pass more slowly than at other periods in the prison year. High temperatures are an additional factor directly impacting the conditions under which prisoners work and are detained, leading to countless problems in prison establishments: mental and physical health problems, an uptick in staff absenteeism and sick leave, an increase in the number of prisoners requiring off-site medical attention, a rise in tension and violence, vulnerability of IT systems, difficulties in accessing water, etc.

"High temperatures are an additional factor directly impacting the conditions under which prisoners work and are detained, leading to countless problems in prison establishments : mental and physical health problems, an uptick in staff absenteeism and sick leave, an increase in the number of prisoners requiring off-site medical attention, a rise in tension and violence, vulnerability of IT systems, difficulties in accessing water, etc."

To tackle these issues, since summer 2023 the laboratory has been running a forecasting project looking at heatwaves in detention. The project encompasses a research phase, forecasting phase and activation phase. The first two phases are run in collaboration with Laboratoire des Déviations Ecologiques and Strategic Design Scénarios. The joint project team is made up of specialists in design, design fiction, and cognitive science.

The project team began the research phase with a retrospective study to document literature on heatwaves, a comparative study of prisons around the world,[12] a review of literature on the topic in France and internationally, and enquiries in the field. Learnings from this phase were then used to map the vulnerabilities to heat of prison establishments.[13]

Consequences of heatwaves in prisons around the world

Extract from the study Prison Administration Responses to the Climate Crisis, Prison Insider.[14]

"Numerous studies have highlighted the consequences of high temperatures on the health of prisoners. Some have found a correlation between extreme heat and increased cases of suicide in detention. In Louisiana (United States) between 2015 and 2017, the number of people placed under surveillance due to the risk of suicide increased by 36% when the temperature was above 32.2°C [...].[15] In addition to impacting rates of self-inflicted violence, heat tends to result in increases in other acts of violence in prison. A study conducted on the facilities in Mississippi (United States) indicates that days with temperatures of over 26°C, with no way to mitigate the heat, result in 44[16] additional acts of violence per year among the prison population, a 20% increase."

8 User expertise corresponds to day-to-day expertise gained through lived experience.

9 Professional expertise is gained through more advanced skills and insights, reflecting a high degree of knowledge.

10 Prison Insider. (2024). Prison administration responses to the climate crisis: A study conducted by Prison Insider and ordered by the French Directorate of Prison Administration (July 2023–February 2024). Prison Insider. https://www.prison-insider.com.

11 Employees (prison service, medical, education service, delegated manager, etc.), friends and families of detainees, members of the justice system, actors from civil society, researchers, etc.

12 Prison Insider. (2024). Prison administration responses to the climate crisis: A study conducted by Prison Insider and ordered by the French Directorate of Prison Administration (July 2023–February 2024). Prison Insider. https://www.prison-insider.com.

13 The results of this work have not been made public at this stage.

14 Prison Insider. (2024). Prison administration responses to the climate crisis: A study conducted by Prison Insider and ordered by the French Directorate of Prison Administration (July 2023–February 2024). Prison Insider. https://www.prison-insider.com.

15 Inside Climate News. (2023, August 18). Suicide watch incidents in Louisiana prisons spike by nearly a third on extreme heat days, a new study finds. Inside Climate News. https://insideclimatenews.org/news/18082023/louisiana-prisons-heat-suicide-study/

16 Mukherjee, A., & Sanders, N. J. (2021). The causal effect of heat on violence: Social implications of unmitigated heat among the incarcerated (NBER Working Paper No. 28987). National Bureau of Economic Research. https://www.nber.org/system/files/working_papers/w28987/w28987.pdf.

Subsequently, all the material collected was used to create a design-fiction workshop to jointly construct other futures capable of mitigating the impact of heatwaves on France's prisons. These forecasting workshops are now open to various groups: detainees, prison staff, employees, civil society, etc. Feedback gathered during workshops is used to identify topics to work on and ensures enhanced understanding of the topic and potential blind spots. The working topics are then explored during the activation phase via specific working groups.

At this stage of the project, a number of working groups have already been identified, including:

- action research looking at how to combat heat islands in exercise yards;
- a working group shared across several organizations (gendarmes, Paris fire service, etc.) examining changesto personal protective equipment;
- action research looking at changes in how cells are fitted out to improve adaptation to winter and summer temperatures;
- a focus group examining changes to the typical operating model of a prison during a heatwave.

Led by the laboratory, these working groups are intended to create bridges between research and the rollout of concrete actions in prison establishments.

Supporting projects initiated by individual prisons

The laboratory also supports the rollout of concrete projects initiated in the field by different structures and prison service agents. Support can take the form of funding or assistance with technical or logistical aspects, and may concern experimental projects with a high potential for transformation, as well as more everyday initiatives that provide a solution to a clearly identified problem.

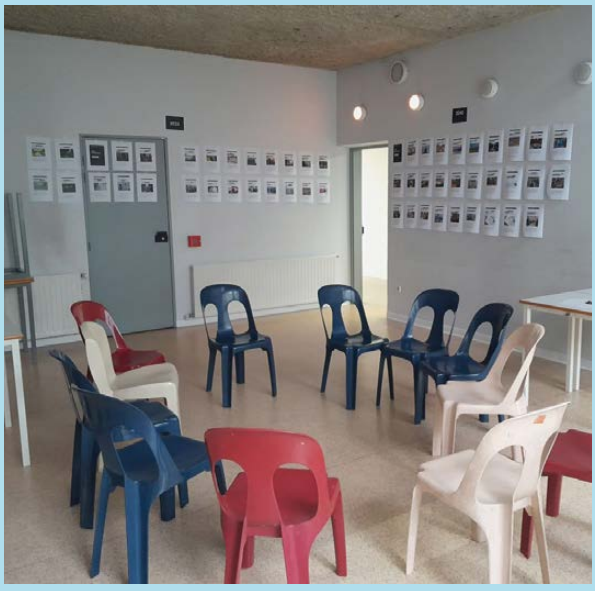
> *"Support can be provided to an extremely broad range of projects: evaluation of greenhouse gas emissions; creation of ornamental and vegetable gardens; installation of equipment designed to reduce the environmental footprint; etc."*

In this way, support can be provided to an extremely broad range of projects: evaluation of greenhouse gas emissions; creation of ornamental and vegetable gardens; installation of equipment designed to reduce the environmental footprint (e.g., prison composting stations, rainwater collection tanks, collection and recovery of cigarette butts, electric cycles and electric-vehicle charging stations, etc.); plantings in certain areas to promote biodiversity and combat heat islands; halting the use of pesticides to maintain green spaces; installation of bee hives; conducting workshops to raise awareness among detainees, and training prison service directors in ecological challenges and creating digital tools.

An inside-outside citizens' project:
Moving Toward Paris 2050 at La Santé Prison

In the autumn of 2023, the laboratory supported a teacher from La Santé prison in Paris to enable a group of detainees

The workshop starts by introducing scenarios illustrating the impacts of heat domes on French prisons in a few years' time. Participants are encouraged to invent and describe a world where actions have been taken to ensure that the scenarios described will not recur or get worse. To support their reflection, inspiration cards are provided to them - some examples are presented below.



Inspiration scenario (season 2)

Topic(s): internal layouts, cooling system

What if there was a system to create shade and limit sunlight entering cells?

☐ *Invented scenario*
☐ *Generic illustration*

On its south-facing side, the prison is forced to invest in a system to protect people from sunlight that makes conditions unbearable for detainees in their cells. This flexible canopy solution is easy to fit and designed to improve conditions inside the building without compromising security.

Inspiration scenario (season 2)

Topic(s): operation

What if there were more frequent staff changeovers during a heatwave?

