environmental SCIENTIST

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December 2022
Journal of the Institution
of Environmental Sciences

Risk: a fundamental lens for examining the human and natural world

By understanding risk, we can see potential futures and pathways for the society and economy we want to create for future generations. Equally, risk can inform our understanding of tipping points and other systems elements that shape our interactions with the environment. As the global community makes decisions about which approach to take to the interconnected issues of climate change, biodiversity loss and environmental pollution, we must grapple with many of these concepts lest we cross thresholds from which we cannot return.

Humanity may struggle to imagine a future where tipping points such as mass coral bleaching or the cascading shift of major biospheres around the world are crossed. If there is a way to help communicate the urgency and necessity of action to address these threats, risk holds the answers. The language of risk speaks about the future in ways that have eluded the combined efforts of science, politics and poetry. Risk is both a fundamental tool for addressing scientific issues and an excellent resource for communication and the encouragement of action.

The examination of risk is also a crucial enterprise of environmental science. The expertise of environmental professionals in demystifying risk and explaining its consequences has played a significant role in helping our society come to terms with some of the environmental challenges that will continue to shape our world over the coming generations.

The consideration of risk is also increasingly crucial beyond the science community. When climate activists march, their concern is ultimately about risk: the potential for a future where we face adverse consequences as a result of the decisions we make today. When businesses set out strategic plans or corporate targets, one of their most important considerations will be risk and how they can mitigate the implications of their actions.

To that end, the scientific exploration of risk is a vitally important endeavour for our society. If we know how risks manifest, we can begin to prepare for them; if we know how to mitigate risks, we can begin to embed solutions that address them. In each case, the first step is a better understanding of how risk begins to form across complex systems and the myriad ways that risk can shape the future of our world.

Whether we engage in risk on the scientific level or not, it remains the best lens we have for seeing the possibility of threats to our future. If we care about the inherent value of our natural world, or at the very least the challenges we are creating for future generations, then we must also care about risk. This edition brings together interdisciplinary voices to share understandings of risk, but the conversation must continue beyond its pages, reaching into each corner of our society to give us the best possible chance of dealing with the potential for adverse consequences for humanity and the natural world.

Editorial: Joseph Lewis is Policy Lead for the Institution of Environmental Sciences and is responsible for working to promote the use of the environmental sciences in decision-making. In 2022, he coordinated a deep-dive research project on risk and systems thinking and in 2023 will be directly involved in the IES's foresight and horizon scanning project, Future of ES23.

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CONTENTS >

environmental SCIENTIST
The journal of the Institution of Environmental Sciences
Volume 31 No 4 | ISSN: 0966 8411

The environmental SCIENTIST provides a platform to discuss key issues within the environmental sciences, hosting original articles written by professionals, academics and experts working across the sector.

The views expressed in the journal are those of the authors and do not necessarily reflect IES views or policy.

INTRODUCTION

Framing risk for environmental science and environmental scientists

David Viner reflects on the complex area of risk and its crucial role in effective decision-making.

'Risk: The potential for adverse consequences for human or ecological systems, recognising the diversity of values and objectives associated with such systems.'

DEFINING RISK

This widely used definition both clarifies and clouds how environmental scientists can discern and address risk. While it provides a broad basis of understanding, it also raises numerous questions: what is risk composed of; where can it be found; is it stand-alone, systemic, or can it be both; how can we deal with it when we encounter it?

INTRODUCTION

The term 'risk' is multi-dimensional yet simultaneously often used in a transferable way to define the sum of a series of components: hazard, exposure, vulnerability, (and sometimes) response. For environmental scientists to usefully examine, assess and respond to this multitude of risks, there must first be clarity about its definition. One conceptualisation of risk based on the framework used by the Intergovernmental Panel on Climate Change (IPCC) was first reported in the Special Report on Extreme Events (see **Figure 1**).[1] This framework has undergone rigorous scrutiny, leading to a tightening of the definition of the components of risk. Modifications have been added – including addressing the dynamic nature of these elements, which themselves must be defined and addressed individually before risk can be properly understood.

The components of risk are broadly defined as:[2]

Hazard: The potential occurrence of a natural or human-induced physical event or trend that may cause loss of life, injury or other health impacts as well as damage and loss to property, infrastructure, livelihoods, service provision, ecosystems and environmental resources.

Exposure: The presence of people; livelihoods; species or ecosystems; environmental functions, services and resources; infrastructure; or economic, social or cultural assets in places and settings that could be adversely affected.

Vulnerability: The propensity or predisposition to be adversely affected. Vulnerability encompasses a variety of concepts and elements, including sensitivity or susceptibility to harm and lack of capacity to cope and adapt.

Risk, therefore, results from *dynamic* interactions between multiple parts. Against the tendency of the numerous risk assessments used within the environmental science and practitioner communities to date – which have considered risk as relatively static and qualitative – each risk component is subject to uncertainty in terms of magnitude and likelihood of occurrence, and each is likely to change over time and space due to interactions with socio-economic systems and the subjectivity of decision-making. When appreciated in this manner, risk is no longer condensed into merely a function of impact and likelihood of occurrence – an easily constructed and communicated but ultimately oversimplified framing.

The IPCC suggests several scenarios within which discussion of risk is suitable and in line with its definition. Firstly, the term should be used when 'explicitly considering potential adverse consequences and the uncertainty relating to those consequences'.[3]

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The more clearly adverse consequences are characterised in terms of magnitude, scale, distribution, reversibility and the nature of uncertainty, the more useful the risk concept is. Risk assessments are also fundamental to informing decision-makers of how different action paths can reduce or exacerbate adverse consequences. Within this, best practice stipulates that risk is not made synonymous with hazard, but instead focuses on the *consequences* of hazards. Finally, risk is not the generic term for anything bad that may happen now or in the future. This is often conflated with the urgency needed to address many risks. Urgency most often stimulates prompt risk management. However, as conditions approach a crisis state, urgency can weaken decision-making rather than support it. Rushing decisions and courses of action will often produce unintended consequences.

MANAGING RISK

Managing risk appropriately is becoming increasingly important as humankind continues to disrupt delicately balanced environmental systems. Decision-support tools and decision-analytic methods are available and are being more widely applied to managing climate risks in varied contexts and across a range of spatial and temporal scales, including in the presence of deep uncertainty. These tools and methods have been shown to support deliberative processes, where stakeholders jointly consider factors such as the rate and magnitude of change and the uncertainties, associated impacts and timescales of adaptation needed along multiple pathways and scenarios of future risks.[4]

In many places, consideration of risk is now enshrined in law or government standards. In the UK, the Climate Change Risk Assessment (CCRA) is a rigorous and lengthy five-year analysis of risks and opportunities relating to the environment, legally instigated by the Climate Change Act 2008. Government standards in risk assessment and subsequent knowledge are being strengthened with the third assessment, CCRA3, delivered earlier this year.[5]

Although risk can appear to be a technical, specialist subject, it touches every corner of the environmental sciences. The CCRA3 considered no less than 61 risks, grouped into five major categories:

- Natural environment and assets;
- Infrastructure;
- Health, communities and the built environment;
- Business and industry; and
- International dimensions.

This issue therefore includes articles relating to all these categories, contributed by authors working in diverse environmental fields. The issue opens with Joseph Lewis demystifying the complex dynamics

▲ **Figure 1. Risk components. (© David Viner)**

and theories of risk and uncertainty at a deeper level, presenting a case for mainstreaming systems literacy in our approach to tackling environmental problems.

An interview with Luke Kemp follows, explaining the value of studying the most extreme and catastrophic risks we might face and revealing the deep parallels and interactions between climate and socio-political risks. Kemp offers a thought-provoking insight into the ways we conceptualise and communicate risk, with an emphasis on how democratic deliberation is essential to reducing future threats.

Mark Workman and colleagues tackle the processes on the other side to science, navigating a route through the complex research–policy interface and discussing how risk can be better translated to make more effective decisions under uncertainty.

Duncan McLaren's inspection of solar geoengineering considers the role of risk framing. McLaren weighs up the possible merits and pitfalls of risk–risk analysis when applied to a high-stakes, controversial topic, interrogating whether arguments surrounding geoengineering represent a false binary for climate governance.

With a global demographic shifting to urban areas, and this trend expected to only increase in intensity over time alongside climate change, consideration of environmental risks specific to urban areas is crucial. David Dodman shares his personal thoughts, including his views on the unique challenges cities face, the importance of community participation in building resilience and the possible barriers to risk-sensitive adaptation.

In a case study that demonstrates the complex chain of risks that can develop in the work of environmental scientists, Conor Armstrong and Adam Bamford relay the remediation process for a domestic property following an oil spill. In particular, they explore the role of guidance and contaminant testing, demonstrating how and why risk assessments can help overcome hurdles and uncertainties.

Providing a thorough view of risk within a pressing global topic, Nicky Jenner and Pippa Howard plunge into the potential dangers of deep seabed mining. This analysis arrives at a time of great debate, where calls for a mining moratorium or total ban compete with a push to attain the rare earth metals that lie on our seafloor.

The presence of risk in every corner of environmental science warrants that we pay close attention to it. With a firm grasp of risk and all its component parts, the environmental sector may be able to translate its crucial knowledge into the most effective decisions yet. **ES**

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INTRODUCTION

REFERENCES

1. Intergovernmental Panel on Climate Change (2012) *Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation.* A Special Report of Working Groups I and II of the Intergovernmental Panel on Climate Change. C.B. Field, V. Barros, T.F. Stocker, D. Qin, D.J. Dokken, K.L. Ebi, M.D. Mastrandrea, K.J. Mach, G.-K. Plattner, S.K. Allen, M. Tignor and P.M. Midgley (eds). Cambridge: Cambridge University Press. https://www.ipcc.ch/site/assets/uploads/2018/03/SREX_Full_Report-1.pdf (Accessed: 7 December 2022).
2. Intergovernmental Panel on Climate Change (no date) *Annex II Glossary*. https://www.ipcc.ch/site/assets/uploads/2018/02/WGIIAR5-AnnexII_FINAL.pdf (Accessed: 17 December 2022).
3. Reisinger, A., Howden, M., Vera, C., Garschagen, M., Hurlbert, M., Kreibiehl, S., Mach, K.J., Mintenbeck, K., O'Neill, B., Pathak, M., Pedace, R., Pörtner, H-O., Poloczanska, E., Rojas Corradi, M., Sillmann, J., van Aalst, M., Viner, D., Jones, R., Ruane, A.C. and Ranasinghe, R. (2020) *The Concept of Risk in the IPCC Sixth Assessment Report: A Summary of Cross-Working Group Discussions.* Guidance for IPCC Authors. Geneva: Intergovernmental Panel on Climate Change. https://www.ipcc.ch/site/assets/uploads/2021/02/Risk-guidance-FINAL_15Feb2021.pdf (Accessed: 16 November 2022). https://www.ipcc.ch/site/assets/uploads/2021/02/Risk-guidance-FINAL_15Feb2021.pdf (Accessed: 7 December 2022).
4. Intergovernmental Panel on Climate Change (2022) *Climate Change 2022: Impacts, Adaptation and Vulnerability.* Working Group II Contribution to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change. H-O. Pörtner, D.C. Roberts, M.M.B. Tignor, E. Poloczanska, K. Mintenbeck, A. Alegría, M. Craig, S. Langsdorf, S. Löschke, V. Möller, A. Okem and B. Rama (eds). Cambridge: Cambridge University Press. https://report.ipcc.ch/ar6/wg2/IPCC_AR6_WGII_FullReport.pdf (Accessed: 7 December 2022).
5. Betts, R.A. and Brown, K. (2021) 'Introduction', in R.A Betts, A.B. Haward and K.V. Pearson (eds) *The third UK climate change risk assessment technical report.* Prepared for the Climate Change Committee, London. https://www.ukclimaterisk.org/wp-content/uploads/2021/06/Technical-Report-The-Third-Climate-Change-Risk-Assessment.pdf (Accessed: 7 December 2022).

FEATURE

Peeling apart the theory of risk

Joseph Lewis examines the theory of risk and what it means for environmental science.

WHAT IS RISK AND WHY DOES IT MATTER?

As a society, our relationship with risk is a complicated one and often varies significantly depending on the context in which we encounter it. When we stack too many plates we have a strong sense of the risk involved; however, when we make consumer choices that promote environmentally damaging consequences, our understanding of the risk involved is far less comprehensive.

Understanding what risk is and why it matters is crucial since risk and uncertainty are increasingly important in the decisions we make – from the individual level to national and international governance. For the environment, risks of degradation are linked to many of the daily choices we make. Risk as a concept also has a substantial body of academic and non-academic literature associated with it, particularly in the environmental world where much of the work being done by environmental professionals tackles risk on a day-to-day basis. The result of that collective knowledge is a theoretical understanding that helps to peel apart the mysteries of risk.

THINKING ABOUT RISK

Our ways of thinking about risk are important; they determine how we make choices in our daily lives, potentially with significant effects for society and the natural world. Where our perspectives on risk differ, it can be more challenging to bring people together to solve environmental crises. In that context, risk theory is the search for a map through the wilderness of uncertainty that stands between us and many of the outcomes we want to achieve.

'Risk theory is the search for a map through the wilderness of uncertainty that stands between us and many of the outcomes we want to achieve.'

The Intergovernmental Panel on Climate Change has concisely summarised the simplest definition of risk as 'the potential for adverse consequences'.[1] When it comes to applying risk to the real world, there are also helpful heuristics to open the door. Many people think of risk as a matrix of likelihood and severity: how likely is the event to happen and how bad would it be if it did? For most risks, we also need to consider the concept of vulnerability: are we resilient to the adverse consequences that could occur, or are we predisposed to additional harm?

Another way to look at risk would be to take the source–pathway–receptor model used by many practitioners dealing with pollution: where does the risk come from, what pathways does a pollutant take, and what possible receptors will it reach (i.e. which people or environments might be affected)?[2] Helpfully, this kind of model encourages us to think about risk in terms of the systems involved, because failing to control for risks at their source makes it more difficult to prevent them from rippling out into other systems. If there was a poorly managed sewage discharge pipe at the top of a hill, not addressing the risk of pollution before it emerges from the pipe could lead to consequences downhill: waste may flow into fields or watercourses and be carried onwards to other places. Once the pollution is in the water and soil, it may cause even more adverse effects if it is not properly addressed.

That relationship speaks to an important but often undervalued truth: risk and systems are linked on a fundamental level and we need a systems approach to fully conceptualise risk. Our approach to environmental risk must be trans-disciplinary if we want a complete picture of the potential adverse consequences that may apply across the environment and social systems.

Naturally, this raises questions and challenges for the practical approaches we can take. If risk applies across complex systems, how can we get a full picture of it (see **Figure 1**)? If risk applies at different levels, how should we conduct our measurements? And if there is a subjective element to how we perceive and assess risks, how can we find objective and satisfying answers? The answers are easier to find than we might think. However, as we tackle risk on the macro scale, we must get comfortable with the concept of known unknowns and the idea that there are some elements of the risk matrix that we may not be able to fully measure but can still account for somewhat when we plan ahead.

ACCOUNTING FOR AMBIGUITY

There is no absolute system of value in the world, particularly when it comes to nature. Yet the existence of subjectivity has not stopped work such as the Intergovernmental Science–Policy Platform on Biodiversity and Ecosystem Services' Values Assessment,[3] which goes a long way to helping us understand the ways in which we value nature despite that ambiguity. Similarly, we can make assessments of the exact nature of risks even where there is disagreement about how they can be assessed.

Most risks, however, do not pose such a challenge. For many of the risks we encounter, particularly in the environment, we have objective and widely accepted approaches to tackling them. Environmental governance and regulation have helped to embed procedures for managing risk into most infrastructure processes, while professionals have accrued best practice over time. The level at which we measure risk and the tools we use to do so will inevitably vary based on the purpose and scope of our risk assessment. Typically, we gather sufficient information to inform the immediate projects we work on, while environmental governance handles questions of risk over the long term and at the big-picture stage, even if the particularities of policy sometimes mean that those considerations are not properly acted upon.

Environmental work concerning risk is not without challenges. Naturally, such work deals with complex issues that often require advanced modelling and considerable technical expertise. On issues where projections are based on data with a lower degree of certainty risks can be harder to appreciate, and as more information emerges from rigorous science our appreciation of the risk changes and evolves alongside it.