☐ *Invented scenario*
☐ *Generic illustration*

Violence in prison increases after a heatwave lasting several days, among detainees as well as staff, who have trouble staying calm. Shift lengths are reduced to allow staff more time to rest.

Some of the items produced by detainees that were exhibited at Pavillon de l'Arsenal

to take part in Moving Toward Paris 2050, a project run by the city council that culminated in an exhibition at the Pavillon de l'Arsenal.[17] The laboratory created and led a series of forecasting workshops where participants were invited to create fragments of a future where the city of Paris had adapted to climate change. This project, which examines larger issues than simply the future of prison services under the new climate realities, gave participants a chance to discuss and construct a critical viewpoint and contribute to thinking about how society can adapt, offering their personal visions of possible futures that were exhibited to the general public alongside proposals from other private individuals and groups. This project illustrates another approach to using forecasting adopted by the laboratory.

CONCLUSION

Although the laboratory's projects are part of the general field of action defined by state ecological planning, they are rooted in the close attention paid to weak signals and actively listening to the experiences, needs and desires of people who live and work in prison establishments. These actions have to find their place amidst day-to-day practices and expertise born of hands-on experience. The idea is to shift from a top-down method to a collaborative approach.[18] In terms of efforts to combat the effects of environmental and climate change and promote ecological transformation, responsibility is shared between the different levels (prison establishments, regional management and national administration), which makes collaboration indispensable. One of the laboratory's roles is to act as a catalyst or trigger, pushing these issues up stakeholders' agendas and giving them a chance to discuss them, informed by the data its work generates. Activating all these levers is no simple task. It takes human and financial resources, time, attention, and action. While these questions can appear hard to grasp because they are too technical, distant or disheartening, creating narratives is proving to be a promising mechanism that allows everyone concerned to feel involved and play a role in constructing government policy.

By developing this forecasting approach, the laboratory offers a temporary space within which new ways of thinking become possible, allowing people to think in terms of "and if... then..." This act of exploration allows people to step outside the hard-to-escape present and to return there with more insight and agility, reconnecting with the concepts of long-term timescales, heritage, dependencies, and sustainability.

It offers a horizon. The greater the number of people involved in deciding which paths to take to reach it, the safer, more peaceful and profitable those paths will be.

17 Moving Toward Paris 2050 | Exhibitions | Pavillon de l'Arsenal (pavillon-arsenal.com).

18 Escach, N. (2024, July). Forecasting for ecological action: Toward other territorial narratives [Symposium presentation]. Symposium, Cerisy, France.

Water services and climate change:

Winning innovations delivering greater resilience

Geneviève Leboucher, Senior Vice President, Municipal Water at Veolia
Sandrine Oberti, Director of Scientific Valorization – DEST (Veolia Research & Innovation)

Geneviève Leboucher, a graduate of the Ecole Polytechnique, AgroParisTech and the Collège des Ingénieurs, has 25 years of experience in water services and sanitation. Her career in wastewater and water management has included roles in business units, operational management, technical management, R&D and marketing. Since 2020 she has occupied the post of Senior Vice President, Municipal Water at Veolia, where she oversees the municipal water segment and develops solutions for tackling environmental challenges, particularly in relation to preserving resources and adapting to climate change.

With a doctorate in analytical chemistry, Sandrine Oberti began her career 25 years ago as technical director at OFIS, the French Office for Sanitary Engineering. Since 2004 her career has focused on leading research and innovation projects for water resources management, disinfection, water analysis, resilience and sustainable cities. Today, as Director of Scientific Valorization at DEST (Veolia's scientific and technological expertise department), her mission centers on promoting scientific excellence by making research results accessible to all.

Climate change places our water resources under enormous pressure. Depending on the particular region, it leads to increasing shortages, severe droughts and ever-growing pressure on essential infrastructure. Water services have to evolve if they are to deal with these urgent challenges. Innovation plays a crucial role in this transformation: advanced leak detection techniques, proactive management of corrosion, and reuse of treated wastewater are all key solutions for optimizing how this precious resource is managed and guaranteeing a reliable supply.

And the challenges don't end there. To stave off water stress and preserve this vital resource, there is an urgent need to adopt alternative strategies such as groundwater recharging, forward planning to anticipate vulnerabilities in drinking water production systems triggered by climate change, and rolling out frugal solutions that use less water. It is equally vital that sewer systems are reinforced so they can better deal with heavy rainfall and pollution.

Read on to discover how these solutions are transforming water management and tackling climate challenges while also working to protect public health.

INTRODUCTION

WATER: A MARKER OF CLIMATE CHANGE

Climate change is disrupting water cycles, leading to extreme weather events such as droughts, flooding, storms and coastal flooding. These disruptions also have a direct impact on public health, particularly by degrading water quality, which in turn favors the propagation of water-borne diseases. Around 36% of the global population already lives in a region where water is rare, and according to the IPCC this could climb to 40% by 2040.[1] The impacts of these events are amplified by urbanization and migration, which increase the need for water

1 Intergovernmental Panel on Climate Change (IPCC, 2021). IPCC Sixth Assessment Report: Climate Change 2021 – The Physical Science Basis. Cambridge University Press.

and overload existing infrastructure. An instructive figure to bear in mind is that 90% of natural disasters are linked to water[2], due to resource scarcity or extreme events.

ADAPTATION AND MITIGATION STRATEGIES: BOOSTING THE RESILIENCE OF WATER SERVICES

Operators of water services[3] face a major challenge that centers on managing chronic water shortages and very heavy rainfall while maintaining water quality to protect public health. They have to anticipate crises, ensure continuity of services, and adapt their infrastructure while simultaneously making plans for long-term solutions. This critical challenge facing operators and regional authorities requires them to constantly re-evaluate systems and adapt investment plans. This article explores the strategies used to boost the resilience of water services, with a special focus on challenges relating to water stress and flooding.

Without water no organism, be it human, animal or plant, can survive. However, its availability and quality are threatened around the world by climate change, a reality that has major repercussions on public health. Rising incidences of drought and flooding, persistent obstacles to rolling out WASH (water, sanitation and health) infrastructure to all corners of the planet, and the growing vulnerability of infrastructure to climate disasters are forcing water operators to revise how they manage their water resources so they can maximize its availability. Close to one in eight Europeans lives in an area potentially at risk of flooding, while 30% of people living in southern Europe have to deal with permanent water stress.[4] These phenomena demand immediate solutions: reduction of leaks, sustainable infrastructure management, adoption of less resource-intensive water management solutions, and interconnection between networks and wastewater reuse. As of right now, operators need to prepare for the future by adapting their drinking water production systems, for example, by planning solutions based on groundwater recharging to guarantee a resilient supply source.

NEW TECHNOLOGIES FOR TRACKING AND REPAIRING WATER LEAKS

Fighting water wastage is a priority and the first step is detecting and repairing leaks. Globally, on average leaks account for 30% of the volume of drinking water produced, rising to as much as 50% in certain aging networks. This massive wastage compromises our water resources and leads to much higher costs.

To reduce leaks, water operators use a mix of conventional and innovative technologies, such as acoustic correlation, which uses analysis of the speed of sound to locate leaks, and tracer gas to find faults in pipes. Acoustic sensors detect noise generated by leaks, making it possible to locate them with a high degree of accuracy, even in complex environments. In 2023, sensors resulted in a 15% cut in water losses in the Barcelona network, as well as a 20% fall in leaks over five years in the network used for Bordeaux, France. However, major leaks sometimes go undetected.

Innovative new techniques are being tested: in France a project called Echoleaks uses acoustic sensors and artificial intelligence to create a “digital ear” to assess the severity of leaks, quantify the volumes of water lost, and prioritize the order of repairs. Other solutions are already in operation, such as LeakTracker from Alcom Technologies, which uses a smartphone to detect leaks in less than 60 seconds, and sniffer dogs trained to spot the presence of traces of chlorine that provide an effective alternative in several regions.