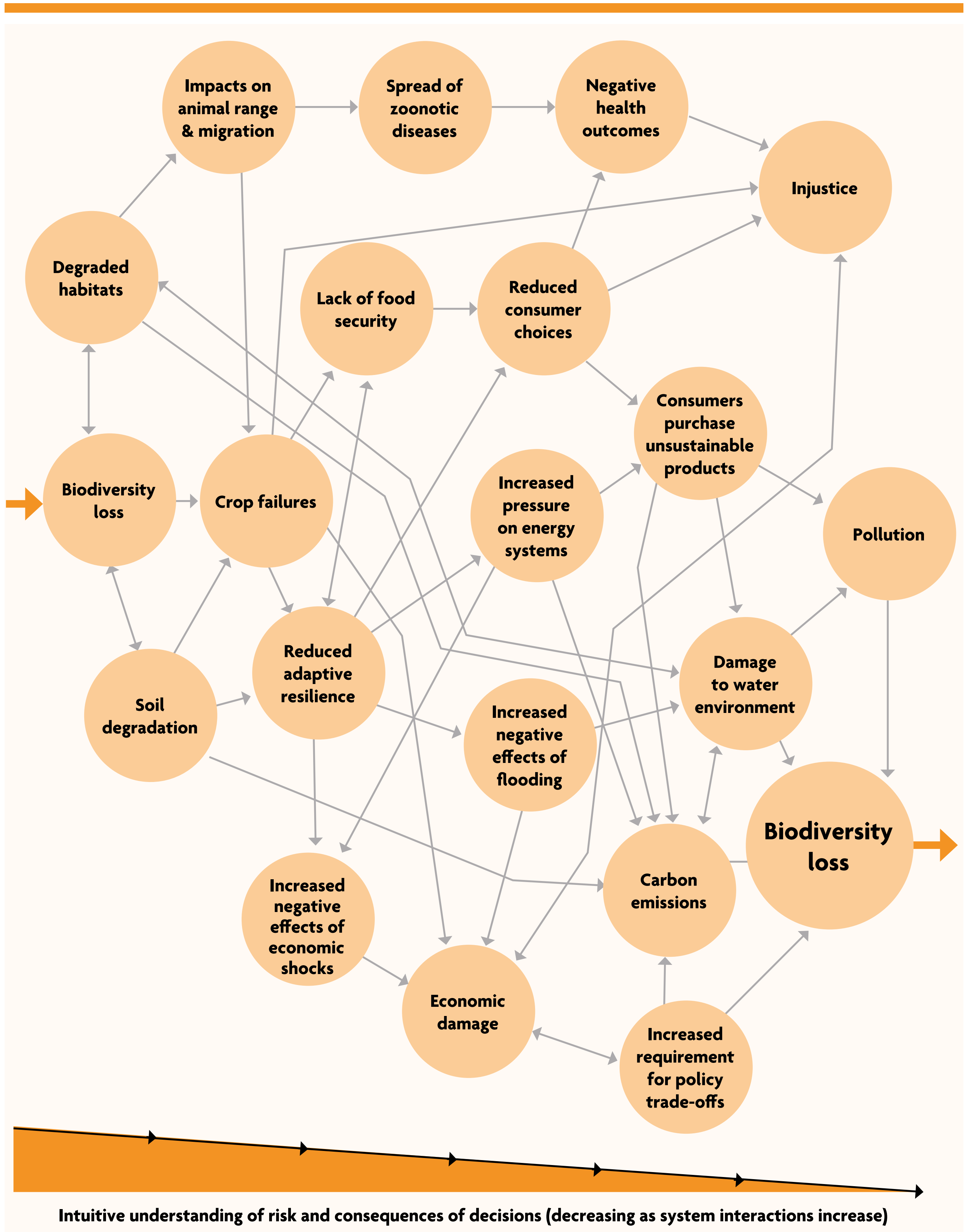
Those uncertainties can be controlled, but in the world of risk some uncertainty is natural. Without uncertainty risk would not be 'the potential for adverse consequences', but a statement of certainty. In some cases, the likelihood is so high that the two are virtually the same, but for the majority of our interactions with the natural world a classical view of cause to effect may be too simplistic to fully capture the complex relationships involved.

RISK AND HUMAN BEHAVIOUR

As we contemplate increasingly complex areas of risk, it becomes harder to describe them in simple terms. Since many such risks interact with critical areas of environmental policy, the ability to relate them to non-technical audiences, such as policy-makers and the public, is crucial. Though much as the complexity of risk and the inherent uncertainty attached to it can create challenges for communication, risk can also serve as a common language through which public engagement in environmental crises becomes more easily attainable.

On the simplest level, our typical understanding of climate change is one of risk: the climate is changing and without significant intervention it will continue to do so, leading to substantial harm. In basic terms, there is a potential for adverse consequences, depending on our actions. The reason this concept has been so easy to understand – despite the complex climate science underpinning it – is that risk reaches people on a basic psychological level, uniting different value systems and understandings of the world through a shared desire to avoid harm to ourselves.

FEATURE



▲ Figure 1. A simplified systems diagram demonstrating decreasing understanding of risk as system interconnectedness increases. (© Joseph Lewis)

FEATURE

▼ **Table 1. Common intuitive human strategies for handling risk under different expectations of loss or gain, according to behavioural economics, and the resulting challenges for addressing environmental crises. (© Joseph Lewis)**

Scenario	Common intuitive human strategies	Challenge for environment	Science communication adaptations
Potential for greater gain but risk of losing smaller benefits	Inaction, based on the view that the greater gain is too risky and not worth losing guaranteed marginal benefits	Some individuals or companies favour minor conveniences that cause environmental harm over the potential for larger benefits from enhancing the environment	Provide greater certainty of the benefits of a healthy environment, as well as articulating the scale
Potential for no losses but risk of greater loss	Gamble for a chance to lose nothing, even if it risks leading to a larger loss	Some individuals or companies gamble on the possibility of not having to make any changes to address environmental crises, even if it increases the likelihood of disastrous consequences	Provide greater certainty of the guaranteed losses already being caused by environmental crises, as well as the potential worst-case scenarios

In behavioural economics, the idea of risk aversion is a key factor in dictating how economists expect people to react. Behavioural economics suggests that when we are hoping to gain something, we tend to prefer a certain gain over a much larger but riskier gain. Conversely, when we fear we might lose something, we prefer to gamble on the chance of losing nothing, even if it poses a risk that we might lose much more in the long term (see **Table 1**).[4] The latter is important for environmental risk because it explains why people are often unwilling to make minor concessions in their own lives to avoid a much greater environmental harm occurring, even if that environmental harm causes them to lose more than the conveniences they are protecting.

By understanding how people think about risk, we can use those insights to make uncertain environmental impacts more tangible, guiding people to better decisions.[5] One approach is to demonstrate what people gain from a healthy environment rather than solely focusing on avoiding environmental harm. Similarly, the more certainty that we can provide of the losses people face from environmental crises – and the better understanding they have of the consequences of their decisions – the more likely they are to act in environmentally positive ways.

RISK VULNERABILITY AND CASCADING FAILURES

Despite the ways in which psychology can help us to communicate risk, there are certain concepts that remain hard to fully conceptualise, where a more technical understanding is needed. Issues such as systematic risk vulnerability and cascading failures are increasingly important in our consideration of interlinking environmental challenges and global economic decision-making.

Both concepts go beyond the evaluation of a single risk to consider how a collection of risks functions in the aggregate. A cascading failure happens when one risk leads to another, eventually spiralling into a series of greater risks, particularly where each risk has not been subject to proper adaptation measures.[6] For example, biodiversity loss could lead to crop failures that could produce food insecurity, which could encourage consumers to make more environmentally damaging decisions and in turn begin a new chain of cascading failures.

Where the adverse consequences associated with a risk cause a natural tipping point to be crossed, such as in the climate system, it may create new risks while also jeopardising our ability to address existing ones. Tipping points are typically changes to a natural system that are difficult or impossible to reverse and which often manifest as a result of cumulative changes over time; therefore, our theoretical understanding of risk is crucial to predicting and preventing the threat they pose.

Systematic risk vulnerability, by comparison, measures how vulnerable we are to aggregate risks resulting from systems interactions.[7] For example, as we decarbonise, many of our mitigation measures place an increasing burden on electricity generation, leading to an enhanced degree of vulnerability to that system failing, which requires us to increase resilience alongside our mitigation efforts. Each concept plays a role in helping us to think about the ways in which we need to be more resilient, although each requires an understanding of the complex and interlinking environmental, economic and social systems involved.

MAINSTREAMING SYSTEMS LITERACY

Public engagement through systems literacy can go a long way towards informing individuals, although many of these more complex considerations of risk may ultimately be the responsibility of governments and large organisations.

The consequence for the environment is that despite the challenges posed by risk and uncertainty we can expect positive developments from efforts to engage the public in order to facilitate a deeper understanding of environmental risk. Given the high stakes for the environment, society and the economy, deeper considerations of risk should be mainstreamed in policy with a view to the benefits that scientific understanding of the concept can provide.

When we address the environmental risks of pollutants in land or water, we often find ways to manage that risk so that the potential for harm does not manifest. For more complex risks, such as global environmental crises, our approach often needs to be one of governance, where we are seeking to find ways to live in a riskier world.

Either way, the increasing prevalence of risk empowers science to help society find answers. Where risks are complex or tied to interlinking systems, science can help to peel away the theory so that people can visualise what those risks mean for them. Where risks are more widely understood, science can play a technical role in managing them for the benefit of both people and the planet. Our understanding of risk is vital to the future of the environment, both on a theoretical and practical level. In that context, tools like systems thinking are valuable for citizens, policy-makers and scientists as we collectively seek better outcomes for the natural world. ES

Joseph Lewis is Policy Lead for the Institution of Environmental Sciences and is responsible for working to promote the use of the environmental sciences in decision-making. In 2022, he coordinated a deep-dive research project on risk and systems thinking and in 2023 will be directly involved in the IES's foresight and horizon-scanning project, Future of ES23.

REFERENCES

1. Reisinger, A., Howden, M., Vera, C., Garschagen, M., Hurlbert, M., Kreibiehl, S., Mach, K.J., Mintenbeck, K., O'Neill, B., Pathak, M., Pedace, R., Pörtner, H-O., Poloczanska, E., Rojas Carradi, M., Sillmann, J., van Aalst, M., Viner, D., Jones, R., Ruane, A.C. and Ranasinghe, R. (2020) *The Concept of Risk in the IPCC Sixth Assessment Report: A Summary of Cross-Working Group Discussions.* Guidance for IPCC Authors. Intergovernmental Panel on Climate Change: Geneva. https://www.ipcc.ch/site/assets/uploads/2021/02/Risk-guidance-FINAL_15Feb2021.pdf (Accessed: 16 November 2022).
2. White, G. (1981) *A Perspective of Environmental Pollution, by M.W. Holdgate.* Cambridge University Press: Cambridge.
3. Intergovernmental Science–Policy Platform on Biodiversity and Ecosystem Services (2022) *Methodological assessment of the diverse values and valuation of nature of the Intergovernmental Science–Policy Platform on Biodiversity and Ecosystem Services,* P. Balvanera, U. Pascual, M. Christie, B. Baptiste and D. González-Jiménez (eds). IPBES Secretariat: Bonn. https://doi.org/10.5281/zenodo.6522522 (Accessed: 16 November 2022).
4. Tversky, A. and Kahneman, D. (1988) 'Rational choice and the framing of decisions', in D.E. Bell, H. Raiffa and A. Tversky (eds) *Decision making: descriptive, normative, and prescriptive interactions.* Cambridge University Press: Cambridge, pp. 167–192. DOI:10.1017/CBO9780511598951.011.
5. Baddeley, M. (2017) 'Risky choices', in *Behavioural economics: a very short introduction.* Oxford Academic: Oxford (online edn). DOI: 10.1093/actrade/9780198754992.003.0005.
6. Buldyrev, S., Parshani, R., Paul, G., Stanley, H.E. and Havlin, S. (2010) Catastrophic cascade of failures in interdependent networks. *Nature*, 464, pp. 1025–1028. DOI:org/10.1038/nature08932.
7. Pitilakis, K., Argyroudis, S., Kakderi, K. and Selva, J. (2016) Systemic vulnerability and risk assessment of transportation systems under natural hazards towards more resilient and robust infrastructures. *Transportation Research Procedia*, 14, pp. 1335–1344. DOI:10.1016/j.trpro.2016.05.206.

Climate change and existential risk

OPINION

Bea Gilbert talks to researcher **Luke Kemp** about understanding and preventing the extreme risks of climate change.

Why is the study of existential or worst-case scenario risk so important, and how can it be used practically by the scientific community?

Large-scale risks, even if improbable, characterise our world. Think about history: global recessions, wars, revolutions. These ruptures define much of our history. They will also shape our future. When it comes to risk management, we require knowledge of worst-case scenarios. When operating under deep uncertainty, we should use what are called robust decision-making tools. One of these is the minimax principle: ranking options by their worst-case outcomes. It is difficult to do that if we don't know what the worst case is. On top of that, in many areas the extreme risks are unknown and neglected. While there are more-developed disciplines such as disaster risk management and peace and conflict studies, the focused study of catastrophic risk only really started in the last couple of decades and is still a nascent field. It is somewhat surprising given that stopping calamities that could harm a large number of people is morally intuitive.

What constitutes catastrophic risk for you and for the Centre for the Study of Existential Risk (CSER)? As we face increasingly worse environmental outcomes in many contexts, how, if at all, has this affected our goalposts for catastrophe?

There is no one single agreed definition of global catastrophic risk. There is some consensus around the definition of risk itself. Risk is usually both an adverse outcome and an attached probability, and is composed of at least three tenets: hazard, exposure and vulnerability. For instance, a hazard could be a tsunami. Exposure is being in an area that is hit by the tsunami. Vulnerability is a lack of infrastructure adapted to this tsunami, such as houses on stilts. In its most recent assessment report, the Intergovernmental Panel on Climate Change added a fourth dimension: response. Responses can either mitigate or aggravate the risk.

I define catastrophic risk as a level of risk that would lead to the loss of a quarter of the global population and a disruption of key global-critical systems, such as the food system, within decades. This is notable because it is unprecedented. We've never lost a quarter of our global population in such a short time. What is *precedented* is what I refer to as a global decimation risk: a loss of 10 per cent of the population in a given period of time with a disruption of critical systems.

That appears to have happened at least once or twice throughout global history: both the recurring bouts of the Black Death and the invasion and colonisation of the Americas. The latter led to the loss of roughly 90 per cent of Indigenous people on the continent – constituting roughly 10 per cent of the global population. Think of this as being a spectrum of global catastrophe, all the way from global decimation risks to eventual long-term human extinction.

How can we hope to accurately assess the outcomes of extreme and cascading climate hazards when we are facing the only time in history when huge natural and anthropic risks are interacting?

Understanding and foreseeing the unprecedented is challenging. If we don't have a statistical track record, we can't take a frequentist approach. Even for those hazards where we do – such as supervolcano eruptions or asteroid impacts – it is not straightforward. Many would consider a supervolcano eruption to be a threshold catastrophic event. Yet, that only considers the magnitude of the hazard, not the associated vulnerabilities. Work by my colleague Lara Mani[1] suggests that there could be a catastrophic impact from the eruption of a volcano of a lower order of magnitude if it hit at a global 'pinch point' where there is a cluster of international supply chains. This is far more likely to occur than a supervolcano eruption, which has a

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probability of roughly 1 in 10,000 per century. The probability of a high-impact volcanic eruption, on the other hand, could be as low as 1 in 6 – a roll of the dice.

It is difficult to consider risk cascades and vulnerabilities. I don't think we need exact probability, and we don't need to have a completely comprehensive and high-resolution model. What we really need to do is understand the most plausible pathways in which a cascade could occur and have policies in place to prevent them from occurring. We should also bear in mind the purpose of modelling risk. For me, it is to inform democratically created policy. I want models that can be understood, and which will inform a citizen's jury or assembly. This means that transparency and showing the rough pathways through which risk occurs are key.

Is there a danger that by attempting to find pathways to avoid worst-case scenarios or existential risk we might pay less attention to the character of near-catastrophic futures?

No, I don't think so. Particularly because large catastrophes will likely have local and regional beginnings. We'll have to characterise and understand the near-term and small-scale catastrophes and how they can potentially grow. For instance, if you're thinking about pandemics, you'll want to know about hotspots where zoonotic infections could occur, and how to prevent and control those local outbreaks before they spread into something much larger. So, quite to the contrary, I think an emphasis upon the extreme risks and catastrophes, if anything, helps to reinforce concerns about the more local, small-scale extreme risks. That said, there is the potential for a focus on speculative extreme risks to channel attention and resources away from more real near-term dangers. For instance, scholars in biosecurity have expressed concerns that a philanthropic focus on engineered pandemics could divert expertise and funding from other concerns.[2]

I think there is one danger of studying catastrophe that we need to be acutely aware of and vigilant to: the justification of emergency powers and crisis responses. Governments are prone to the use and abuse of emergency powers during a crisis. These powers can become permanent, normalised and eventually underpin a shift towards more autocratic forms of governance. In an article I published with BBC Future, I referred to this as 'despotic drift'.[3] Another problem with emergency powers is that they're usually inherently undemocratic. They're about empowering those at the top of the hierarchy to control a large populace during a crisis, usually on grounds of expediency and speed. Yet, looking at disaster risk management literature, there's no good basis for doing this. We know that people tend to respond relatively pro-socially and effectively to disasters. By comparison, there's a long track record of leaders making disaster responses substantially worse.

My main concern is that by looking at the bigger risk we justify even greater intrusive emergency powers and responses: interventions like mass surveillance and geoengineering. We need to bear in mind the dangers of these emergency options. For example, my work with Aaron Tang of the Australian National University has highlighted that stratospheric aerosol injection (inserting particles that reflect sunlight into the atmosphere to offset global warming) changes the distribution of risk. If the system were to be disrupted by a calamity such a nuclear war, then we would face 'termination shock'; the level of global warming that was being offset by that system would come back at an accelerated rate. This would mean that rather than getting an increase of 3C over a century, it would happen within decades. In short, the tail of the risk distribution fattens, even if the average outcome is better. We need to understand these risks if we are to make democratic decisions about emergency responses.

An aim stated in CSER's mission is to focus on risks that are 'plausible but poorly characterised or understood'. Do some risks intrinsically evade characterisation, and if so, how can they be managed?

I think there are two categories of risk which evade characterisation. The first is about risks that are complex and hence difficult to clearly characterise. The second category relates to the risks we couldn't foresee: the unknown unknowns.

Given that environmental risk is so interwoven with other types of risk, such as pandemics, war and societal collapse, how can environmental scientists attempt to isolate it, and is it wise to do so?

I don't think we should isolate it. Risk needs to be understood at an overall level. One of the key points we make in Climate Endgame is that when talking about global catastrophic risk, existential risk, extinction risk or global decimation risk, we're really talking about an overall likelihood of extinction or catastrophe occurring in a given timeframe, in a given scenario.[4] We're not talking about climate change by itself. Indeed, it is impossible to estimate the risks posed by climate change unless you place it into a wider scenario. Three degrees in a world that is characterised by multilateral cooperation, good adaptive technologies, democratic governance and high levels of social capital and equality could potentially be adapted to. Three degrees in a world marked by polarisation, disinformation, conflict and the build-up of dangerous disruptive technologies is a far more precarious prospect.