REDUCING CORROSION TO MAKE WATER NETWORKS MORE SUSTAINABLE AND MORE RESILIENT

Aging infrastructure, particularly pipes, is very vulnerable to climate change impacts such as flooding and drought.[5] The main cause of failure is not age but corrosion, which weakens networks and can lead to breakages and leaks.

Corroded water pipe

If corrosion is not proactively managed, metal pipes will degrade at an accelerating rate, increasing maintenance costs and leading to interruptions in drinking water distribution. Even when water meets applicable standards, if it is corrosive – or the surrounding soil is corrosive – it can weaken networks, making them more vulnerable to extreme climate events.

2 The human cost of weather-related disasters 1995-2015. (November 24, 2015). UNDRR. https://www.undrr.org/publication/human-cost-weather-related-disasters-1995-2015.

3 **Water and sanitation services** are responsible for distributing drinking water to water service customers as well as collecting and treating the wastewater these customers produce.

4 European Environment Agency. (2024). Climate health risks posed by floods, droughts and water quality call for urgent action.

5 OECD. (2024). Infrastructure for a Climate-Resilient Future. OECD Publications. https://doi.org/10.1787/a74a45b0-en.

A research program called CROWN (Corrosion & Reliability Optimization of Water Networks) provides a proactive approach to tackling this issue. By using **corrosion coupons** to measure the speed of pipe deterioration, the critical zones that are corroding the fastest can be identified. This then allows **adjustments to the water's physicochemical profile**, via remineralization treatments or optimizing chemical dosages at the treatment works.

This approach reduces the corrosiveness of the water, extends the service life of infrastructure, and guarantees a reliable water supply while also increasing the resilience of water services in the face of climate events.

The research project has been successfully rolled out in several areas in France where Veolia is contracted to provide water services. In Sablé-sur-Sarthe it slowed the speed of corrosion by up to 50% in certain areas.

WATER SUFFICIENCY: EVERYBODY IS INVOLVED!

Adopting sustainable water-use habits is crucial to relieving pressure on resources used to produce drinking water. There are an array of solutions, from technical to price-based, including remote meter readings.[6]

FLOODING: URBAN FLOOD SOLUTIONS

As well as shortages of water and increasingly frequent droughts, we are also witnessing periods where there is **too much water. Flooding**, more frequent and severe as a consequence of climate change, poses a major challenge to water services. The increase in very heavy rainfall, rising sea levels and ever-growing urban spread combine to accelerate water run-off and multiply the risks of flooding. And flooding adversely impacts water quality by transporting pollutants and sediments and placing enormous strains on sewage infrastructure. To strengthen the resilience of water systems in the face of flood risks, it is essential to implement solutions that combine risk management with sustainable infrastructure.

These include **hydro-meteorological management** to monitor and predict weather conditions in real time, making it easier to react quickly in the face of extreme events. For example, the town of Dinard in France uses hydrodynamic valves to limit spillage during heavy rain, leveraging the storage capacity of its collection basins. In the city of Nimes, a plan known as AR3ENE combines early warnings, obtained by analyzing past events and looking at hydrometeorological parameters, with constant surveillance to organize preventive measures and targeted emergency interventions. The town of Tønder in Denmark, which has experienced severe flooding during the past decade caused by rising sea levels, has set up a dynamic system to manage its rain water collection and storage installations in real time. The system uses artificial intelligence and can provide authorities with as much as six hours' notice of imminent flooding.

"The increase in very heavy rainfall, rising sea levels and ever-growing urban spread combine to accelerate water run-off and multiply the risks of flooding."

Equally, **dynamic management of wastewater networks** also helps prevent spillages during heavy rain. For example, Kolding in Denmark uses a real-time surveillance system (Hubgrade Performance Sewer) to optimize wastewater flows, avoid spillages and reduce energy costs.

In some cases a more comprehensive approach is needed, including **flood forecasting and systems to warn local people directly**. In the Bièvre valley, near Paris, an early-warning system warns residents in the event of a flood risk based on forecasts that are updated every five minutes, a three-hour lead-time and a 2D hydraulic model that displays at-risk zones in real time. Since it was set up the system has been used to manage floods comparable to those experienced in the 1980s, but with far less damage incurred.

Other solutions, based on **collecting and storing rainwater** in temporary accumulation zones, provide innovative approaches to attenuating the risk of flooding. In Alicante, in Spain, El Marjal city park is a 3.6-hectare site that includes green spaces and two ponds that can hold up to 45,000 cubic meters of rainwater. This artificial wetland supports local biodiversity as well as offering local people a recreational area.

Finally, in cases where preventive measures prove insufficient,**crisis management solutions** become crucial for maintaining drinking water supplies and restoring wastewater infrastructure in the aftermath of an extreme climate event. In 2019, storm Alex

6 For more details, please see Sufficiency: challenges for Veolia Water France, an article in the 2024 issue of FACTS on the social and economic challenges of sufficiency: Source : Veolia Institut. (2024). Sufficiency: Challenges for Veolia Water France. In FACTS: Social and economic challenges of sufficiency (Edition 26). https://www.institut.veolia.org/sites/g/files/dvc2551/files/document/2024/10/Veolia_FACTS_26_2024_GB_Web_Interactif_0.pdf.

caused widespread destruction in the Alpes-Maritimes region of France, with exceptional volumes of rainfall, flooding, partial destruction of several villages and considerable loss of life. An operational center was set up in Breil-sur-Roya to coordinate repair work, including laying pipes for drinking water supplies and connecting to water sources, as well as the use of mobile sewage treatment units to restore essential services as rapidly as possible.

These crises illustrate the importance of having a rapid response capability as well as underlining the need to adapt drinking water production to anticipate future needs in the light of new climate challenges.

ADAPTING DRINKING WATER PRODUCTION IN THE FACE OF CLIMATE CHALLENGES

Climate change leads to greater scarcity of water resources, rising temperatures, flooding, and lower water quality, which is a threat to drinking water production. There is now a vital need to adapt water systems, particularly in regions afflicted by water stress, as required by France's **2021 Resilience and Climate Act**.[7]

If they fail to adapt, regions risk experiencing **water shortages, high operating costs**, and **weak infrastructure**, threatening continuity of service. This is precisely the problem facing the **Toulouse metropolitan authority**, which has entrusted management of its drinking water to SETOM, a Veolia company, tasking it to forecast impacts likely to affect the city in the period 2035-2050.

To meet these challenges, teams from Veolia carried out a study to identify the **system's vulnerabilities according to different climate scenarios**, evaluate risks facing drinking water production, and improve the scaling of future infrastructure. The diagnosis of Toulouse's vulnerability centered on three areas: analysis of previous climate events, examination of the vulnerability of its infrastructure, and an assessment of the financial impacts (operating costs versus capital investment costs). This approach will be rolled out at other sites to increase the robustness of climate risk assessment and provide adaptation recommendations that are more detailed.

"Faced with droughts, water shortages and water stress, reuse of treated wastewater offers an important alternative solution for preserving freshwater resources. Yet in France less than 1% of wastewater is reused, compared to countries such as Israel where the reuse rate is as high as 90%."

WATER IS FAR TOO PRECIOUS TO BE USED JUST ONCE!

Faced with droughts, water shortages and water stress, **reuse of treated wastewater** offers an important alternative solution for preserving **freshwater resources**. Yet in France less than **1%** of wastewater is reused, compared to countries such as Israel where the reuse rate is as high as **90%**. While the technologies for treating wastewater to make it suitable for reuse are well known to water operators, uptake in France continues to be hampered by **regulatory restrictions**.

Bearing in mind what is at stake, research and innovation have played a key role over the past decade, demonstrating the absence of health risks posed by wastewater reuse solutions as well as optimizing their implementation. Standout projects include **Irri-Alt'Eau**, which tested the benefits of micro-irrigation for vines using treated wastewater, and **SmartFertiReuse**, combining wastewater recovery with optimized management of fertilizers in agriculture.

These advances have resulted in the development of a safe and reliable solution: **ReutBox**, which makes reused wastewater accessible for the uses permitted by France's public health rules.

Reutbox is a **plug & reuse** system capable of reusing anywhere from **5 to 20 cubic meters** of wastewater every hour. Already in use at over **30 treatment plants** in France, the technology has resulted in annual drinking water savings of **15,000 cubic meters in Narbonne** and **18,000 in Rodez**. The recycled water covers the plants' **internal water needs**, for tasks such as preparing polymers, cleaning equipment and, more infrequently, cleaning premises or watering green spaces without having to apply for official authorization. In configurations where it meets type-A quality criteria and with the appropriate authorizations, it can also be used to cover **external needs** locally, such as high-pressure water jetting or street cleaning.

7 Légifrance. (2021). Act no. 2021-1104, dated August 22, 2021, on fighting the climate crisis and strengthening resilience to combat its effects. https://www.legifrance.gouv.fr/jorf/id/JORFTEXT000043956924.

GROUNDWATER RECHARGING: AN EFFECTIVE SOLUTION FOR COMBATTING WATER SHORTAGES

Around 95% of freshwater comes from groundwater reserves, as does a large part of the water we consume (25% to 40%).[8] However, disruptions to the natural water cycle caused by climate change compromise the **natural process of groundwater recharge from rainfall**. According to the IPCC, there may be a 10% to 30% reduction in groundwater recharging around the world by 2070,[9] leading to problems such as finding a balance between the availability and need for water and water-related conflicts.

Southern Europe is badly impacted, **Spain** in particular, with **60%** of the country suffering from a water deficit and water reserves in 2022 at their lowest levels in **25 years**. One interesting response to this critical situation is an initiative to **infiltrate reclaimed wastewater to groundwater** so they can be recharged. This is the goal of **LIFE Matrix**, a **36-month project** co-financed by the European Union that aims to demonstrate the technical, environmental and health feasibility of **managed groundwater recharge** using reclaimed water in the **Costa del Sol**.

The planned treatment techniques combine **physicochemical and biological processes** with **nature-based solutions**[10] such as artificial wetlands. Thanks to these advanced treatments, wastewater will be transformed into **very high quality water,** suitable for reinfiltration into groundwater. Concretely, **50,000 cubic meters** of recycled wastewater will be used to recharge groundwater in the **Costa del Sol**, delivering a **15%** increase in available underground water reserves.

Another initiative, **artificial groundwater recharging**, consists of compensating for falling groundwater levels by infiltrating water from alternative sources, such as rivers, into groundwater. During high-water periods, excess water is re-routed and infiltrated to boost groundwater levels. This technique offers an effective alternative to dams by limiting the evaporation and eutrophication of surface waters. Widely used in Australia and California, but far less in France, the technique regenerates groundwater, limits evaporation, and prevents salt contamination of coastal groundwater.

A trial run by the Mining and Geological Research Bureau uses excess water drawn from the River Garonne in springtime to refill alluvial groundwater. The water temperature of 14-15°C helps combat warming of the river. This project forecasts a deficit in excess of a billion cubic meters of water by 2050, highlighting the importance of this solution for managing water stress. In addition to regenerating groundwater reserves, the technique mimics the natural infiltration cycle, limits evaporation and eutrophication, and contributes to biodiversity. However, it can alter hydrological balances and presents pollution risks if the quality of the infiltrated water is not properly controlled.

"Disruptions to the natural water cycle caused by climate change compromise the natural process of groundwater recharge from rainfall. According to the IPCC, there may be a 10% to 30% reduction in groundwater recharging around the world by 2070."

NATURE-BASED SOLUTIONS AS KEY COMPONENTS IN WATER SERVICE RESILIENCE IN THE FACE OF CLIMATE CHANGE

Nature-based solutions provide an approach that uses natural processes to tackle environmental and climate problems. For example, restoring wetlands makes it possible to recharge groundwater, prevents flooding and promotes biodiversity. Similarly, making cities greener and more permeable helps them absorb rainwater, which in turn reduces the risk of flooding in the city.

8 *Les nappes phréatiques [Groundwater], Agence de l'Eau Artois-Picardie* (n.d.). https://www.eau-artois-picardie.fr/education-leau-dossiers-thematiques/les-nappes-phreatiques#:~:text=Environ%2095%20%25%20de%20l'eau,infiltrations%20of water%20de%20pluie.

9 IPCC. (2022). Climate Change 2022: Impacts, Adaptation, and Vulnerability. https://www.ipcc.ch/report/ar6/wg2/chapter/chapter-4/.

10 **Nature-based solutions** are actions designed to protect, sustainably manage, and restore ecosystems to address issues such as climate change, water management and biodiversity while also providing benefits to society.

These solutions offer many advantages. They help mitigate the effects of flooding, improve water quality and boost the resilience of ecosystems in the face of extreme climate events. Nature-based solutions are often also cheaper than traditional infrastructure in the long term. This focus on resilience drives Veolia in its commitment to deliver actionable solutions for saving water, illustrated by a key indicator: volume of freshwater saved.

POWERFUL COMMITMENTS FOR SAVING WATER, TRANSLATED BY A KEY INDICATOR: VOLUME OF FRESHWATER SAVED

With climate change making it critical to save freshwater resources, Veolia is actively committed to protecting this vital resource. Veolia has set up a key indicator, **annual volume of freshwater saved**, aiming to save 1.5 billion cubic meters of water by 2027. The indicator is based on three components: volume of water reused post-treatment, volume of water desalinated, and volume saved thanks to improvements in yields in drinking water networks. Veolia is implementing a range of concrete solutions to help it meet its target: reducing the amount abstracted and increasing recycling at its drinking water plants and industrial sites; a 40% cut in pipe leaks in France to reach a rate of under 10% in most parts of the country; encouraging water sufficiency, and supporting farmers to switch to less water-intensive practices.

WASTEWATER: A VALUABLE HEALTH INDICATOR FOR THE CLIMATE EMERGENCY

Water services are boosting their resilience in the face of climate change thanks to solutions that are ecological, such as nature-based solutions, and innovative, all while protecting human health. Wastewater can also be an invaluable source of public health indicators. The climate emergency leads to variations in temperature and rainfall that **encourage the propagation of vector-borne diseases**. With these growing risks, wastewater can act as an advanced early-warning tool to identify the propagation of emerging pathogens.

During the Covid-19 pandemic, wastewater was an essential tool for monitoring and anticipating changes in how the virus was circulating. This approach, known as wastewater-based epidemiology, was successfully applied by Veolia's research teams in 2020. Veolia's researchers demonstrated the validity of this surveillance approach by developing an innovative services model based on the use of digital PCR[11] and an online dashboard using operational data (rainfall, sewage plant loading, etc.) to provide the analysis with context. The solution was used to **forecast peaks in hospitalizations as much as two weeks in advance**, giving local authorities an important head start so that they could react efficiently to the evolving epidemic and take the necessary measures.

CONCLUSION

ADOPTING RESILIENT STRATEGIES TO PROTECT THE HEALTH OF HUMANS AND THE ENVIRONMENT

Climate change demands in-depth changes in how water services are managed. Faced with growing problems centering on water shortages and surpluses, innovations and infrastructure adaptability are vital to maintaining continuity and security of supply. By rolling out advanced technologies for detecting leaks and anticipating the effects of corrosion, promoting the reuse of wastewater and shifting to greener infrastructure and nature-based solutions, water network managers are providing real-world responses to the challenges of water shortage.