OPINION


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Do you believe that policy-wise there is a case for positive-reinforcement framing when it comes to looking at decision and action pathways – for example, quantifying existential security or existential hope?

There are good reasons to think about and characterise desirable futures. We could even potentially backcast from them: what are the steps we took as a collective society to make those better futures? I often think that we can bring the future into the present. When most people think about what they really want in the future, it tends to be more political empowerment, greater equality, better access to affordable healthcare and so on. Those are things that we can feasibly achieve right now; we don't need to think about space colonisation and Dyson spheres millennia into the future.

I believe the problem with thinking about existential hope or security is twofold. First is the terminology. When thinking about existential security, we automatically start to move away from politics and into the realm of security. This is dangerous. It begins justifying exactly the kind of emergency responses that I worry about, like mass surveillance. The second problem is that existential hope varies dramatically depending on the person. Ultimately, if we are going to talk about existential hope and existential security, we need to change the terminology and decide democratically on our visions of the future. Moral pluralism needs to be respected when we think about different futures, and the same can be applied to risk. There are some things we can all roughly agree on. Human extinction would be bad, as would large-scale human suffering and mortality, and they should be prevented. Yet, how the future should look and what trade-offs we should accept to reduce risks are areas that need to be decided on through democratic deliberation. These cannot be top-down, technocratic projects.[5]

Since hazards, exposure and vulnerability are subject to uncertainty, whereas we have more control over our responses to these impacts, how crucial is it that we focus our efforts on constructing resilient responses?

It is fundamental. To me, the point of risk management is not disaster voyeurism. Instead, it is to inform resilience and adaptation interventions. However, we can't think about responses in isolation. If you're responding while blind to your vulnerabilities, where you're exposed and what hazards you are facing, then your responses are going to be poor. You need to think about all the determinants of risk. Yet, I think exposure is where the main game is. If we understand what the institutions producing extreme risk are, then we can stop risk at its source. I have already undertaken some initial work on this.[6] In short, catastrophic risks appear to largely stem from a few economically powerful and secretive countries, such as the USA, Russia and China, and sectors, such as military industrial complexes, the fossil fuel industry and big tech. I believe making these institutions accountable, transparent and democratic is the most promising and reliable way of reducing the threat of future calamities. ES

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REFERENCES

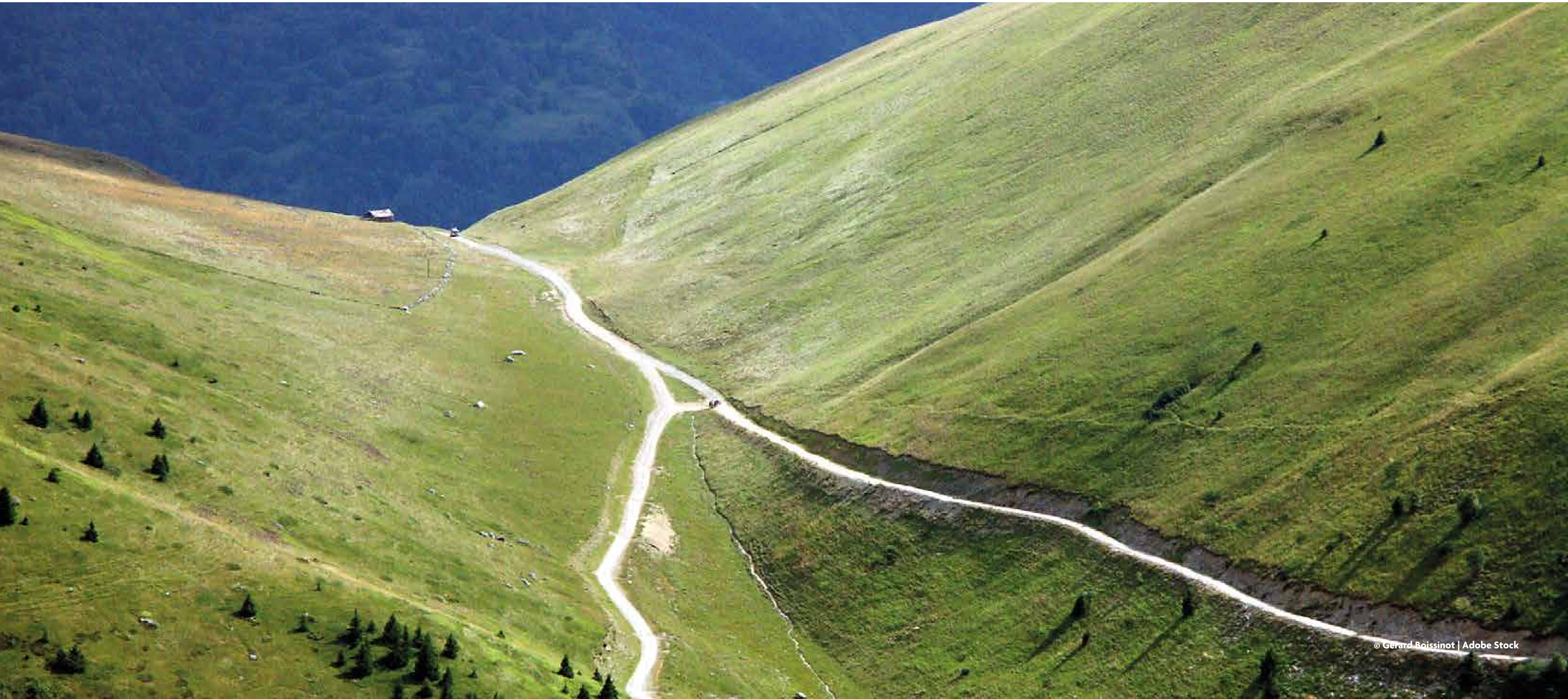
1. Cassidy, M. and Mani, L. (2022) *Huge volcanic eruptions: time to prepare*. https://www.nature.com/articles/d41586-022-02177-x (Accessed: 7 November 2022).
2. Lentzos, F. (2019) *Will splashy philanthropy cause the biosecurity field to focus on the wrong risks?* https://thebulletin.org/2019/04/will-splashy-philanthropy-cause-the-biosecurity-field-to-focus-on-the-wrong-risks/ (Accessed: 16 November 2022).
3. Kemp, L. (2021) *The 'Stomp Reflex': when governments abuse emergency powers*. https://www.bbc.com/future/article/20210427-the-stomp-reflex-when-governments-abuse-emergency-powers (Accessed: 7 November 2022).
4. Kemp, L., Xu, C., Depledge, J., Ebi, K.L., Gibbins, G., Kohler, T.A., Rockström, J., Scheffer, M., Schellnhuber, H.J., Steffen, W. and Lenton, T.M. (2022) Climate Endgame: exploring catastrophic climate change scenarios. *Proceedings of the National Academy of Sciences of the United States of America*, 119 (34), e2108146119. https://doi.org/10.1073/pnas.2108146119 (Accessed: 7 November 2022).
5. Cremer, C.Z. and Kemp, L. (2021) Democratising risk: in search of a methodology to study existential risk. *Social Science Research Network*. https://ssrn.com/abstract=3995225 (Accessed: 14 November 2022).
6. Kemp, L. (2021) *Agents of Doom: who is creating the apocalypse and why*. https://www.bbc.com/future/article/20211014-agents-of-doom-who-is-hastening-the-apocalypse-and-why (Accessed: 14 November 2022).

FEATURE

Translation at the research–policy interface: risk-based decision-making for net zero

Mark Workman, Erik Mackie, Irena Connon, Emily Shuckburgh and **Alyssa Gilbert** examine why this is necessary and how it can enrich climate action and decision-making.

As climate negotiators recover in the aftermath of COP27 – the latest conference of the parties (COP) – it is clearer than ever that more focus is urgently needed into how improved support can enhance policy design and decision-making on climate risk. While the body of scientific evidence on climate change grows increasingly larger, climate policy in the UK and globally continues to fall short of achieving the required reductions in greenhouse gas emissions. Rather than simply calling for more research into the climate risk problem itself, there is an urgent need to improve knowledge about how to implement and operationalise climate-related decisions.



PERCEPTION OF RISK

The impacts of climate change are evident, with extreme weather events increasing in frequency and severity. Scientifically informed warnings about the future risks posed by climate change are becoming clearer.[1] However, current climate policy is deficient and will not stave off the risks posed by climate change, many of which pose a high risk to life.[2] Existing national climate policies and pledges set us on course for a 2.7C temperature increase above pre-industrial levels – well above the Paris Agreement ambition of limiting warming to 1.5C.[3] This brings into focus the mechanisms by which scientific research on climate risk, emissions reduction and achieving net zero are being translated into policy and action.

This is especially salient following the considerable role that science played in the UK's response to the Covid-19 pandemic, where the translation timeframe for new research was reduced from 17 years to a matter of days.[4] There are clear differences in political and societal willingness to readily adopt scientific research relative to the immediacy of the risk's impacts. The pandemic response demonstrated that when risks occur in real time substantially greater willingness to quickly adopt scientific insight occurs compared to when risks unwind over longer timescales.[5]

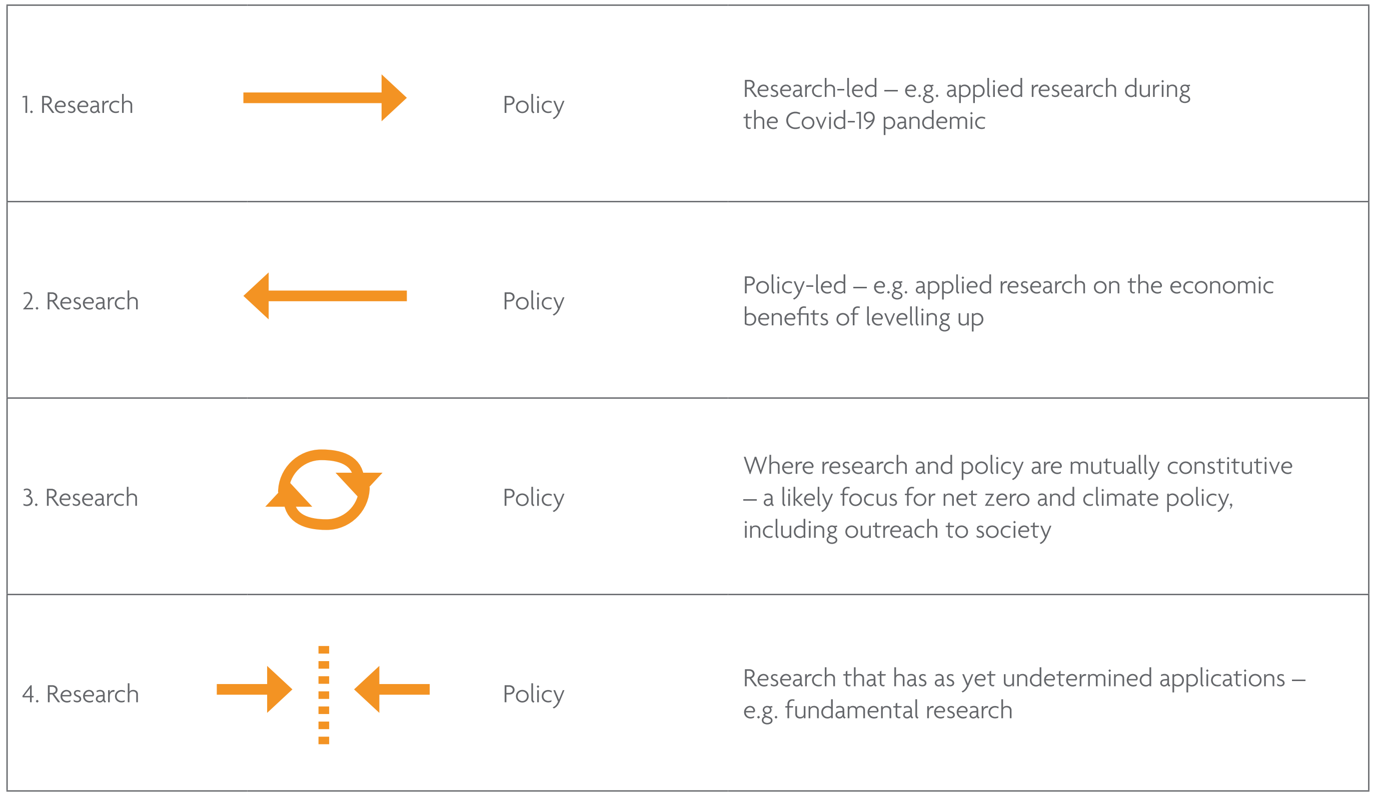
Climate change-related impacts would make the risks faced during the pandemic pale into insignificance.[1] Yet they remain largely perceived as an anticipated future outcome that will be thrust upon future generations.

But the need for immediate anticipatory action to realise net zero means that urgent policy action here and now is essential, as the climate will take decades if not centuries to stabilise from the emissions that have already been discharged since the start of the Industrial Revolution. This contrasts heavily with the months it took for the effects of decisions made during the pandemic to manifest.[6]

However, the effects of climate change *are* happening now, in real time. Alarmingly, the extent of carbon dioxide emissions already released amounts to such a level that the global atmospheric system is starting to behave in ways that scientists are struggling to anticipate through modelling tools – suggesting that the effects could be greater and happen sooner than predicted.[7] Therefore, revisiting the question of how we can improve the translation of climate risk analysis for better policy decision-making is timely.

THE RESEARCH–POLICY RELATIONSHIP

At present, research exploring how climate risk analysis is integrated into policy decision-making remains finite, subject to limited funding[8] and relatively poorly understood.[9] The concept of policy paradigms[10] highlights that, rather than a clear-cut distinction between analytical and decision-making functions in policy design, policy-making is shaped by divergent agendas and values. The role of co-production and boundary work (operating at the boundary between science and politics to shape the discourse) around science and policy in conferring legitimacy on analytical policy



▲ **Figure 1. Research–policy relation categories with examples. (Source: Based on Boswell and Smith[12])**

inputs is well documented.[11] Furthermore, according to Boswell and Smith[12] current science–policy relations emphasise perceived cultural differences between the scientific community[13] and policy-makers.[14] The distinction is emphasised by the fact that: 'Politics is not fundamentally preoccupied with what is true, but with what is relevant to securing power and producing collectively binding decisions.'[9]

The relational categories (see **Figure 1**) reflect how existing mechanisms for translating research into policy are heavily posited on a supply and demand construct. This applies in particular to categories 1, 2 and 4, and emphasises the need for better mutually constitutive research aligned with net zero and climate change to develop collectively binding decisions. In the UK, Impact Acceleration Accounts – strategic funding awards that are applied for only following completion of a research programme – further entrench the notion that policy impact is an afterthought rather than an integrated, integral function of the research process. Other mechanisms – such as developing relationships and networks and undertaking internships, secondments and fellowships – highlight the need to better understand respective distinct cultures in a systemic rather than ad hoc fashion through the establishment of structures, whereby researchers and policy- and decision-makers engage in an ongoing dialogue as evidenced by category 3.[15]

IMPROVING TRANSLATION TO REDUCE RISK

A recent study by the UK Universities Climate Network examined the nature of the research–policy translational interface through a combination of literature review, case study assessment and input from policy workshops with stakeholders.[16] Issues explored included: why the plethora of climate risk assessments and decision-support tools available to decision-makers are not translating into effective policy action on climate risk; what the challenges, complexities and uncertainties associated with the translational process are; and how the research translation pipeline could be improved to achieve more effective decision-making.

Substantial synergies and alignment within the scientific and policy-making communities were found, which allows category 3 of the research–policy relationship to be better hardwired and potentially institutionalised. Researchers seek impact to re-shape the social world they describe. This implies that research–policy models to promote engagement with knowledge users do not have to result in the aforementioned cultural distinctions. Both researchers and policy-makers have a fundamental interest in securing societal buy-in and collectively binding decisions to address information gaps and market failures. Both recognise the role of societal stakeholders in providing the policy-enabling environment to 'legitimise' the actions of decision-makers to motivate action on climate change.

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The role of communicating climate risk, therefore, goes beyond the discrete end-of-process component of decision-making and policy design to which it is often relegated. There exists an increasing need for researchers and policy-makers to enable inclusive societal dialogue about pathways forward to achieve net zero and the trade-offs that need to be considered. Opening the discussion in this way would force societies to confront the disruptive reality that limiting global average warming to well below 2C, let alone 1.5C, is only achievable by making transformative changes throughout all elements of society, the impacts of which could be unequally distributed, thus making the inclusion of diverse stakeholders and viewpoints an imperative.

The study made three recommendations aimed at policy-makers and other stakeholders, including academic researchers and third-sector organisations.

1. Enhance collaboration. This refers to improving collaboration between decision-makers, policy-makers, analysts, researchers and other stakeholders in the co-development and co-design of operational climate risk assessments and policies. Specific effort must be given to unpacking the nuances of risk, uncertainty and complexity in system contexts to highlight how audience worldviews and the way decision-makers investigate the world can distort climate policy design and effectiveness, especially when system contexts are complex. There is a tendency for policy-makers, operational planners and the analytical community to think with perspectives that are often deterministic, optimised and technocentric, which blind decision-makers as to how to reconcile the management of uncertainty, complexity, non-linearity and emergence that prevail in managing climate risk in policy design. It is fundamental that we move beyond reductionist perspectives that characterise problems as complicated rather than complex. Instead, the multiple technological disruptions simultaneously being stimulated within a highly interconnected and reflexive socio-economic system need to be recognised.

2. Identify research and capacity gaps. There are remaining gaps around climate risk decision-making under uncertainty and working with stakeholders across decision value chains can help to address them. The focus of much climate decision-support research is on developing modelling capability, despite this representing only a small part of the decision-making process. A more holistic approach to climate policy design and decision-making research should be operationalised: one that embraces deep uncertainty, adopts participatory approaches and enables climate communication and decision-making to exist in an iterative exchange with policy development rather than separate from it. The role of many integrated components for decision-making also need to be better understood – ranging from the role of mixed methods[17,18] and exploratory modelling[19] to culture and psychology[20,21] in climate decision-making, and the role of narratives,[22] visualisation[23] and language[24] in conveying aspects of decision-making to different audiences.

3. Co-create effective translation mechanisms. These are required to better embed decision-support tools into policy and employ a participatory approach to ensure inclusion of diverse values and viewpoints. Developing climate policy by relying solely on expert knowledge in traditional elite-to-elite fora can lead to groupthink and a lack of insight as to what the disparate range of societal decision-makers consider important. A more inclusive approach is needed where participatory approaches allow multiple values to be considered. Although recent

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climate assemblies have calibrated the capacity for solution sets to be societally acceptable, these remain poorly connected to policy design and their effectiveness in generating more traction around issues relevant to net zero still needs to be assessed.[25] Despite a surge in activism amongst young people, youth participation in climate policy design remains limited. This has significant implications for climate justice, as younger generations will be most affected by the future impacts of policy decisions made today.

CONCLUSION

As the protracted and somewhat distant COP process testifies, more effective translation of climate risk analysis into policy is required. It is imperative that research and policy-making are better integrated through improved dialogue between researchers, policy-makers and society. We have ample evidence about the risks posed by climate change, but this evidence must translate into improved policy for climate action if we are to address the enormity of the climate risk challenge. Resources are not currently being targeted towards this aspect of the climate risk challenge and research timelines are not well matched to the needs of the policy-making community. If this does not change, it is likely that the policy response to climate change enacted through the COP process will continue to lack the effectiveness required to achieve a climate-stable future. ES

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REFERENCES

1. Intergovernmental Panel on Climate Change (2021) 'Summary for Policymakers', in V. Masson-Delmotte, P. Zhai, A. Pirani, S.L. Connors, C. Péan, S. Berger, N. Caud, Y. Chen, L. Goldfarb, M.I. Gomis, M. Huang, K. Leitzell, E. Lonnoy, J.B.R. Matthews, T.K. Maycock, T. Waterfield, O. Yelekçi, R. Yu and B. Zhou (eds) *Climate change 2021: the physical science basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change.* Cambridge: Cambridge University Press, pp. 3–32. doi:10.1017/9781009157896.001.
2. Quiggin, D., de Meyer, K., Hubble-Rose, L. and Froggatt, A. (2021) *Climate Change Risk Assessment 2021.* London: Chatham House. https://www.chathamhouse.org/2021/09/climate-change-risk-assessment-2021 (Accessed: 6 December 2022).
3. Climate Action Tracker (no date) Home page. https://climateactiontracker.org/ (Accessed: 7 November 2022).
4. Morris, Z.S., Wooding, S. and Grant, J. (2011) The answer is 17 years, what is the question: understanding time lags in translational research. *Journal of the Royal Society of Medicine*, 104 (12), pp. 510–520. https://pubmed.ncbi.nlm.nih.gov/22179294/ (Accessed: 7 November 2022).
5. Ariely, D. (2015) *Irrationally Yours: On Missing Socks, Pickup Lines, and Other Existential Puzzles.* New York: Harper Perennial.
6. Andrijevic, M., Schleussner, C-F., Gidden, M.J., McCollum, D.L. and Rogelj, J. (2020) COVID-19 recovery funds dwarf clean energy investment needs. *Science*, 370 (6514), pp. 298–300. https://www.science.org/doi/abs/10.1126/science.abc9697 (Accessed: 7 November 2022).
7. Clark, P. (2021) *Have we entered a new phase of climate change?* https://www.ft.com/content/3125bee9-73ae-4abf-ac58-615fe8e43396 (Accessed: 6 December 2022).
8. Woolf, S.H. (2008) The meaning of translational research and why it matters. *Journal of the American Medical Association*, 299 (2), pp. 211–213. https://pubmed.ncbi.nlm.nih.gov/18182604/ (Accessed: 7 November 2022).
9. Connelly, S., Vanderhoven, D., Rutherfoord, R., Richardson, L. and Matthews, P. (2021) Translating research for policy: the importance of equivalence, function, and loyalty. *Humanities and Social Sciences Communications,* 8 (Article no. 191). https://www.nature.com/articles/s41599-021-00873-z (Accessed: 7 November 2022).
10. Burns, T.R., Calvo, D. and Carson, M. (2009) *Paradigms in Public Policy. Theory and Practice of Paradigm Shifts in the EU*. Bern, Switzerland: Peter Lang AG.
11. Beck, S. and Mahoney, M. (2018) The IPCC and the new map of science and politics. *Wiley Interdisciplinary Reviews*, 9 (6), e547. https://wires.onlinelibrary.wiley.com/doi/full/10.1002/wcc.547 (Accessed: 7 November 2022).
12. Boswell, C. and Smith, K.E. (2017) Rethinking policy 'impact': four models of research policy relations. *Palgrave Communications,* 3 (44), pp. 1–10. https://strathprints.strath.ac.uk/68525/ (Accessed: 7 November 2022).
13. Sutherland, W.J. and Burgman, M. (2015) Policy advice: use experts wisely. *Nature*, 526, pp. 317–318. https://www.nature.com/articles/526317a (Accessed: 7 November 2022).
14. Tyler, C. (2013) Top 20 things scientists need to know about policy-making, *The Guardian*, 2 December. https://www.theguardian.com/science/2013/dec/02/scientists-policy-governments-science (Accessed: 7 November 2022).
15. Evans, M.C. and Cvitanovic, C. (2018) An introduction to achieving policy impact for early career researchers. *Humanities & Social Sciences Communications*, 4 (88). https://doi.org/10.1057/s41599-018-0144-2 (Accessed: 7 November 2022).
16. Mackie, E., Connon, I.L.C., Workman, M., Gilbert, A. and Shuckburgh, E. (2022) *Climate risk decision-making: translation of decision support into policy.* UK Universities Climate Network. https://www.cambridge.org/engage/coe/article-details/634fd089e3f3eeab966 0a214 (Accessed: 6 December 2022).
17. Lempert, R.J., Popper, S.W. and Bankes, S.C. (2003) *Shaping the Next One Hundred Years: New Methods for Quantitative, Long-Term Policy Analysis.* Santa Monica, CA: RAND Corporation.
18. Gambhir, A., Cronin, C., Matsumae, E., Rogelj, J. and Workman, M. (2019) *Using Futures Analysis to Develop Resilient Climate Change Mitigation Strategies.* Grantham Briefing Paper No 33. https://spiral.imperial.ac.uk/bitstream/10044/1/74659/7/Grantham%20Briefing%20Paper%2033%20Futures%20Analysis%20for%20Climate%20Mitigation.pdf (Accessed: 7 November 2022).
19. Workman, M., Darch, G., Dooley, K., Lomax, G., Maltby, J. and Pollitt, H. (2021) Climate policy decision making in contexts of deep uncertainty – from optimisation to robustness. *Environmental Science & Policy,* 120, pp. 127–137. https://www.sciencedirect.com/science/article/pii/S1462901121000733 (Accessed: 7 November 2022).
20. Lewis, M. (2017) T*he Undoing Project: A Friendship that Changed the World.* New York, NY: Penguin Press.
21. Heick, T. (no date) *The cognitive bias codex: a visual of 180+ cognitive biases.* https://www.teachthought.com/critical-thinking/cognitive-biases/ (Accessed: 7 November 2022).
22. Bushell, S., Colley, T. and Workman, M.H. (2015) A unified narrative for climate change. *Nature Climate Change*, 5 (11), pp. 971–973. https://www.researchgate.net/publication/283536967_A_unified_narrative_for_climate_change (Accessed: 7 November 2022).
23. Levontin, P., Walton, J.L., Auffeger, L. and Barons, M.J. (2019) *Visualising Uncertainty: A Short Introduction.* London: AU4DM Networks.
24. Granger Morgan, M. (1998) Commentary: uncertainty analysis in risk assessment. *Human and Ecological Risk Assessment,* 4 (1), pp. 25–39. https://doi.org/10.1080/10807039.1998.11009680 (Accessed: 6 December 2022).
25. Climate Assembly UK (2021) Home page. https://www.climateassembly.uk/ (Accessed: 7 November 2022).

Are we jumping out of the frying pan and into the fire?

Duncan McLaren explores the risks of incorporating solar geoengineering in the debate on climate change responses.

ANALYSIS

In recent years the impacts of climate change have become more visible and widespread, and the evidence of growing future risks increasingly indisputable. Yet effective responses to climate change have remained difficult to agree upon and deliver, with continued resistance from vested interests and fears of undesirable social or economic impacts. Some climate researchers now suggest that the combination of growing impacts with inadequate progress on cutting emissions makes it important to reconsider technological ways to suppress temperatures, known as geoengineering. In particular, they argue that the apparent risks of geoengineering should be compared with the risks arising from continuing climate change to decide whether to pursue such technologies.

ANALYSIS

SOLAR GEOENGINEERING

There is an ongoing debate regarding what geoengineering encompasses. Most definitions of geoengineering include carbon-removal techniques, some of which are already being deployed, alongside a more consistently controversial group of technologies that directly manipulate the Earth's radiative balance, mainly by reflecting sunlight. The use of such so-called 'solar' geoengineering as a possible way to cool the planet is not a new idea. But in recent years hypothetical and as yet untested solar geoengineering methods have increasingly gained attention in scientific circles, notably in the USA.[1] Ideas include deploying mirrors in space to reflect sunlight or dispersing cloud condensation nuclei (water droplets and salt particles) to make marine clouds thicker and brighter. But the method that gets most attention is spraying particulates in the high atmosphere to screen out some incoming sunlight. This is usually called stratospheric aerosol injection (SAI) and is inspired by evidence that large volcanic eruptions can trigger temporary global cooling in this way.

However, when informed about such ideas, people are often fearful, perceiving solar geoengineering as 'messing with nature' in unpredictable and undesirable ways.[2] Many policy-makers, activists and climate scientists have previously rejected such ideas as too risky, not only worrying about technical uncertainty and possible side effects, but also fearing disruption of climate negotiations, geopolitical challenges and deterrence of emissions-reduction efforts.[3,4]

Research using climate models indicates that technologies such as SAI would reduce global temperatures, but inevitably reconfigure global climate systems, with possible harmful effects on crucial processes such as precipitation, which could undermine food security. Furthermore, SAI merely masks the effects of greenhouse gases, so if deployed without deep emissions cuts, there is a risk of a 'termination shock' effect if it were halted for technical or political reasons. Termination shock refers to the effect in which temperatures would rebound rapidly to the higher levels dictated by the prevailing greenhouse gas concentrations. Concerns have also been raised about the inability of SAI to ameliorate ocean acidification, and its potential to lead to increased acid deposition and slow the recovery of stratospheric ozone.[3,5,6]

MEANINGS OF RISK AND INCOMMENSURABILITY

But before trying weigh solar geoengineering's risks against those of continued climate change, it is important to step back and look at what a discussion dominated by questions of risk might imply. There are diverse meanings to risk. In common parlance a focus on risks draws attention more to what we might lose rather than what we might gain. And although much has been said about the need to better consider tipping points and extreme climate risks, on balance there may have been too much attention to the risks of climate change – generating anxiety, hopelessness and inaction[7] – and too little attention to the potential co-benefits of emissions reduction, such as fewer deaths from air pollution or greater energy security from reduced dependence on fossil fuel imports.

More technically, risk is a product of the knowable likelihood and impact of a given outcome. By contrast, the challenges involved here suggest a broad understanding of risk, encompassing uncertainties in outcomes as well as in probabilities and impacts. This seems appropriate: both climate change and solar geoengineering are characterised by deep uncertainty about social, political and environmental consequences.

But this creates serious problems for assessment. Such diverse risks and uncertainties are incommensurable – there is no common measuring scale. Their impacts cannot be reduced meaningfully to proxies such as monetary values or even healthy life years. Political and cultural differences will always matter. So a useful comparison of risks will need to incorporate public deliberation and political judgements in some form. It will also need to consider the distribution of risks, not just their scale or likelihood.

> **"What matters is not just aggregate risk, but also who faces those risks and their resilience and ability to participate in the decisions that determine which risks they should face."**

Such questions are in danger of being excluded by a simplistic framing of the issue of whether solar geoengineering involves *more* or *less* risk than climate change, especially if that risk is itself defined narrowly in terms of material impacts.

A broad definition of risk also helps avoid the trap of assuming that the public necessarily overestimates the risk of novel technologies by also capturing the political and systemic risks that ordinary people tend to take more seriously than scientists (such as fears that genetically modified seeds would enable greater corporate control of food chains). We must beware of framing such concerns out of the analysis. Public revulsion and activist rejection of solar geoengineering most likely reflect a rich understanding of the diverse incommensurable risks and the politics and power relations involved as well as a gut reaction to the idea.

RISK–RISK FRAMING

Recently, advocates for more geoengineering research have argued increasingly strongly that the risks involved should be put into the context of the risks associated with climate change.[8,9] Critically, they suggest that in assessing solar geoengineering interventions we should balance the risks of pursuing them against those of eschewing them: the risks of continued climate impacts. Some have argued for the development of a systematic framework for risk–risk analysis.[10] Yet it is not entirely clear how such assessments might differ from prior attempts to examine the risks and benefits of geoengineering (where the benefits have often been framed in terms of reduced climate risk).[5,6]

Advocates for risk–risk analysis acknowledge that solar geoengineering involves significant risks and uncertainties. But they are concerned that the risks of continued climate change are greater, especially as global temperature rises seem destined to exceed the 1.5C guardrail. In direct, material terms focused on climate responses, the modelling evidence suggests SAI may be less risky than allowing global warming to progress as currently anticipated. Such advocacy may also reflect scientists' beliefs that public fears of risks from geoengineering are exaggerated, resembling views regarding other novel technologies such as genetic modification.[11]

Yet climate risks are not simply material issues of scientific evaluation. They are deeply political and also arise in contesting framings of the issue. One of the most worrying risks regarding solar geoengineering, for example, is that merely considering it could provide a new excuse for denialist obstruction of climate action and deter or delay emissions reduction – a problem often described as a moral hazard or mitigation deterrence.[4] And there are other ways in which arguing for a risk–risk assessment of solar geoengineering could unintentionally affect the politics of climate change, and thus the risks involved.

MITIGATION DETERRENCE AND THE FALSE BINARY

Mitigation deterrence can arise where promises of geoengineering create the misconception that the worst impacts of climate change can be averted without accelerating emissions reduction. For example, when added to integrated models of climate economics, hypothetical future geoengineering consistently crowds out near-term emissions cuts. Guarding against such problems is clearly essential, but not simple. Advocates for more research typically try to make it clear that they do not see solar geoengineering as a *substitute* for mitigation but a *supplement*, yet the mechanics of the problem – emerging through political, economic and cultural feedback – mean that such declarations alone cannot prevent mitigation deterrence.[12] Even strong research governance cannot control what happens to


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research findings in the corporate, political and media domains. But a reflexive approach to responsible research could at least ensure that researchers and funders consider these dangers in advance and tailor research and the dissemination of its findings carefully.[13,14]

Of course, a sophisticated risk–risk analysis would itself encompass consideration of the mitigation deterrence problem. And if the process could be effectively insulated from the risk of distracting from mitigation while it was being undertaken – perhaps by a formal moratorium on the development and deployment of solar geoengineering – then it would probably help us to better understand and manage this risk in the future.

Closely related to the mitigation deterrence issue is the problem that framing the necessary comparison as being between the risks of solar geoengineering and those of continued climate change might construct a false binary – in other words, implying that there are no (longer) any other options that might help us avoid dangerous climate change-related effects. It need not be the intention of geoengineering research advocates to imply this; indeed, most are careful to highlight that other interventions should also be considered in assessing the residual risks of climate change, but whatever specific scenario of continued or residual climate risk is invoked, the structure of the risk–risk argument approach tends to frame out other possible responses.

THE RISKS AND NEED FOR RADICAL INTERVENTIONS

Yet, other radical responses to overcome climate procrastination and reduce climate risks may still be technically and politically feasible. Scholars have exposed the continuing obstructionism of the fossil fuel industry and other vested interests.[15] Decarbonisation potential, driven by the falling costs of renewable energy, is growing. Investment is pouring into innovative carbon-removal techniques. And public deliberation exercises such as citizens' assemblies typically call for more radical emissions reductions than their governments have promised, often placing more emphasis on climate safety than on economic growth.

We may wish to subject alternative radical responses – such as large-scale deployment of carbon removal or deliberate economic degrowth – to the same rigorous scrutiny of a comprehensive risk–risk analysis. However, we should be careful not to imply that such alternatives do not exist. Such responses may involve serious side effects and risks of non-delivery due to political or social opposition; but so does solar geoengineering. Solar geoengineering should not be treated as a uniquely feasible response, even as carbon budgets approach exhaustion. Its risks should be compared with the risks of other possible interventions, not only with those arising from climate change.

CONCLUSIONS

Too narrow a framing of risk is clearly problematic. For such critical issues as climate change we need to consider a broad set of risks and understanding of risk. But defining risk broadly also brings additional political challenges. Since the September 11 attacks, governments have increasingly sought to manage not just probabilistic (i.e. likely) risks, but also possibilistic (i.e. unlikely but extreme) risks.[16] This has serious downsides. Defining risks in this way exacerbates the likelihood of securitisation, in which responses to extreme or existential threats are removed from democratic politics as usual and treated as matters of sovereign security, justifying military interventions or disregard for human rights. If this were to happen to climate policy the chances of just and sustainable outcomes would seem remote.