At the same time, tackling issues raised by excess water requires a variety of flood management strategies that look beyond the question of crisis management. Setting in place hydrometeorological systems, water retention mechanisms and forecasting and alert solutions allows local authorities to plan ahead for extreme events and limit the risks to local people.

Lastly, to preserve this precious resource and ensure equitable access to it, sustainable and adaptable economic models must be put in place while involving all actors in society in the task of managing water together. This represents a significant challenge, entailing as it does a real transformation in how we use and manage water so that we can protect a resource that is vital to life and essential to the development of our societies.

11 PCR = polymerase chain reaction. An analytical technique used to amplify the DNA or RNA of a microorganism. It allows direct detection of the presence or absence of the microorganism in a sample of water.

LEKO: Monitoring sounds to assess and track ecosystem health

Contact: Marie Maurel, Head of Water and Biodiversity Activities – BIRDZ
Author: Sandrine Oberti, Director of Scientific Valorization – DEST (Veolia Research & Innovation)

THE IMPORTANCE OF MONITORING BIODIVERSITY

Biodiversity is declining steeply, with 75% of terrestrial ecosystems and 40% of marine ecosystems degraded, a situation that threatens a million species with extinction, largely as a result of human activities (IPBES 2019, IUCN 2021). Biodiversity is vital for regulating the climate and protecting against natural disasters. Preserving biodiversity requires constant automated monitoring to overcome the drawbacks of the manual inventories traditionally used in the past.

Ecosystem health and human health are inextricably linked, as underlined by the One Health concept. This approach recognizes their interdependence and seeks to achieve a balance between the health of people, animals and ecosystems. The deterioration of natural habitats can facilitate the emergence of zoonotic diseases that impact human health directly. Monitoring and preserving biodiversity thus helps to prevent future health crises (WHO).

MONITORING BIODIVERSITY BY LISTENING TO BATS!

Birdz, working with France's natural history museum, has developed a monitoring system that uses acoustic sensors to listen to and analyze sounds made by over 100 species, from bats to grasshoppers, birds to nocturnal insects. The sensors identify and count the number of species in an ecosystem, constantly monitoring indicators for ecosystem health and helping to protect biodiversity.

Developing autonomous solar-powered sensors that communicate via cellphone networks and wifi was a major challenge. They have to be robust, safe from vandalism when sited in built-up areas, and effective at collecting data continuously, even in hard-to-reach locations.

ARTIFICIAL INTELLIGENCE ASSISTING BIODIVERSITY

Further significant technological challenges were successfully tackled, including the integration and analysis of bioacoustic data. The project, a result of a collaboration between Veolia and France's natural history museum via a chair in mathematical modelling, led to the development of advanced scripts and algorithms used to detect and identify different species' sonic signatures.

Establishing reliable and accurate correlations between species and sonic signatures was key to identifying the species present, understanding their interactions, and directly measuring the health of ecosystems and the effectiveness of measures to conserve them.

To date, the solution has identified 29 species and groups of bats, 42 species of grasshoppers, four species of mammals, three bird species and nine other species (butterflies, glow-worms and amphibians). Research is ongoing to expand the number of species identified. The ability to adjust these systems to suit different regions and variations in biodiversity is crucial to rolling them out worldwide.

KEY BIODIVERSITY INDICATORS THAT CAN BE USED TO MEASURE THE IMPACT OF MITIGATION SOLUTIONS

Leko is a major step forward in environmental monitoring because the data it collects can be used to define four key indicators for the impact of human activities on biodiversity.

1. **Ecosystem health:** proportion of specialist species (marker of the good health of an ecosystem).
2. **Light pollution:** species' light sensitivity.
3. **Tree cover:** health of forested habitats.
4. **Surface water quality:** presence of specialist species in bodies of water.

The indicators are accessible via a portal and are used to assess the health of ecosystems and measure the impact of biodiversity conservation strategies implemented as part of urban or industrial developments. Leko thus opens the door to proactive management of environmental challenges.

AWARD-WINNING SOLUTION

Leko has won several high-profile prizes recognizing its innovative approach to sustainable management of natural resources and protecting biodiversity: IoT Awards 2023, Grand Prix Change 2023, and winner of the Frost & Sullivan 2021 Company of the Year Award.

The Leko solution is already used in static and mobile applications in France, Spain, Italy and the UK and is soon to be rolled out in the USA. It provides long-term monitoring of biodiversity and ecosystem health, with no significant environmental impact. The innovations offered by this technology support ecological transformation by improving the protection of health and the environment.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ICI ON ÉCOUTE LA NATURE
En savoir +
birdz
by VEOLIA
MUSÉUM
NATIONAL D'HISTOIRE
NATURELLE

Making AI an ally for sustainable agriculture in the face of climate change

Lalit Gautam
CEO and Founder of SenseGrass

Lalit Gautam is the CEO and Founder of SenseGrass, an agri-tech company optimizing crop and soil health using AI Agronomist's data from sensors, satellites, weather and users' inputs. Third generation farmer from India, Lalit Gautam founded his startup with a deep understanding of the challenges faced by Indian farmers (soil degradation, impacts of climate change on productivity, social impacts etc.). He received numerous awards (two times Forbes 30 Under 30 for Technology and Manufacturing for India and Europe, MIT 35 Under 35) and fellowships.

Climate change is profoundly reshaping socio-economic structures worldwide, posing challenges to various sectors, especially agriculture. The agricultural industry is particularly vulnerable to unpredictable weather patterns, increased extreme events and the degradation of natural resources. These disruptions threaten food production, global food security, economic stability and community livelihoods. As agriculture both influences and is affected by climate change, it is crucial to develop and implement solutions that address these complex issues to foster resilience and sustainability.

This article explores the role of technology and artificial intelligence (AI) in mitigating the effects of climate change on agriculture. By examining the sector's challenges, the article highlights the importance of data and technological innovation in transforming agricultural practices, particularly in developing countries. Through the innovative work of SenseGrass, it illustrates how AI-driven solutions are transforming farming, enhancing sustainability and building climate resilience. Based on examples from the industry, this article provides a glimpse into the future, demonstrating AI's potential to drive positive change not only in agriculture, but also in addressing broader issues posed by climate change.

INTRODUCTION

Climate change is increasingly impacting agriculture. Rising temperatures, unpredictable precipitation and more frequent extreme weather events disrupt crop growth cycles, reduce yields and compromise food quality. For instance, while hotter temperatures may accelerate crop growth, they also increase pests and diseases, leading to significant losses. The disruption of agriculture – a vital industry – has far-reaching consequences on human health. Lower yields not only reduce the quantity of food available but also lead to higher prices, pushing vulnerable populations toward food insecurity and malnutrition. Children are particularly at risk, as reduced access to nutritious food can lead to stunted growth and long-term health problems.[1] Sudden floods and droughts often wipe out entire harvests, leaving farmers in a vulnerable and precarious situation.

1 See the article by Jessica Fanzo in the second section of the review: *Climate change and food systems interactions: Ensuring resilient and healthy diets.*

The challenges extend beyond immediate climate impacts. Indirect consequences such as altered ecosystems and dwindling resources further strain agriculture. Water scarcity, reduced soil fertility and changing pollinator behaviors significantly affect crop production. Farmers, already grappling with direct climate impacts, face these indirect effects as well. The socio-economic repercussions are profound, with increased food prices and heightened food insecurity impacting vulnerable communities the hardest.

THE IMPORTANCE OF SOILS

Soils are vital for agriculture, essential for plant growth, water regulation and nutrient cycling.[2] They support diverse ecosystems, enhance crop resilience and play a crucial role in mitigating climate change through carbon sequestration. However, climate change threatens soil health. Elevated temperatures and irregular precipitation accelerate soil erosion, nutrient depletion and organic matter loss, weakening soil structure and fertility. According to the Food and Agriculture Organization of the United Nations (FAO), 33% of soils worldwide were already moderately to highly degraded in 2015, and over 90% of soils could undergo degradation by 2050.[3]

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Extreme weather exacerbates soil degradation as well. Heavy rains cause severe erosion, while prolonged droughts desiccate soils and diminish microbial activity, and rising sea levels and over-irrigation can lead to salinization. Healthy soils are essential in sustaining agricultural productivity. Without urgent action, the cascading effects of climate change will continue to erode food security and environmental stability. Only through innovation, resilience and collective commitment can we hope to avert these disastrous risks.

THE ROLE OF DATA AND TECHNOLOGY IN AGRICULTURE

In the face of climate change, data and technology have emerged as important allies. Modern agriculture increasingly relies on advanced technologies and artificial intelligence (AI) to enhance productivity, manage resources efficiently and mitigate the adverse effects of climate change. The integration of data-driven insights allows farmers to make informed decisions, optimize crop yields and improve the overall resilience of agricultural systems.

2 The nutrient cycle is a system where energy and matter are transferred between living organisms and non-living parts of the environment, as animals and plants consume nutrients found in the soil that are then released back into the environment via death and decomposition.

3 Food and Agriculture Organization. (2015). Agroecology to reverse soil degradation and achieve food security. FAO. https://openknowledge.fao.org/server/api/core/bitstreams/bb2a86db-7f53-4e70-91ca-35ceb9d777db/content.

TECHNOLOGICAL SOLUTIONS OVERVIEW

Numerous technological solutions are remodelling agriculture, providing farmers with tools to monitor, analyze and respond to various challenges. Here are some key innovations:

- **Precision Agriculture:** Utilizing GIS[4] and IoT[5] sensors, precision agriculture enables farmers to monitor soil conditions, crop health and weather patterns in real-time, allowing for precise application of water, fertilizers and pesticides.
- **Remote Sensing:** Satellite imagery and drone technology offer valuable insights into crop health, soil moisture levels and pest infestations, facilitating timely interventions and reducing resource wastage.
- **AI, Machine Learning and Big Data Analytics:** AI-powered models predict crop yields, detect diseases and recommend optimal planting schedules, helping farmers enhance productivity and reduce losses.
- **Climate-Smart Solutions:** Technologies that focus on climate resilience, such as drought-resistant crop varieties and efficient irrigation systems, are essential for adapting to the impacts of climate change.

These technological advancements are transforming traditional farming practices, making agriculture more efficient, sustainable and resilient.

4 GIS (Geographic Information System) is a spatial and geographic data technology that allows users to understand patterns, relationships and trends related to location.

5 IoT (Internet of Things) refers to a network of interconnected devices that collect and share data through the internet, enabling real-time monitoring and automation.

SENSEGRASS: INNOVATING WITH ARTIFICIAL INTELLIGENCE

SenseGrass was born out of a deep connection to agriculture and a desire to address the challenges that small-scale famers face globally, especially as climate change exacerbates their difficulties. Growing up in India a community of farmers, I witnessed firsthand how unpredictable weather patterns, droughts and storms further strain those who depend on their land for sustenance and income. Agriculture remains a backbone of many economies, especially in developing nations. 70% of India's rural households still depend primarily on agriculture for their livelihood, with 80 % of farmers being small or marginal.[6] Many of them are forced to take up additional jobs to survive, while their farms suffer from soil degradation and outdated agricultural practices.

In fact, traditional soil analysis methods, commonly used in India and around the world, are costly, slow and inaccessible to the majority of smallholder farmers. Farmers typically have to send soil samples to labs, where testing takes weeks and often produces inaccurate or incomplete results. In Rajasthan for instance, despite the government spending billions of Rupees on mobile testing vans and labs, many farmers avoid using them as they find the process too complex and of little practical value. As a result, soil health data remains inaccessible, contributing to significant crop loss. This led us to create SenseGrass, to transform agriculture through the power of Artificial Intelligence (AI), Machine Learning (ML) and Internet of Things (IOT). Our product combines both hardware and software technologies, with the IoT-based system representing the hardware and the AI based system representing the software:

"Traditional soil analysis methods are costly, slow and inaccessible to the majority of smallholder farmers. [...] As a result, soil health data remains inaccessible, contributing to significant crop loss."

- **The Artificial Intelligence (AI) technology** analyses data to formulate smart solutions for existing challenges related to soil health, fertilizer conditions and other environmental factors. It provides real-time notifications and actionable solutions to end users. Acting like a personal "human" agronomist, the AI software empowers farmers with precise, data-driven recommendations.
- **The Internet of Things (IoT) system** is responsible for sensing and monitoring soil conditions, water levels, rainfall predictions, temperature and other relevant metrics. It measures 18+ parameters in real-time, with no need to send soil samples to a lab. In short, it automates the entire process of sensing, data collection, and analysis, transitioning from manual to automated operations.

Additionally, we use satellite data to provide information on vegetative indices, enabling farmers to monitor crop health effectively. By identifying the precise health needs of soils at any given time, our technology addresses the common agricultural challenge of over-fertilization. On average, crops absorb only about 50% of the nitrogen in fertilizers, with the excess often running off into waterways or being broken down by soil microbes, releasing harmful nitrous oxide into the atmosphere. Although nitrous oxide contributes a smaller share of global greenhouse gas emissions, it has a warming potential 300 times greater than carbon dioxide.[7] Thus, with SenseGrass, farmers can make informed decisions that improve soil health, ultimately reducing their dependency on fertilizers.

PILOT AI PROJECTS

In addition to our long-running project, we are running several pilot projects designed to harness the power of AI.

Yield Prediction Model

We have developed an advanced AI model to predict crop yields, with a particular focus on data from farms in Nepal. By integrating historical yield data, weather patterns and remote sensing inputs, the AI models generate yield forecasts for wheat crop. These predictions help farmers plan their planting schedules, allocate resources efficiently and anticipate potential challenges.

Crop Insurance Weather Index AI

SenseGrass is developing an AI-based weather index models for crop insurance, particularly for rice farmers across over 300 districts in India. By analyzing historical weather data, crop performance and climate patterns, the AI models establish correlations between weather events and crop losses. This approach allows for the creation of weather-indexed insurance products that offer timely and accurate compensation to farmers affected by adverse weather conditions.

Carbon Credit Framework

SenseGrass is also working on the development of a global carbon credit framework, based on 17 specific AI models tailored to individual terrestrial biomes. This initiative aims to quantify and monetize the carbon sequestration potential of agricultural practices. By integrating remote sensing data, estimated soil carbon measurements and advanced Machine Learning algorithms, SenseGrass's AI models estimate the carbon capture capacity for different biomes globally. This framework would enable farmers to participate in carbon credit markets, providing them with an additional revenue stream while promoting climate-friendly practices.

6 Food and Agriculture Organization of the United Nations. (n.d.). India at a glance | FAO in India. FAO. https://www.fao.org/india/fao-in-india/india-at-a-glance/en/.

7 *Fertilizer and Climate Change | MIT Climate Portal.* (2021). MIT Climate Portal. https://climate.mit.edu/explainers/fertilizer-and-climate-change.

Today, more than 12,000 farmers are impacted by our technology globally. Our presence in key states in India including Rajasthan, Utar Pradesh and Punjab but also in the USA, France, Chile, the UK and Finland, testify of the global need for innovative solutions to ensure sustainable agricultural practices.