Solar geoengineering may yet have a role to play in reducing climate risks, and a risk–risk analysis might help us evaluate this role. But it seems premature to endorse such methods without first better understanding exactly which problem they are expected to solve. Moreover, this brief review of the issues involved suggests that conclusions drawn from a narrow risk–risk analysis might be seriously misleading, and how a focus on risk could even distort climate policy in unhelpful ways. For a risk–risk approach to be useful we must first guard against the mitigation deterrence problem and then carefully clarify what we mean by risk. In conducting risk–risk assessments we must ensure they consider multiple meaningful scenarios (and multiple possible interventions), include political and social risks as well as climatic and environmental ones, find better ways to compare different types of risk, consider distribution of risks and pay close attention to ways in which risks might interact.

Critically, the process must be embedded in open, deliberative methods to help identify salient risks and judge between diverse risks. The central lesson from recent years of climate procrastination is not that we need to become more or less afraid of risks, but that we need more open, deliberative and democratic ways to apply multiple criteria to guide responses to climate change. Risk-based assessments might inform such processes but only if constructed in ways that are open about the presumptions and politics involved.

At heart the argument for a risk–risk framework seems entirely reasonable. We should not reject an apparently risky approach out of hand if so doing might expose us to worse harm. It would be wise to examine it more closely and do so in the context of predicted and possible risks that might be averted or lessened by its use. But we should also be wary of the dangers of framing the question in this way. Hurriedly grasping at an approach that leads to the securitisation of climate action or undermines essential emissions reduction would be equally problematic, akin to leaping from the frying pan and into the fire. ES

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REFERENCES

1. National Academy of Sciences (2021) *Reflecting Sunlight: Recommendations for Solar Geoengineering Research and Research Governance.* Washington DC: National Academies of Science, Engineering, and Medicine.
2. Corner, A., Parkhill, K., Pidgeon, N. and Vaughn, N.E. (2013) Messing with nature? Exploring public perceptions of geoengineering in the UK. *Global Environmental Change*, 23 (5), pp. 938–947. https://doi.org/10.1016/j.gloenvcha.2013.06.002 (Accessed: 16 November 2022).
3. Robock, A. (2016) *Smoke and Mirrors Are Not the Solution to Global Warming*. Environmental Chemistry Group Bulletin. https://www.rsc.org/images/Smoke%20and%20mirrors%20are%20not%20the%20%20solution%20to%20global%20warming_tcm18-249333.pdf (Accessed: 16 November 2022).
4. McLaren, D. (2016) Mitigation deterrence and the 'moral hazard' in solar radiation management. *Earth's Future,* 4 (12), pp. 596–602. https://doi.org/10.1002/2016EF000445 (Accessed: 16 November 2022).
5. Royal Society (2009) *Geoengineering the Climate: Science, Governance and Uncertainty.* The Royal Society: London. https://royalsociety.org/-/media/Royal_Society_Content/policy/publications/2009/8693.pdf (Accessed: 16 November 2022).
6. National Research Council (2015) *Climate Intervention: Reflecting Sunlight to Cool Earth.* Washington, DC: The National Academies Press.
7. Hickman, C., Marks, E., Pihkala, P., Clayton, S., Lewandowski, R.E., Mayall, E.E., Wray, B., Mellor, C. and 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), pp. E863–E873. https://doi.org/10.1016/S2542-5196(21)00278-3 (Accessed: 16 November 2022).
8. MacMartin, D.G., Visioni, D., Kravitz, B., Richter, J.H., Felgenhaur, T., Lee, W.R., Morrow, D.R., Parson, E.A. and Sugiyama, M. (2022) Scenarios for modeling solar radiation modification. *Proceedings of the National Academy of Sciences*, 119 (33), e2202230119. https://doi.org/10.1073/pnas.220223011 (Accessed: 16 November 2022).
9. Parson, E.A. (2021) Geoengineering: symmetric precaution. *Science*, 374 (6569), p. 795. DOI: 10.1126/science.abm8462.
10. Harrison, N., Pasztor, J. and Barani Schmidt, K-U. (2021) *A Risk-Risk Assessment Framework for Solar Radiation Modification*. Carnegie Climate Governance Initiative. Lausanne: International Risk Governance Center. https://infoscience.epfl.ch/record/287240 (Accessed: 4 December 2022).
11. Oreskes, N. (2020) *Why do white men and scientists tend to downplay the risks of technology?* https://www.scientificamerican.com/article/why-do-white-men-and-scientists-tend-to-downplay-the-risks-of-technology/ (Accessed: 4 December 2022).
12. McLaren, D., Willis, R., Szerszynski, B., Tyfield, D. and Markusson, N. (2021) Attractions of delay: using deliberative engagement to investigate the political and strategic impacts of greenhouse gas removal technologies. *Environment and Planning E: Nature and Space.* https://doi.org/10.1177/25148486211066238 (Accessed: 16 November 2022).
13. Stilgoe, J. (2015) *Experiment Earth: Responsible Innovation in Geoengineering.* Abingdon: Routledge.
14. McLaren, D. and Corry, O. (2021) The politics and governance of research into solar geoengineering. *WIREs Climate Change*, 12 (3), e707. https://doi.org/10.1002/wcc.707 (Accessed: 16 November 2022).
15. Ekberg, K., Forchtner, B., Hultman, M. and Jylhä, K.M. (2022) *Climate Obstruction: How Denial, Delay and Inaction are Heating the Planet.* London: Routledge.
16. Amoore, L. (2013) *The Politics of Possibility: Risk and Security Beyond Probability.* Durham: Duke University Press.

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OPINION

The role of cities in tackling climate-related risks

Bea Gilbert in conversation with **David Dodman** on urban risk assessment and adaptation and how communities can shape our future.

Is it important that cities are considered as standalone entities in terms of risk? If so, which type of urban risk has the strongest interaction with the environment?

I think it is important that cities are considered as significant but not standalone entities. They are significant in our understanding of risk because the way that risk gets created, mediated and experienced has some very urban dimensions to it. The way cities function brings together people, economic enterprises, culture and infrastructure in very dense networks. However, I do not think they are standalone because cities are connected to the areas around them through their hinterlands, trade and capital networks, movement of people, and relationships with nearby and distant ecosystems and other cities. In terms of risk, you cannot isolate it within any one city because actions taken in any one location can be very influential in activating or reducing risk elsewhere – for example, manufacturing that is dependent on materials grown or extracted from elsewhere. The idea of systemic risk is helpful: there is not one single driver, but multiple connecting drivers of risk that interact with the environment.

In one of your papers, you write that 'each city has a huge inertia to change'.[1] Can you outline why this is the case and how it influences risk?

There is a tension in cities between a great deal of dynamism on the one hand and strong resistance to change on the other. Where there is resistance to change it can be caused by the legislative frameworks at a national level, or by fixed assets with an extensive lifespan – for example, energy or transport infrastructure and the built environment. Many of these things have a significant lifetime, meaning that they cannot be very flexible. Decisions that were made 20 years ago and those that are being made now will be fixed in place in cities for a considerable length of time. This influences risk: as the nature and location of hazards change over time, these fixed assets are going to remain in place. At an institutional level, fixed decision-making processes, which are not designed to be flexible or responsive to changing circumstances, can drive an increase in risk as well since cities are not equipped to deal with these changing external circumstances. However, cities are also dynamic: innovation, new forms of social

OPINION

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organisation and technological innovation take place. The flipside is that dynamism and innovation in cities is where the solutions to climate change will come from.

In your opinion, which cities have shown good examples of risk-sensitive development and why have they been successful? Are there examples of cities that are underperforming in this sense?

It is hard to identify cities that are performing particularly well in all aspects of risk-sensitive development. What can be found are interesting examples of ideas that are being put into practice in different ways. I think the challenge is to learn from these various examples – rather than having an ideal city as a model – especially because cities exist under different circumstances with regard to political economies and environmental situations. I do, however, think Durban, South Africa, is a good example. There has been an excellent effort to institutionalise climate responses in the way the city functions as a whole. Taking climate change and the environment seriously in all decisions across the municipality has shown how one can make risk-aware decisions in sectors from housing to health as well as in the narrow confines of the environmental department.

Elsewhere, grassroots urban groups, including women's savings groups in the Philippines, have been instrumental in trying to understand the risks that communities face on low-lying land or next to rivers, as well as trying to find alternative places for low-income groups to acquire affordable land. Often, people in many low-income and informal settlements do not have access to formal land titles and, therefore, bank accounts. It is common for women to club together on a daily basis as a way of making financial savings and providing collective support. Sometimes, those groups have grown beyond the narrow focus on savings and have thought about the provision of basic services and access to land for low-income groups. They have also developed ways to understand and document risk in poor neighbourhoods and have put systems into place to respond to disasters when they strike.

Another good risk-sensitive example is from Nairobi, Kenya. The city government has been implementing special planning areas for some of the large low-income neighbourhoods, which has made a significant difference in managing risk. The local government has taken a multi-sectoral approach, bringing together all the aspects of planning and urban design – housing, water, sanitation, education, economic development – and treating them in an integrated way to redevelop and regenerate low-income neighbourhoods.

I do not think it is helpful to identify cities that are underperforming. Rather, there are a lot of cities that are not being enabled to perform because they do not have the appropriate level of devolved responsibility around things that can reduce risk, such as land-use planning, infrastructure development or housing. Similarly, they may not have the financial autonomy or revenue to make investments. These are structural issues at national and global levels, which mean that cities cannot perform as well as they should. Most city officials want to make their cities better places to live but are often working under circumstances that do not enable them to effect change.

Why is community participation important when aiming to build risk resilience?

The first reason is a moral imperative. The people who are most affected should have the right to be involved in identifying problems and creating solutions. People are not passive subjects but active agents in the creation of the city. Cities are more than the infrastructure that defines them; they are also the way in which people come together and build societies.

There are also practical reasons. Decades of experience shows that projects involving affected communities achieve more, last longer and are more cost-effective than ones that are imposed. Such projects achieve more because people feel invested in them; they respond to identified needs rather than an abstract, outsider's perspective. Particularly with climate risk, where the location of housing is so important, there are so many cases of resettlement programmes in locations that people do not want to live in. This makes them unsuccessful; people may lose their livelihoods or return to their original homes and the investment spent by both individuals and the authorities is wasted. Involving people in decisions means the programmes themselves are more successful.

It is also important to go beyond just thinking of community participation and into recognising the differences within communities and the roles within them. Community planning needs to be gender-sensitive, taking into account roles and expectations, and the different needs and priorities of all involved. It needs to be sensitive to the power relations within communities – landlords, tenants, the employed and unemployed. There are also questions of age, recognising that a high proportion of African and Asian cities are made up of younger residents,[2] and taking into account the participation of young people and children in decision-making.

On an intra-city level, particularly with a focus on the global south, where might there be an imbalance between those who are creating hazards and those who are most exposed to them?

Some of it is about how hazards are produced and some is about the capacity of different groups to protect themselves from those hazards. There are some basic things in the built environment that must be considered – for example, there may be wealthier groups with larger housing plots whose construction practices could lead to higher, more rapid levels of run-off in a river basin, which may adversely affect people living downstream. There might also be infrastructure that meets the needs of wealthier groups but that displaces risk to create hazards for poorer groups. For example, commercial developments, shopping malls or road networks can only


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serve a fraction of the urban population but create hazards for many others because of the way the built environment is modified, leading to repercussions for run-off and the urban heat island effect. Any urban environmental change process has political implications and creates winners and losers. If we are looking to reduce risk, it is important that we genuinely reduce it rather than just transfer it between areas or groups of people.

How important is it that urban policy-makers have comparable metrics for assessing different types of risks?

Policy-makers have basic data and information needs. Some of those are fundamental, quantifiable metrics. Decision-makers need to know where the urban heat island will be most severe, where flooding is more likely and what the return periods are for those floods as well as have sound mapping of the biodiversity and ecological hotspots across a city. These quantitative metrics are necessary to understand risk.

However, I think it is even more important to have processes in place to agree on what the risks are and how to respond to them. This is more complicated because responses to risks have important human and behavioural dimensions to them, and inevitably involve trade-offs. Identifying, agreeing on and responding to those trade-offs is the tricky part of assessing different types of risk and the priority that needs to be given to them. How do you assess the different types of risk from urban expansion in a particular direction when you are trying to avoid floodplain locations and biodiversity hotspots, or attempting to provide accessibility for local livelihoods and urban services? Every one of these has associated risks attached, so the challenge is for policy-makers to have ways of engaging with urban residents – particularly low-income communities – around assessing and prioritising risks.

Urban residents can also be involved in the co-production of risk-reduction measures. Co-production goes beyond community consultation and can either be a tick-box exercise or more meaningful engagement where governments take on board community priorities. The co-production element operates at a level beyond that: by jointly implementing solutions. This is particularly important where municipal governments are under-resourced and rely on community labour and participation for delivering solutions like micro-drainage, water networks or community sanitation. These examples show ways in which municipal governments and communities can work together more constructively.

What place do nature-based solutions have in combating risk, given that some urban areas may have little to no natural space remaining?

Nature-based solutions have an important role to play alongside investments in social and physical infrastructure. At their best, they provide a lot of benefits such as biodiversity conservation, livelihoods for low-income groups and low-cost recreation opportunities. Urban low-income groups often depend more on the collective facilities available in cities. Low-income residents don't have private gardens or green spaces, so nature-based solutions can provide collective benefits to those who might not otherwise have them. At the same time, such facilities are just one approach – one which can be implemented well or poorly – and which might be used as a justification for pushing people off land rather than giving them greater access to resources. Such decisions might be done in ways that are imposed from the top and not reflective of local priorities or be informed by these priorities. So while nature-based solutions have a significant potential, they can't be applied in an unthinking way and must be adapted to local contextual situations.

Looking at possibilities such as extreme water shortages and flooding, do you believe certain cities are in danger of becoming uninhabitable within the next few decades?

On the one hand, cities show a remarkable amount of resilience and ability to change and reinvent themselves. The real driver of urbanisation, and the things that maintain cities, is whether there is a fundamental economic purpose for their existence. Some cities do exist in incredibly inhospitable environments but are successful because there are many other reasons why they are there. What is clear, however, is that sizeable city areas that will become home to millions more people – almost all global population growth in the next few decades will take place in cities across Africa and Asia – will mean more people are at risk from climate-related disasters and the health impacts of climate change and generally become more inhospitable, particularly to those on low incomes. We have not yet seen the tipping point between the economic logic for a city's location and the hazard logic for it not being located somewhere. But we have seen that cities decline for all sorts of reasons, and there is definitely a possibility that environmental causes will be a driver for urban decline.

What might be the biggest resistance to urban risk adaptation from a management and leadership perspective?

I see two areas of resistance. One is economic: advanced investment in risk reduction is far better than responding after the fact, but it requires upfront investment where there are many other pressing needs. Trying to get such funding from government and corporate organisations to invest in risk adaptation – when they are more focused on the immediate rather than longer-term returns – is very difficult.

The second is the lack of an enabling environment for city leaders to act on risk reduction. Even where city leaders are knowledgeable and committed, with an engaged civil society, they may not have the autonomy, rights or resources to reduce risk. There is a role here for governments to have national urban plans and policies that create the right conditions for city leadership to reduce risk. There is a role for global agreements, such as the United Nations Framework Convention on Climate Change, to recognise cities as significant contributors and to provide the environment and funding for them to fulfil their potential. While the annual conference of the parties negotiations have increasingly recognised cities as important locations for climate action, this has not been reflected in the creation of support mechanisms for city authorities. We must close the gap between acceptance of their importance and facilitation of potential fulfilment. ES

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REFERENCES

1. Satterthwaite, D. and Dodman, D. (2013) Towards resilience and transformation for cities within a finite planet. *Environment and Urbanization*, 25 (2). https://doi.org/10.1177/0956247813501421 (Accessed: 23 November 2022).
2. Dodman, D., Leck, H., Rusca, M. and Colenbrander, S. (2017) African urbanisation and urbanism: implications for risk accumulation and reduction. *International Journal of Disaster Risk Reduction*, 26, pp. 7–15. https://doi.org/10.1016/j.ijdrr.2017.06.029 (Accessed: 4 December 2022).

New members and re-grades

Fellow is for esteemed individuals in environmental science and sustainability who are held in high regard by their peers.

Ian Buchan – Lead Principal Environmental Consultant
Julie Hill – Chair & Non Executive Director

Associate is for individuals beginning their environmental career or those working on the periphery of environmental science.

Abigail Urquhart – Geo-Environmental Scientist
Adam Bamford – Senior Environmental Scientist
Alasdair Robertson – Graduate Air Quality Consultant
Alexander Tasker – Geo-Environmental Specialist
Alicia Becker – Senior Geoenvironmental Consultant
Anastasia Zyganitidou – Geo-Environmental Engineer Graduate
Angus Wilsdon – Land Quality Scientist
Bethany Piercy – Graduate Environmental Due Diligence Consultant
Calvin Mclay – Environmental Incident Response Technician
Cameron Couston – Waterway Operative
Cody Izatt – Geo-Environmental Engineer
Edwina Dominic – Junior Environmental Consultant
Elliott Lamond – Graduate Air Quality Consultant
Faten Bazine – Environmental Scientist
Gbenga Joshua Ogunleye – Waste Management Process Specialist
Georgie Coppin – Graduate Air Quality Consultant
Gregory Pitcher – Graduate Environmental GIS Consultant
Heather Gore – Nuclear Graduate
Holly Smith – Claims Handler
Jack McLoughlin – Graduate Environmental Consultant
Jasmine Bowler – Graduate Geo-Environmental Consultant
Jessie May – Graduate Air Quality Consultant
Joseph Izzard – Graduate
Kaitlin Eames – Environment & Consent Graduate
Kate Swan – Graduate Environmental Consultant
Katie Strazzanti – Graduate Environmental Scientist
Katie Keirl – Graduate Air Quality Consultant
Katie Dowrick – Sustainability & Environmental Management Graduate Consultant
Lucy Pearson – Air Quality Technical Officer
Luke McEvoy-Hughes – Bat Surveyor
Maria del Carmen Alarcon Tapia – Air Quality Consultant
Natalie Roxburgh-Smith – Geo-Environmental Consultant
Nicole Laing – Geo-Environmental Engineer
Niranjchan Ramanathan – Graduate Air Quality Consultant
Rachel Southall – Graduate Environmental Consultant
Rhiyan Patel – Student
Robert Brett – Agri-Environmental Consultant
Robin Bruce – Graduate Air Quality Consultant
Ross Higson – Graduate Environmental Consultant
Samuel Willby – Graduate
Sinead Doran – Graduate Environmental Consultant
Swathi Arivalagan – Assistant Air Quality Consultant
Ugne Ankenaite – Environmental Engineer
Weng Lam Kam – Assistant Consultant
Yasmin Mueller – Air Quality Graduate Consultant

Affiliate is for individuals with an interest in environmental issues but who don't work in the field, or for students on non-accredited programmes.

Ajibola Oyebamiji – PhD Student
Alex Johnson – Graduate Air Quality Consultant
Alice Sparkes – Student
Amy Hughes – Student
Arvind Tiwari – Research Fellow
Emma Clarke – Graduate & Activity Leader
Joshua Ugor – Student
Lindis Kipp – Student
Louis Brown – PhD Student
Louise Wright – Senior Environmental Manager
Lucas Kulczak – Student
Muhammad Khan – Student
Noah Richter-Mahr – Student
Sei Hoe Tan – Relationship Manager for the Bank of China
Timothy Lovell – Joint Managing Director
Tushar Gairola – Assistant Consultant Air Quality
William James – Teacher

Member is for those individuals who have substantial academic and work experience within environmental science.

Aidan Nelson – Senior Environmental Engineer
Alexander Wilson – Principal Environmental Professional
Alexandra Pitcher – Principal Consultant
Alice Waylett – Principal Geo-Environmental Consultant
Alicia Thew – Climate Analysis Manager
Alun Roberts-Jones – AQMAU Senior Technical Advisor
Amanda Sterkenburg – Marketing Manager, Europe
Anil Waduge – Geo-Environmental Consultant
Aoife O'Leary – Environmental Consultant
Christy Carr – Technial Director
Clement Ogunkunle – Senior Lecturer
Colin Slater – Senior Design Environmental Coordinator
Cormac Dunne – Senior Environmental Consultant
Daniel Newbery – Senior Acoustic & Air Quality Consultant
Daniel Barrett – Head of Sustainability & Net Zero
Edward Betteridge – Environmental Scientist
Emily Pears-Ryding – Principal Air Quality Consultant
Fiona Russell – Environmental Advisor
Gavin Roberts – Environmental Advisor & Coordinator
Georgina Snaize – Project Coordinator & Minerals & Estates Surveyor
Gopinath Kalaiarasan – Post Doctoral Researcher
Hamid Atta – Senior Environmental Consultant
Hassan Anagreh – Environmental Assessment Technical Specialist
Henry Obanya – PhD Researcher in Ecotoxicology
Hiu Yue Sze-To – Engineer
Huw Davies – Head of ESG
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Jennifer Reid – Assistant Environmentalist
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John Fox – Senior Associate Director, Sustainable Infrastructure
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Tobias Duchene – Senior Geo-Environmental Consultant
Tom Middleton – Project Manager for Remediation
Ugonna Nkwunonwo – Lecturer & Researcher
Wael Hefny – Senior Environmental Manager
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An egret reflected in water
© Brenton Nichol

IES photography competition

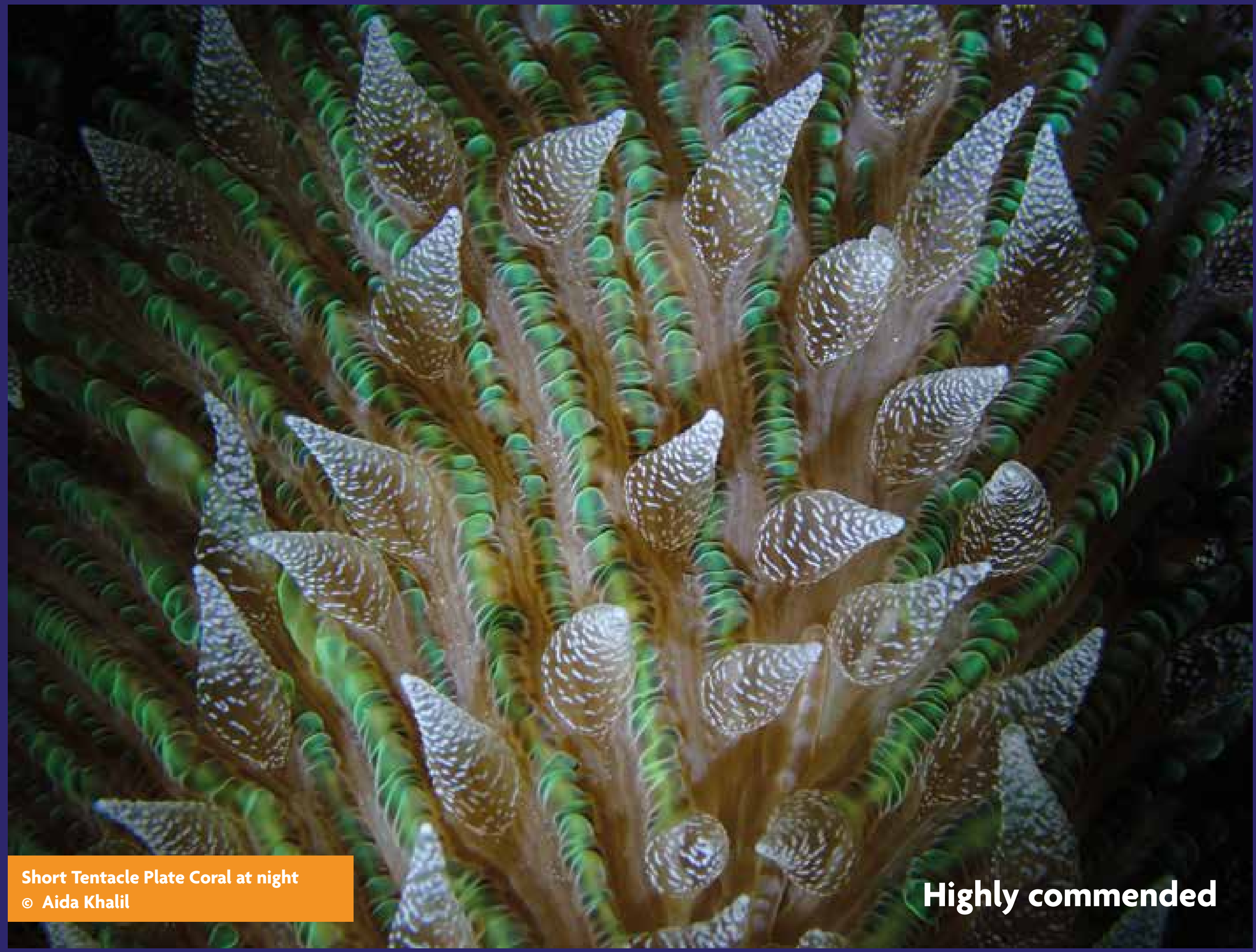
Water is a broad theme, and whether captured in imposing landscapes, peaceful ebbs, or at the minute scale, we were once again impressed by the quality of photos this year.

Choosing favourites amongst nearly 100 submissions was a difficult yet enjoyable task, and we're happy to announce that the winning photo is 'An egret reflected in water' by Brenton Nichol. The judges were particularly struck by its composition and subtle tone.

On capturing the image, Brenton said:

'The photo was taken at the Reserva Natural de s'Albufereta in Majorca, Spain in July 2022. I went down to the reserve just before sunrise and scoped out subjects from the observation platform. The coastal wetland attracts many bird species, and several were observed on the morning of the capture including purple heron, shag and black-winged stilt. The egret was wading in the shallows of the estuarine wetland hunting for food. I waited for the egret to get into a position where it wasn't impeded by long vegetation or other obstacles. The photo was taken with a Sony Alpha a6400 with a Sony 200-600mm lens. Aperture size f-8, shutter speed 1/500, ISO 320. Focal length was 600mm. A local photographer was also there at the same time taking photos. Although I don't speak any Spanish, and he didn't speak any English, we still managed to point out subjects to each other whilst observing from the platform.'

Fishermen on Nwungi beach, Zanzibar
© Roger Barrowcliffe



Short Tentacle Plate Coral at night
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The melee
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CASE STUDY

Remediation of a domestic property following an escape of oil

Conor Armstrong and **Adam Bamford** outline the complexities and challenges involved in oil spill remediation.

Assessing risk following a domestic oil spill is often problematic. There are various receptors in a typical property that are affected in different ways by hydrocarbon contamination. Therefore, it is crucial that an appropriate sampling methodology is implemented from the outset to ensure an accurate contaminant plume is identified before remediation can proceed. However, there are often limitations to sampling in certain locations, compounded by a lack of relevant assessment criteria for many of the affected receptors and the desire by stakeholders (often a home insurer) to minimise costs by limiting the extent of testing where possible.

CASE STUDY

SITE CONTEXT

This case study outlines the remediation of a property close to Enniskillen in County Fermanagh, Northern Ireland (see **Figures 1** and **2**). The property sits on an elevated site surrounded by agricultural land, with a watercourse at the bottom of the slope. An on-site septic tank is used for wastewater, and storm and rainwater are piped to the nearby watercourse.

In the centre of the house, an oil-fired AGA cooker (see **Figure 3**) was used to provide domestic heat and hot water, fed from an oil storage tank to the rear of the property that contained approximately 1,300 litres of kerosene. A braided metal flexible hose immediately behind the range failed causing a substantial volume of kerosene to escape into the property.

When assessing such a situation, the following receptors are considered as part of a conceptual site model (CSM):

- Human health;
- Buildings and other structures;
- Services;
- Controlled waters; and
- Third-party impacts.

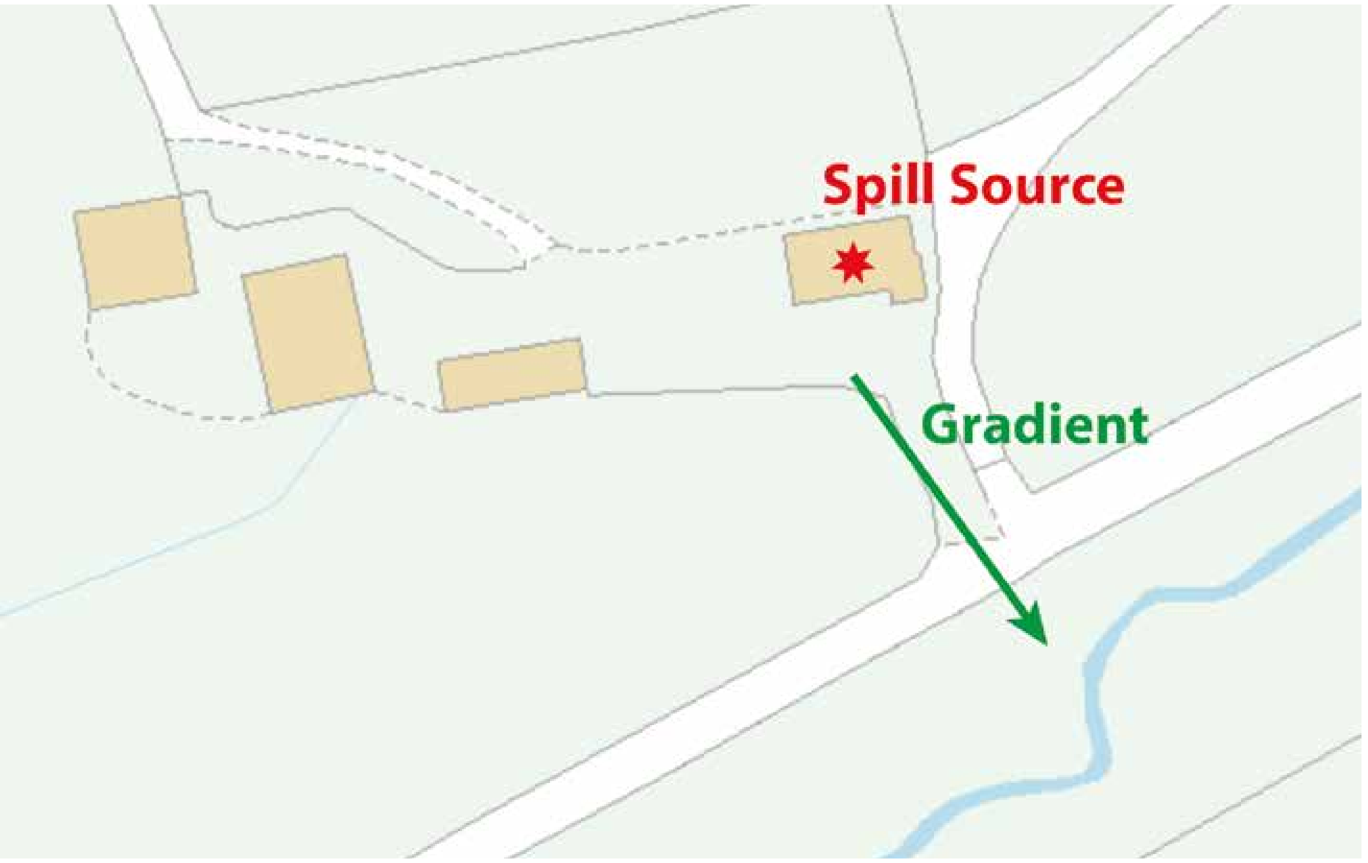
To assess the risk to each receptor, various testing methodologies are utilised.

AIR QUALITY

An initial on-site survey of the internal air quality was tested in the first instance using a handheld photoionisation detector (PID) that measures volatile organic compounds (VOC) originating from kerosene. However, this device can be sensitive to other compounds commonly found in a domestic setting such as air fresheners, perfumes, detergents and polishes. VOCs deriving from these can occasionally present false positive readings. The wide spectrum of compounds to which the PID is sensitive can make it difficult to obtain a single screening value above which an unacceptable risk to occupants exists. Assessors will often set different thresholds, leading to conflicting advice over whether immediate intervention is necessary.

A more robust air quality analysis can be undertaken in a laboratory. When the contaminants of concern are hydrocarbons, analysis that provides speciated – or grouped based on boiling points – aliphatic and aromatic bandings, total VOCs, and benzene, toluene, ethylbenzene and xylene (BTEX) internal air concentrations should be obtained. However, this analysis can take time, so the initial PID readings are used as an interim measure.

Using guidance on suitability for use from Land Quality Management and the Chartered Institute of Environmental Health – known as LQM/CIEH S4ULs [1] – in-house standards are derived for each of the speciated bands and BTEX compounds reported on by the laboratory. This allows for greater certainty in the risk assessment. Of note, however, is the additive effect of the different hydrocarbon bands and the use of hazard quotients and a total hazard index to assess risk. While this is mentioned in the LQM/CIEH S4ULs and expressed in more detail in guidance issued by the Environment Agency, the additive effect of individual bands or compounds is often overlooked.[2]



▲ Figure 1. Location of property in relation to a local watercourse. (Source: Ordnance Survey map obtained from Spatial NI)

▲ Figure 2. Front aspect of the property. (© Avada Environmental Ltd)

SOIL QUALITY

Assessing the risks stemming from soil contamination can be fraught with difficulties. Stakeholders often strive for the most economical testing method to evaluate the risk posed by hydrocarbon contamination. The use of probe holes is often encouraged and can be undertaken by a handheld drill fitted with a 1 m bit. After digging a hole, the PID nozzle is inserted and a reading obtained. The limitations with this approach are that it is impossible to determine which

▲ Figure 3. AGA cooker, the source of the kerosene leak. (© Avada Environmental Ltd) soil horizon gave rise to a positive reading. It is likely that contamination closer to the surface will cross contaminate any clean vapours from deeper within the probe hole or vice versa. In addition, the various soil type characteristics can give differing readings. Finally, as previously noted, the PID will respond to VOCs other than kerosene making it difficult to identify the source. Furthermore, any shallow groundwater present in the probe hole can suppress the on-site VOC concentration.

A more robust approach is to use boreholes or trial pits. These enable the retrieval of physical samples for a visual assessment and accurate soil characterisation determination. Samples can then be sent to a laboratory for contamination analysis using the Total Petroleum Hydrocarbons Criteria Working Group analysis, which is a method of dividing a blended hydrocarbon into fractions based on their boiling point by means of gas chromatography. (While the BTEX analysis is similar, it is limited to the four discrete compounds it is designed to measure.) Different levels of toxicity attach to the various fractions. This enables a comparison with generic assessment criteria such as the LQM/CIEH S4ULs. It is important that this analysis considers any exceedances in individual bands as well as takes into account the potential additive effects and relevant pathways, and the LQM/CIEH S4ULs offers guidance on this. Relevant pathways are important, as the risks arising from contamination 1 m below ground are substantially different to those on the surface, even from the same contaminant.

WATER ENVIRONMENT

The property was surrounded by hardstanding with drainage gullies and roof downpipes feeding into a culvert that exited downhill at a nearby river. Land to the rear of the property was agricultural and uphill. Precipitation and groundwater flowed under the property and discharged into the watercourse below.