CONCURRENT AI AND TECHNOLOGY IN AGRICULTURE

AI and technology are transforming agriculture. These advancements offer farmers tools to monitor, analyze and respond to various challenges, ensuring a more efficient and adaptive agricultural sector. Here are some notable examples of structures and startups showing how AI and technology are revolutionizing farming practices:

Technological Innovations

- **Plantix:** Plantix, a German start-up, uses advanced image recognition technology to diagnose plant diseases, pests and nutrient deficiencies. Farmers capture images of affected plants using a smartphone and the app leverages machine learning to compare these images against a vast database. Farmers receive a diagnosis and actionable recommendations within seconds. This democratizes access to expert-level diagnostic tools, empowering farmers with essential knowledge and resources.
- **Blue River Technology:** Acquired by John Deere, an American corporation specialized in farm machinery and industrial equipment, Blue River Technology has developed the "See & Spray" system, which employs computer vision and machine learning to identify and precisely apply herbicides only where weeds are present. This targeted approach reduces the use of chemicals, lowers costs and minimizes the environmental impact of farming practices.
- **Agribotix:** Specializing in drone-enabled technologies, Agribotix provides data analytics and insights through aerial imagery captured by drones. Their AI-powered platform analyzes crop health, identifies areas of stress and generates actionable reports for farmers, helping to optimize field management.
- **Prospera:** Through its “irrigation insights” solution, Prospera leverages real-time data on soil moisture, weather conditions and crop health to make precise water management decisions. This technology helps farmers both grow healthier crops and use resources more efficiently by preventing over-irrigation.

AI & TECHNOLOGY IN ADDRESSING CLIMATE CHANGE TO GUARANTEE A BETTER HUMAN HEALTH

Link Between Climate, Environment and Health

Climate change significantly impacts both environmental and human health, presenting challenges that require innovative solutions. For example, AI-driven climate models can forecast extreme weather events, allowing for early warnings that help communities prepare and respond effectively. Additionally, AI can track and model the spread of vector-borne diseases influenced by changing climate conditions, enabling targeted interventions to protect vulnerable populations. AI and data-driven technology have the potential to tackle many of the challenges posed by climate change.

> *"AI-driven climate models can forecast extreme weather events, allowing for early warnings that help communities prepare and respond effectively."*

Future Directions – AI and technology solutions for agriculture and beyond

As we look into the future, potential developments in AI and technology for the green sector are vast and diverse:

- **Advanced Climate Modelling and Prediction:** Future advancements in AI could lead to even more accurate and granular climate models, enhancing our ability to prepare for and mitigate the impacts of climate change. IBM, in collaboration with NASA, is developing an advanced open-source foundation model for weather and climate prediction.[8] This AI-powered model processes vast amounts of data, including NASA's satellite information, to improve the accuracy of weather forecasts and climate projections. The project aims to help anticipate extreme weather events and offer long-term insights into climate patterns, which are crucial for climate resilience and sustainable development. Singularly, the model is designed to be accessible and can run on standard desktop computers, making it more widely usable for researchers, developers, and organizations globally.
- **Precision Conservation:** It is estimated that by the end of 2100, nearly half of the world's species will disappear from planet Earth.[9] AI and machine learning can help with conservation efforts. The non-profit organization Wild Me utilizes Microsoft's AI for Earth program to identify and track animals in the wild, analysing photos taken around the world by tour operators, tourists and researchers.[10] Their efforts enable better monitoring of endangered species, such as the Whale shark, ensuring targeted conservation actions. Similarly, another of Microsoft's program called the Global Fishing Watch initiative uses satellite data and AI to monitor illegal fishing activities.
- **Global Collaboration and Data Sharing:** The future of AI in addressing climate change will also involve increased global collaboration and data sharing. Open AI platforms and international partnerships can facilitate the exchange of knowledge and best practices, accelerating the adoption of innovative solutions worldwide. The Global Open Data for Agriculture and Nutrition (GODAN) works to build high-level support among key stakeholders including governments, NGOs, and private sector organizations to ensure data is accessible and beneficial for famers and the health of consumers.[11] Through leveraging growing data generated by new technologies, the initiative seeks to tackle long-standing agricultural and food security challenges.

CONCLUSION

Throughout this article, we have explored the role of AI and technology in addressing the challenges posed by climate change. Enhancing agricultural practices through advanced data analytics and predictive modelling is pivotal in promoting sustainability and resilience. We also highlighted the work of SenseGrass in developing AI-driven solutions for yield prediction, soil health monitoring and carbon credit framework, demonstrating the practical impact of technology in the agricultural sector for the past, present and future.

The future of AI and technology in the green sector is promising. Ongoing innovation is not just beneficial but imperative for us to address the complex challenges of climate change. By investing in and supporting these advancements, we can contribute to a sustainable, resilient and prosperous future for all.

8 Martineau, K. (2024, September 23). *Introducing Prithvi WxC, a new general-purpose AI model for weather and climate.* IBM Research. https://research.ibm.com/blog/foundation-model-weather-climate.

9 Nguyen, L. (2021, November 4). *What animals will be extinct by 2100?* Earth.Org. https://earth.org/what-animals-will-be-extinct-by-2100/.

10 Wild Me. https://www.wildme.org/.

11 *Global Open Data for Agriculture and Nutrition.* https://www.data4sdgs.org/partner/global-open-data-agriculture-and-nutrition.


AI
CO2

CONCLUSION

Cédric Baecher - Partner at Wavestone

A few weeks prior to COP29 (held in Baku, Azerbaijan, in November 2024), the WHO published a special report demanding "urgent integration of health in climate negociations" and calling on policymakers to make health a decisive argument for climate action.[1] Rooted in the belief that **"the climate crisis is a health crisis"**, this issue of FACTS Reports explores some of the main interdependencies linking climate, environment and human health: a threeway matrix where each domain exerts a systemic influence on the others, making it vital to examine all the challenges from a multi-disciplinary standpoint and to implement properly coordinated holistic strategies. Faced with the multiple complex repercussions of climate change on ecosystems, socio-economic structures and human health, this 360-degree vision is essential to tackling presentday challenges and preparing for the threats of tomorrow. Consistent with the One Health approach promoted by the UN, the thirty experts who have contributed to this publication explore different aspects of the same worrying socio-environmental reality.

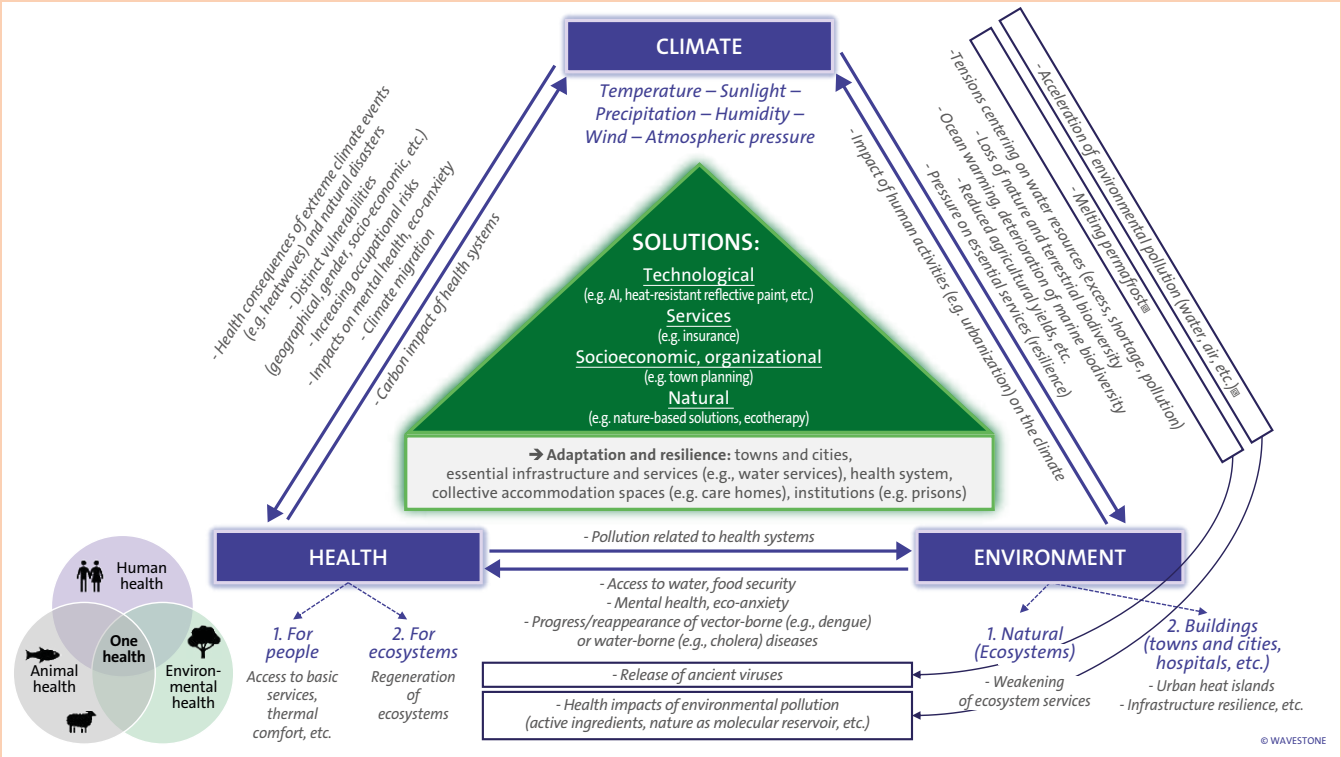
As the diagram below shows, the articles in this issue seek to describe a set of interconnections and systemic risks that relate directly or indirectly to the consequences of climate change on human health and the environment.

The threat is real: 700 million people may be displaced by drought by 2030.[2] The climate crisis also has a direct impact on the natural environment by reducing available water resources and threatening ecosystems, again with real-world repercussions on human health. According to the World

1 *COP29 Special Report on Climate Change and Health*, World Health Organization, November 2024.

2 United Nations Convention to Combat Desertification (UNCCD). (2022). *Drought in numbers 2022.*

***Figure 1:* Schematic representation of the links between climate, health and the environment**



Source: Wavestone (2024)

Meteorological Organization, in 2022, prolonged droughts have affected approximately 3.6 billion people worldwide, leading to water stress and food insecurity for many.

Furthermore, environmental disruption caused by climate change can trigger **cascading repercussions on human health,** although the causal chain is not always easily traceable. The accelerating rate of permafrost melt is an example of one of the as-yet little anticipated indirect risks of climate disruption. In 2016, over 2,300 reindeer were poisoned by anthrax[3] bacterium released by thawing carcasses of the same animal species. Caused by global warming, permafrost melt may release other ancient bacteria and viruses that have been trapped in the ice for millennia and are liable to create new risks to human and animal health owing to an absence of adequate immunity.

"The resilience of ecosystems and human societies must be reinforced through genuine and long-lasting ecological, social and cultural transformations. In this regard, individual and collective commitment is a prerequisite."

These conclusions point to a **new form of inequality: climate injustice.** Certain vulnerable regions feel the full force of the effects of climate change, with vulnerable groups in the population very often the most exposed. For example, drought and torrential rains have ravaged Kenya's Nyanza region, an area with a widespread incidence of HIV/AIDS, aggravating food insecurity, population displacement and the already limited access to healthcare, which in turn intensifies health impacts among marginalized communities.

The identification and gradual quantification of the multiple risks relating to climate disruption highlight the need for collective mobilization to tackle it. This mobilization is needed at different levels, from individuals to policymaking, businesses to multi-actor coalitions. This issue of FACTS introduces several possibilities for solutions and strategies to mitigate or slow the harmful effects. Several complementary approaches have been identified.

- **A technological approach:** innovations can be rolled out to monitor, analyze and mitigate negative health and environmental impacts. This includes advanced tools using artificial intelligence, IoT sensors and modelling systems to predict extreme climate events and design targeted interventions to improve resilience among communities and ecosystems.
- **A services-led approach:** seeking to reduce the impacts of climate change on human health and the environment, this approach offers services that provide individuals with effective protection and support. For example, more inclusive insurance services that provide basic cover without add-ons, making insurance more affordable to lower income groups.
- **A planning-led approach:** public policies, organizations and collective initiatives play a key role in crafting an integrated response to environmental, climate and health challenges. Towns and cities, major emitters of CO_2, have to reinvent themselves to both reduce their climate impact and generate co-benefits for public health and social well-being.
- **An approach based on or leveraging nature:** solutions inspired by the natural environment can also be implemented to tackle disruption caused by climate change. Biomimetic[4] solutions provide one example. The International Union for Conservation of Nature (IUCN) defines Nature-based Solutions (NbS) as actions to protect, sustainably manage, and restore natural and modified ecosystems that address societal challenges effectively and adaptively, simultaneously benefiting people and nature.[5] Human health, particularly mental health, can also be bolstered using nature-based approaches: eco-therapy, for example, focuses on reviving connections with nature and the living world to combat worries and anxieties experienced in the face of ever more visible environmental disruption.

The necessary combination of these different approaches makes a two-pronged strategy possible: anticipating the inevitable effects of climate change, while also cutting the environmental damage caused by our activities in order to prevent the climate crisis from spiraling out of control. Furthermore, the resilience of ecosystems and human societies must be reinforced through genuine and long-lasting ecological, social and cultural transformations. In this regard, individual and collective commitment is a prerequisite. According to the Elabe barometer,[6] **67% of people in the world say they are ready to accept the additional costs and changes in behaviors that ecological actions involve, providing that they help protect their health and that of their family and friends.** Faced with this growing individual awareness, harbinger of a possible move to scale, widespread eco-anxiety may emerge from the youngest generations' almost omnipresent concern: 70% of 16-25 year olds declare that they are very or extremely worried about climate change.[7]

Worries about the heath consequences of climate change are thus evolving: once a collective concern, they are shifting to take the form of a more personal sense of anxiety. In the past, the perception that responsibility was diluted on a global scale could make it difficult to assign 'fault'. Today, responsibility is taking on far more importance, including at the individual level. This is the building block upon which important preventative measures could be implemented. This greater level of individual awareness must be the starting point for a more lasting collective mobilization, essential to protecting the health and well-being of humanity in the face of the challenges posed by climate change.

3 Source: *National Geographic* (2024). Melting cryosphere: ancient viruses may escape from the ice https://www.nationalgeographic.fr/sciences/environnement-fonte-de-la-cryosphere-des-virus-millenaires-pourraient-sechapper-des-glaces.

4 "Biomimetics consists of taking inspiration from the essential characteristics (such as shapes, compositions, processes, interactions) of one or more biological systems to design procedures and organizations that allow societies to develop sustainably."

5 International Union for Conservation of Nature (IUCN). https://iucn.org/our-work/nature-based-solutions.

6 Barometer developed in partnership with Veolia.

7 Hickman, *C., et al* (2021). Climate anxiety in children and young people and their beliefs about government responses to climate change: a global survey. *The Lancet Planetary Health, 5*(12), e863–e873. https://doi.org/10.1016/S2542-5196(21)00278-3.

"One reason the environment plays a crucial role in our health is its pervasive nature. The environment surrounds us throughout our entire lives. It is the air we breathe, the water we drink, the food we consume, the interactions we experience, the stress, the joys, the exposures to chemicals or infections depending on our work or our place of living, and the susceptibility to homelessness or other sources of disruption in our lives."

Harvey Fineberg
President of the Gordon and Betty Moore Foundation
and member of the Veolia Institute's Foresight Committeee

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