When groundwater under a property is contaminated with hydrocarbons, that groundwater will release VOCs, which could then contaminate a property's indoor air. The concentration of contamination in the groundwater and the depth to that groundwater are key factors in assessing this risk.[3] Contamination was being carried by the groundwater and storm system drainage network into the nearby watercourse. Emergency containment measures were installed (see **Figure 4**), and the Northern Ireland Environment Agency was notified of the incident.

STRUCTURES

The assessment of risk to structures is not straightforward because the effects of contamination are not homogenous across the various building features. The main elements considered are masonry and concrete, insulation, membranes and damp courses, which can have an indirect effect on other receptors such as human health, utilities and controlled waters. There is scant information available regarding the impact of hydrocarbon contamination on concrete, and the LQM/CIEH S4ULs are not appropriate since these only apply to soils.

▲ **Figure 4. Oil boom installed at the nearby river. (© Avada Environmental Ltd)**

Most damp-proof membranes in domestic properties are made from polyethylene (also known as polythene) and act as a barrier for water coming up from below ground. This material has an extremely poor chemical resistance to gasoline-range organics (GRO) and diesel-range organics (DRO). Any contact with kerosene will likely compromise the membrane, causing it to fail. Similarly, damp-proof courses – which are built into walls to block rising damp – are also often also made of polyethylene. While they tend to fare slightly better than membranes because they are thicker, they will ultimately fail if there is direct contact with the contaminant.

Insulation can come in many types. Polystyrene sheets have exceptionally poor resistance to GRO and DRO, including kerosene. Bead insulation is generally made from polystyrene and also reacts poorly. High-density insulation is more resistant but is difficult to sample, as the frictional heat of any drilling or coring equipment can cause the release of VOCs, potentially leading to false positive readings even if there is no contamination. Expanding foam (polyurethane) is, however, quite resistant to kerosene. Yet, even resistant insulation can be problematic since it can absorb kerosene and act as a continuing source of hydrocarbon vapours.

SERVICES

Most drainage pipes are made from polyvinyl chloride and offer excellent chemical resistance. However, the seals used in joints are generally made from ethylene propylene diene monomer rubber, which has a poor resistance to GROs and DROs leading to failure when there is direct contact with contaminants. Potable water pipes are typically made from polyethylene. Similar to membranes made from the same material, they offer poor resistance to DROs and GROs such as kerosene. It is often the case that a water main passing through a contaminant plume will need to be replaced. In addition, the plumbing pipework in a property can be tainted, leaving an oily taste in tap water.

THE REMEDIATION PROCESS AT THE PROPERTY

The programme of remedial works at a domestic property largely adheres to the approach set down in the UK Government's land contamination risk management guidance.[4] In addition, investigations should follow the relevant standards such as the code of practice for ground investigations (BS 5930:2015+A1:2020);[5] the investigation of potentially contaminated sites (BS 10175:2011+A2:2017);[6] and taking soil samples to determine VOC presence (BS 10176:2020).[7]

An initial study was undertaken at the property followed by a detailed site investigation to adequately determine the extent of the contamination, with the findings used to create a site CSM. To undertake an effective assessment of a property, a good understanding is required of both the land contamination and the nature of the various structure types and how they are assembled.

Once the extent of the problem was understood, a schedule of remedial works was designed that factored in all the available data together with the economic

▲ **Figure 5. Internal excavations. (© Avada Environmental Ltd)** requirements and needs of the homeowner (e.g. costs and a desire to return home as soon as possible). While there are many ways to remediate a property, a balance should be struck that provides the most sustainable approach. For example, the severance of a pathway may be preferable to the removal of a contamination source; both methods remove the pollutant linkage and are equally valid remediation approaches. However, homeowners may be resistant to anything other than source removal, so it is important to guide them through the process and the validity of the proposed approach.

Ultimately, the remedial works required were extensive. Internally, a chimney breast was removed and a large section of the internal flooring was excavated (see **Figures 5 and 6**). The removal of significant quantities of contaminated material inside the property down to foundation level was necessary. Accumulated groundwater in the excavations was found to have much free product (i.e. kerosene in its pure form) (see **Figure 7**) and iridescence was present on the surface (see **Figure 8**). This indicated that the solubility limits for at least some of the contaminants had been exceeded. An oil–water separator was used on site until all the free product was removed.

The base of the excavation was treated with oxidisers, and the exposed rising wall blockwork was scrubbed.

▲ **Figure 6. Treatment to the exposed blockwork inside the property. (© Avada Environmental Ltd)**

▲ **Figure 7. Free product at property foundations. (© Avada Environmental Ltd)**

▲ **Figure 8. Iridescence perched on the groundwater within the excavations. (© Avada Environmental Ltd)**

The contamination present within the wall cavity was flushed out. Saturated concrete was replaced, and insulation, membranes and damp-proof courses were removed and replaced if they had come into direct contact with kerosene. Where removal was impractical and a particular building element could act as a VOC source, it was either encapsulated to lock in the contamination or treated to degrade the contamination to lower levels. Where no good assessment criteria existed, professional judgement was used. Externally, contaminated soil in contact with the walls of the property was excavated and disposed of. This was necessary to prevent re-contamination of the property and to lower the risk to groundwater.

▲ **Figure 9. Vapour membrane installed under the concrete subfloor. (© Avada Environmental Ltd)**

Following this, the property was restored to its original layout. As part of the reinstatement process a hydrocarbon vapour membrane was installed to sever the pollutant pathway and assist in mitigating the risk of vapours entering the property from any residual low-level contamination that could still be present at depth (see **Figure 9**).

The entire remediation project took nearly nine months. Some initial delays arose over negotiation of the nature of the work and the cost, but it was important that a mutual agreement was reached to ensure final sign-off to everyone's satisfaction. Finally, a validation survey was undertaken to ensure that all previously identified unacceptable risks to receptors had been addressed and the amenity of the property restored. By undertaking a high-quality investigation and thorough understanding of the risks and uncertainties present in the assessment, stakeholders were satisfied that the remedial measures employed were sufficient and appropriate. ES

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REFERENCES

1. Nathanail, C.P., McCaffrey, C., Gillett, A.G., Ogden, R.C. and Nathanail, J.F. (2015) *The LQM/CIEH S4Uls for Human Health Risk Assessment.* Nottingham: Land Quality Press.
2. Environment Agency (2005) *The UK Approach for Evaluating Human Health Risks from Petroleum Hydrocarbons in Soils.* https://webarchive.nationalarchives.gov.uk/ukgwa/20140328084622/http://cdn.environment-agency.gov.uk/scho1104bikb-e-e.pdf (Accessed: 16 November 2022).
3. Society of Brownfield Risk Assessment (2017) *Development of Generic Assessment Criteria for Assessing Vapour Risks to Human Health from Volatile Contaminants in Groundwater.* Version 1.0. https://sobra.org.uk/wp-content/uploads/2016/07/REPORT_SoBRA-Groundwater-Vapour-GAC.pdf (Accessed: 7 November 2022).
4. Environment Agency (2020) *Land Contamination Risk Management.* https://www.gov.uk/government/publications/land-contamination-risk-management-lcrm (Accessed: 7 November 2022).
5. British Standards Institution (2015) *BS:5930:2015+A1:2020 Code of Practice for Ground Investigations.*
6. British Standards Institution (2017) *BS 10175:2011+A2:2017 Investigation of Potentially Contaminated Sites. Code of Practice.*
7. British Standards Institution (2020) BS *10176:2020 Taking Soil Samples for Determination of Volatile Organic Compounds (VOCs). Specification.*

OPINION

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The risks and impacts of deep seabed mining

Pippa Howard and **Nicky Jenner** examine why mining the ocean seabed should not be an option.

CONTEXT

The climate emergency is finally front and centre in the minds of global leaders, with a proliferation of plans and strategies for transitioning to a low-carbon future. Alongside the climate agenda, ambitious biodiversity goals are being negotiated, and in December 2022 stakeholders come together in Montreal to agree a global target to reverse biodiversity loss by 2030 and become nature positive by 2050.

However, one industry looming in the oceans and growing surreptitiously could undermine progress towards global goals and irrevocably impact the planet. Deep seabed mining (DSM) is a new frontier for extraction of the Earth's natural resources that seeks to exploit mineral deposits in the deepest parts of the oceans. It has been fuelled by recent discoveries of wide-ranging mineral deposits (including phosphorite nodules, polymetallic nodules, cobalt-rich ferromanganese crusts and seafloor massive sulphide deposits) as well as rising demand for their use in high-tech industries including electronics and energy storage.

WHAT IS DEEP SEABED MINING?

Deep-sea minerals have been touted as essential for a decarbonised future and an exciting new economic frontier for the blue economy that seeks to realise the full economic potential of the oceans. DSM is portrayed as a low-impact alternative to mineral extraction on land and a silver bullet solution to the challenges of transitioning to a low-carbon future, with cobalt, nickel, copper and manganese simply available for the taking on the seafloor. Yet these metallic deposits are the product of ancient biological processes that take place in a deep, dark, chemosynthetic world – where the synthesis of organic compounds by bacteria or other living organisms uses energy derived from reactions involving inorganic chemicals, typically in the absence of sunlight – that scientists are only just beginning to understand. More than 75 per cent of the seafloor remains unmapped, unobserved and unexplored,[1] and as much as 91 per cent of ocean species are yet to be described.[2] Research

undertaken in the deep ocean continues to highlight just how little we know about life here and the extraordinary diversity that exists.[3,4]

DSM is under pilot testing, predominantly in the Clarion–Clipperton Zone of the mid-Eastern Pacific Ocean, but also in the Indian and Atlantic oceans. Here, a handful of DSM proponents are looking for viable technologies to enable the removal of tens of millions of tonnes of metallic substrates under the guise of responsible mining.

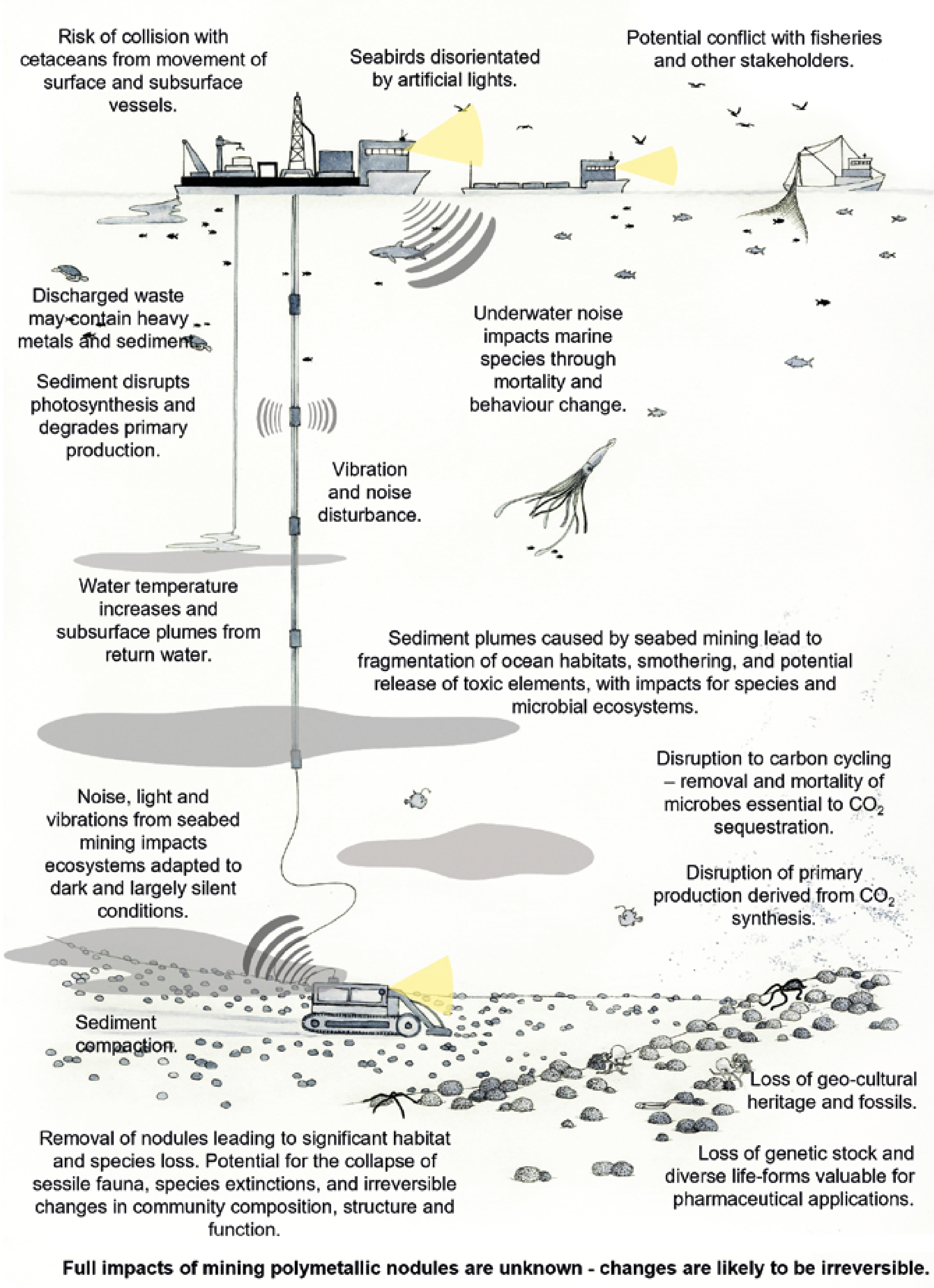
A recent study of the risks and impacts of DSM has found that it will cause irreversible loss and probably widespread extinction of deep-sea creatures, many still unknown to science. Impacts will be compounded by the connectivity of ocean systems, movement of highly mobile species and the oceans' central role in planetary atmospheric processes. Damage to deep-sea ecosystems – which are largely pristine and highly sensitive to human disturbance – will be irreparable.[5]

The timeline for DSM moving from the testing stage to becoming a reality was accelerated in June 2021 when Nauru, the world's smallest island nation, invoked a legal provision that started a countdown clock for DSM in international waters. The move is essentially an ultimatum to speed up the completion of DSM regulations so that commercial enterprises can begin exploiting the seabed.

The International Seabed Authority (ISA) is authorised to act on behalf of humankind in respect of the seabed and ocean floor beyond national jurisdictions, with a mandate to ensure effective protection of the marine environment from the harmful effects of deep seabed-related activities. The ISA has been deliberating on regulations governing commercial mining of the deep seafloor, called the Mining Code, since 2014. It set a completion target of 2020, controversial enough to some, but the process was sidelined by the Covid-19 pandemic. The two-year rule that Nauru triggered compels the ISA to finalise the rules by mid-2023. If it does not, the ISA will have to accept applications for exploitation even in the absence of formal guidelines, with many questions about the long-term effects of mining likely remaining unresolved.

UNCERTAINTY AND THE KNOWN UNKNOWNS

In a complex environment where so little is known it is hard to fathom the full magnitude of the risks posed by DSM. Gaps in basic knowledge constrain our ability to predict how species, ecosystems and processes will respond, what their potential for recovery is and over



▲ **Figure 1. Risks and impacts of mining of polymetallic nodules. Illustration not to scale. (Source: Nicky Jenner, Fauna & Flora International,[5] adapted from Miller et al.[22])**

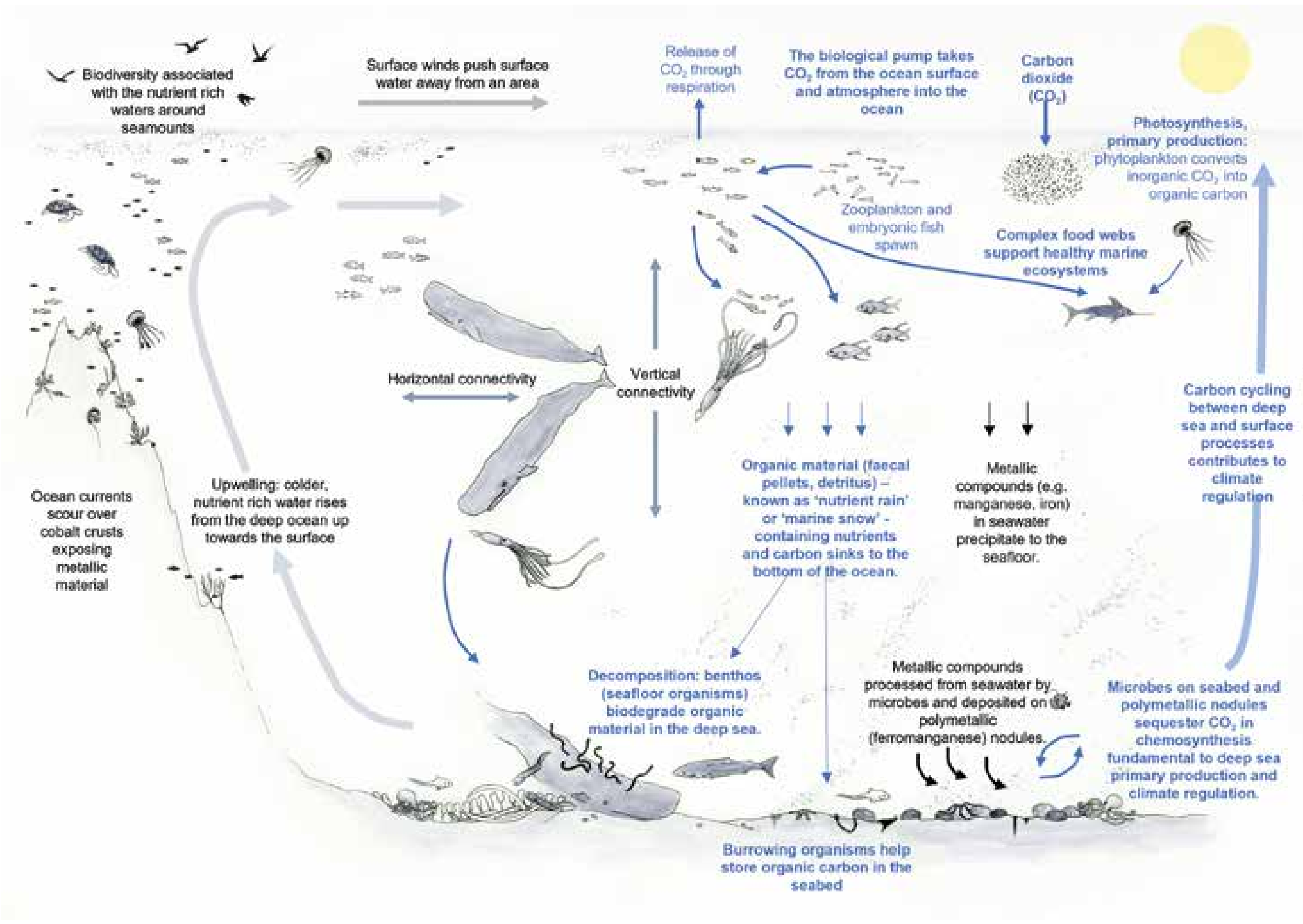
what timescales. As scientific understanding of the deep sea continues to grow, so too does recognition that impact assessments based on current knowledge considerably underestimate the true effects of DSM. Changes to the chemistry underpinning deep-sea biological systems, for example, will not only disrupt the processes on which ocean productivity relies, but also give rise to knock-on effects that we cannot currently comprehend or predict.

The known unknowns are a particular concern among the global scientific community. They relate to the longer-term systemic effects and consequences of removing vast parts of the ocean's substrate – tens of thousands of square kilometres, and even entire habitats if DSM extends to seamounts or hydrothermal vent systems – and associated ecosystem function, trace metals, and nutrient cycles and climate regulation. We know what the likely impacts are but not the magnitude of their effects on the global system. Climate change could compound these, and we will likely not feel the systemic effects of DSM until the medium to long term, when it will be too late to reverse them.

RISKS OF POLYMETALLIC NODULE MINING

Polymetallic nodule mining is the most advanced form of DSM in terms of pilot testing. Polymetallic nodules occur at depths of c. 4,000–6,000 m on the abyssal plains – an environment found to teem with microbial life and support a unique array of organisms. The nodules are formed of concentric layers of manganese and iron hydroxides around a core, with high concentrations of copper, nickel and cobalt. This process occurs extremely slowly and may be the product of microbial activity. This unique ecosystem exerts significant influence upon ocean carbon cycling, dissolution of calcium carbonate and atmospheric carbon dioxide (CO_2) concentrations over hundreds to thousands of years.

Proponents of DSM argue that nodules are located on the seabed, thus implying that there is no overburden to remove. However, it is not quite as simple as 'vacuuming golf balls off the putting green' as Gerard Barron of The Metals Company describes it.[6] The nodules, including the microbes occurring within them, underpin a complex ecosystem, are a vital part of the food web and



▲ **Figure 2. Oceanic processes, including primary productivity and the biological pump, and connectivity. Illustration not to scale. (Source: Nicky Jenner, Fauna & Flora International[5])**

OPINION

support biogeochemical processes and functions.[7] Loss of this ecosystem would have systemic implications; nodule microbial communities, for example, may play key roles in metal, carbon and nitrogen cycles.[8]

New studies reveal deep-ocean sediment to be one of the Earth's richest ecosystems and fossil archives,[9] while the International Union for the Conservation of Nature reports that disturbance to the seafloor is 'one of the biggest potential impacts' from DSM.[10]

Nodules are found partially buried in seafloor sediment. Their extraction will result in the removal and re-suspension of sediment, damaging seafloor habitat, reducing the likelihood of recolonisation of organisms and killing most benthic life – even if some mobile organisms escape. Damage to these communities will potentially have a cascading effect on the wider ecosystem, disrupting carbon and nutrient cycles and with system-wide implications for ocean health and function.

DSM generates sediment plumes from collector vehicles mining the nodules, stirring up an estimated 50,000 tonnes of sediment per day in an environment in which the water is typically very clear and organisms may be highly sensitive to exposure.[11] Plumes, which may contain elevated metal concentrations, can spread and extend to unmined areas, smothering or weakening organisms over time, increasing exposure to toxic metals, changing behaviours, affecting species interactions and potentially limiting recolonisation of disturbed areas. Physical and chemical alteration of the seafloor is expected to be long-lasting. Studies show that simulated DSM impacts will still be evident a quarter of a century later,[12] with plough tracks still visible and microbial activity reduced as much as fourfold.[13] With mining activity anticipated to operate over at least 30-year periods, the effects will accumulate over time.

Light does not penetrate to this depth, so light pollution emitted from collector vessels as well as noise and vibration will also affect marine organisms through, for example, physiological damage, mortality, behavioural impacts (e.g. reducing breeding success) and resilience.

Once extracted, nodules are then pumped up to a tethered vessel where they are removed from the ocean. There will be vast quantities of waste, both at sea and from processing, and the sediment discharged back into the ocean will create significant plumes that could travel over 1,000 km, with a suite of associated impacts in the water column and extending the area affected by the sediment as it settles to the seabed.[14] Although the potential extent of impact is hard to gauge, sediments released near the ocean surface will increase water turbidity, impacting photosynthesis and visibility, with knock-on consequences for pelagic fish and the high-seas fishing industry.[15] If released near the seafloor, risks and impacts can be similar to those from the collection plume.

The resilience of polymetallic nodule ecosystems to mining impacts is expected to be low and the likelihood of extinctions and irreparable losses high. The need for caution cannot be overstated.

BOX 1. THE PRECAUTIONARY PRINCIPLE

In order to protect the environment, a precautionary approach must be applied where there are threats of serious or irreversible damage. The precautionary principle further emphasises preventive action in the face of uncertainty (i.e. insufficient scientific evidence regarding the scope and potential risks of the activity in question should never be used as an excuse for not taking action to avert negative impacts where there are plausible indications of potential risks). It shifts the burden of proof to those who wish to undertake or continue an activity that poses a threat of serious or irreversible damage. This is supported through the Rio Declaration and the Convention on Biological Diversity.

In the context of the deep sea, an important objective and legal obligation under UNCLOS, for both states and the ISA, is to ensure 'effective protection' of the marine environment from 'harmful effects' that may arise from seabed mining activities (UNCLOS Article 145).[16] The Seabed Disputes Chamber of the International Tribunal for the Law of the Sea has further reinforced the role of the precautionary principle in the 'responsibilities and obligations' of the ISA, states and private contractors, and ensures that there is a direct obligation under international law to apply the precautionary principle. 'A sponsoring State would not meet its obligation of due diligence if it disregarded those risks. Such disregard would amount to a failure to comply with the precautionary approach.'[17,18]

GOVERNANCE OF THE DEEP SEA

How we govern, monitor and manage DSM and its associated risks and impacts is a global concern. The ISA has a considerable responsibility and a lot to answer for, but its structure creates fundamental conflicts of interest. This is because the ISA has been set up to both govern and exploit the oceans. It is both poacher and gamekeeper, setting rules of engagement, inspecting performance against standards and regulations it created, and with a financial stake in mineral exploitation. At the same time, the ISA is responsible for delivering on the United Nations Convention on the Law of the Sea (UNCLOS) – the primary legal instrument for the governance of the world's oceans and seas. This calls for strict environmental stewardship, application of the precautionary principle, custodianship of oceans and ensuring the benefits of the common heritage of humankind accrue to all.

How can the ISA deliver on these objectives if it is simultaneously vested in moving exploitation forward despite evidence that the risks and impacts of DSM will have irrecoverable, permanent and extensive effects on ocean health and function? An organisation that is responsible for monitoring and mitigating impacts cannot also determine the governance models, and this is compounded by the challenges inherent in observing and regulating activities in the deep ocean.

CONCLUSIONS

DSM would be an irresponsible and shortsighted idea. Proponents of DSM argue that mining the deep ocean is necessary for a low-carbon future. However, the risks associated with DSM are extremely high, with evidence increasingly showing that impacts will be severe and widespread. DSM itself is expected to disrupt deep-sea carbon cycling processes with implications for carbon sequestration, while above the sea surface a potential DSM operation is estimated to emit tens to thousands of tonnes of CO_2.[19,20] DSM and climate change effects are further expected to synergise in the deep sea.[21] The exact nature of such interactions and the magnitude of these impacts remains uncertain.

A precautionary approach is essential, and in the absence of any suitable, proven impact-avoidance or mitigation techniques, DSM should be avoided entirely. DSM demands a level of precaution and scrutiny that will be impossible to achieve within the decision-making timeframe currently envisaged by the ISA. UNCLOS includes provisions to ensure the marine environment is protected from harmful effects that may occur because of mining-related activities. We need to acknowledge that the oceans are complex, that we would be unable to mitigate impacts in such a vast and interconnected system and that the precautionary principle is needed in this case. We must protect the long-term stability of planetary processes inherent in the living genesis of metal-rich occurrences in our oceans. ES

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REFERENCES

1. Seabed 2030 (no date) *About the Seabed 2030 Project*. https://seabed2030.org/mapping-progress (Accessed: 7 November 2022).
2. Mora, C., Tittensor, D.P., Adl, S., Simpson, A.G.B. and Worm, B. (2011) How many species are there on Earth and in the ocean? *PLoS Biology*, 9 (8), e1001127. DOI:10.1371/journal.pbio.1001127.
3. Amon, D.J., Ziegler, A.F., Dahlgren, T.G., Glover, A.G., Goineau, A., Gooday, A.J., Wiklund, H. and Smith, C.R. (2016) Insights into the abundance and diversity of abyssal megafauna in a polymetallic-nodule region in the eastern Clarion–Clipperton Zone. *Scientific Reports*, 6 (Article no. 30493). https://www.nature.com/articles/srep30492 (Accessed: 7 November 2022).
4. Bribiesca-Contreras, G., Dahlgren, T.G., Amon, D.J., Cairns, S., Drennan, R., Durden, J.M., Eléaume, M.P., Hosie, A.M., Kremenetskaia, A., McQuaid, K., O'Hara, T.D., Rabone, M., Simon-Lledó, E., Smith, C.R., Watling, L., Wiklund, H. and Glover, A.G. (2022) Benthic megafauna of the western Clarion–Clipperton Zone, Pacific Ocean. *ZooKeys*, 1113, pp.1–110. DOI:org/10.3897/zookeys.1113.82172.
5. Howard, P., Parker, G., Jenner, N. and Holland, T. (2020) *An Assessment of the Risks and Impacts of Seabed Mining on Marine Ecosystems*. Cambridge: Fauna & Flora International. https://www.fauna-flora.org/app/uploads/2020/03/FFI_2020_The-risks-impacts-deep-seabed-mining_Report.pdf (Accessed: 8 November 2022).
6. Baker, A. (2021) *A climate solution lies deep under the ocean—but accessing it could have huge environmental costs*. https://time.com/6094560/deep-sea-mining-environmental-costs-benefits/ (Accessed: 23 November 2022).
7. Stratmann, T., Soetaert, K., Kersken, D. and van Oevelen, D. (2021) Polymetallic nodules are essential for food web integrity of a prospective deep seabed mining area in Pacific abyssal plains. *Scientific Reports*, 11 (Article no. 12238). DOI:org/10.1038/s41598-021-91703-4.
8. Molari, M., Janssen, F., Vonnahme, T. R., Wenzhöfer, F. and Boetius, A. (2020) The contribution of microbial communities in polymetallic nodules to the diversity of the deepsea microbiome of the Peru Basin (4130–4198 m depth). *Biogeosciences*, 17 (12), pp. 3203–3222. https://bg.copernicus.org/articles/17/3203/2020/ (Accessed: 7 November 2022).
9. Cordier, T., Barrenechea Angeles, I., Henry, N., Lejzerowicz, F., Berney, C., Morard, R., Cambon-Bonavita, M-A., Guidi, L., Lombard, F., Martinez Arbizu, P., Massana, R., Orejas, C., Poullain, J., Smith, C.R., Wincker, P., Arnaud-Haond, S., Gooday, A.J., de Vargas, C. and Pawlowski, J. (2022) Patterns of eukaryotic diversity from the surface to the deep-ocean sediment. *Science Advances*, 8 (Article no. eabj9309). https://www.science.org/doi/10.1126/sciadv.abj9309#con2 (Accessed: 7 November 2022).
10. Cuyvers, L., Berry, W., Gjerde, K., Thiele, T. and Wilhem, C. (2018) *Deep Seabed Mining: A Rising Environmental Challenge*. Gland, Switzerland: International Union for the Conservation of Nature and Gallifrey Foundation. https://portals.iucn.org/library/sites/library/files/documents/2018-029-En.pdf (Accessed: 7 November 2022).
11. Rolinski, S., Segschneider, J. and Sündermann, J. (2001) Long-term propagation of tailings from deep-sea mining under variable conditions by means of numerical simulations. *Deep Sea Research Part II: Topical Studies in Oceanography*, 48 (17–18), pp. 3469–3485. DOI:org/10.1016/S0967-0645(01)00053-4.

REFERENCES

12. Simon-Lledó, E., Bett, B.J., Huvenne, V.A.I., Köser, K., Schoening, T., Greinert, J. and Jones, D.O.B. (2019) Biological effects 26 years after simulated deep-sea mining. *Nature Scientific Reports*, 9, (Article no. 8040). DOI:org/10.1038/s41598-019-44492-w.
13. Vonnahme, T.R., Molari, M., Janssen, F., Wenzhöfer, F., Haeckel, M., Titschack, J. and Boetius, A. (2020) Effects of a deep-sea mining experiment on seafloor microbial communities and functions after 26 years. *Science Advances*, 6 (Article no. eaaz5922). https://www.science.org/doi/10.1126/sciadv.aaz5922#tab-citations (Accessed: 7 November 2022).
14. Muñoz-Royo, C., Peacock, T., Alford, M.H., Smith, J.A., Le Boyer, A., Kulkarni, C.S., Lermusiaux, P.F.J., Haley, P.F. Jr, Mirabito, C., Wang, D., Adams, E.E., Ouillon, R., Breugem, A., Decrop, B., Lanckriet, T., Supekar, R.B., Rzeznik, A.J., Gartman, A. and Ju, S-J. (2021) Extent of impact of deep-sea nodule mining midwater plumes is influenced by sediment loading, turbulence and thresholds. *Communications Earth & Environment*, 2, (Article no. 148), pp. 1–16. https://doi.org/10.1038/s43247-021-00213-8 (Accessed: 17 November 2022).
15. Van der Grient, J.M.A. and Drazen, J.C. (2021) Potential spatial intersection between high-seas fisheries and deep-sea mining in international waters. *Marine Policy*, 129 (Article no. 104564). https://www.sciencedirect.com/science/article/pii/S0308597X21001755 (Accessed: 7 November 2022).
16. United Nations (1982) United Nations Convention on the Law of the Sea. https://www.un.org/depts/los/convention_agreements/texts/unclos/UNCLOS-TOC.htm (Accessed: 17 November 2022).
17. La Porta, D. (2021) *The Precautionary Principle Applied to Deep Sea Mining*. Report for the Deep Sea Mining Campaign. https://dsm-campaign.org/wp-content/uploads/2021/10/Precautionary-Principle-Deep-Sea-Mining.pdf (Accessed: 17 November 2022).
18. International Tribunal for the Law of the Sea (2011) Responsibilities and Obligations of States Sponsoring Persons and Entities with Respect to Activities in the Area. Advisory Opinion of 1 February 2011. Available at: https://www.itlos.org/fileadmin/itlos/documents/cases/case_no_17/17_adv_op_010211_en.pdf (Accessed: 17 November 2022).
19. Amon, D., Levin, L. and Andersen, N. (2022) *Undisturbed: The Deep Ocean's Vital Role in Safeguarding Us From Crisis*. http://www.stateoftheocean.org/wp-content/uploads/2022/11/DeepSea-Synthesis-31oct-high.pdf (Accessed: 17 November 2022).
20. Heinrich, L., Koschinsky, A., Markus, T. and Singh, P. (2019) Quantifying the fuel consumption, greenhouse gas emissions and air pollution of a potential commercial manganese nodule mining operation. *Marine Policy*, 114. https://doi.org/10.1016/j.marpol.2019.103678 (Accessed: 17 November 2022).
21. Levin, L.A. Wei, C.-L., Dunn D.C., Amon, D.J., Ashford, O.S., Cheung, W.W.L., Colaço, A., Dominguez-Carrió, C., Escobar, E.G., Harden-Davies, H.R., Drazen, J.C., Ismail, K., Jones, D.O.B., Johnson, D.E., Le, J.T., Lejzerowicz, F., Mitarai, S., Morato, T., Mulsow, S. Snelgrove, P.V.R., Sweetman, A.K. and Yasuhara, M. (2020) Climate change considerations are fundamental to management of deep-sea resource extraction. *Global Change Biology*, 26 (9), pp. 4664–4678. https://doi.org/10.1111/gcb.15223 (Accessed: 17 November 2022).
22. Miller, K.A., Thompson, K.F., Johnston, P. and Santillo, D. (2018) An overview of seabed mining including the current state of development, environmental impacts, and knowledge. *Frontiers in Marine Science*, 4 (418). https://doi.org/10.3389/fmars.2017.00418 (Accessed: 17 November 2022).

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Editors	Bea Gilbert and Rosie Bowyer
Guest editor	David Viner
Subeditor	Christina Petrides www.lastglance.net
Designer	Kate Saker katesaker.com
Printer	Lavenham Press Ltd
Published by	Institution of Environmental Sciences 1st Floor 6–8 Great Eastern Street London EC2A 3NT
Tel	+44 (0)20 3862 7484
Email	info@the-ies.org
Web	www.the-ies.org
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